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DEGREE

Development of fishing Gears with Reduced Effects on the Environment

Scientific Support to Policy (SSP)

Area 1.3 – Modernisation and sustainability of fisheries, including aquaculture-based production systems

Instrument: **STREP**

Thematic Priority: **8.1.B.1.3. Task-12: Reducing the impact of fisheries activities on benthic habitats**

DEGREE Final Publishable Activity Report

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1 Project summary

Thirteen participants worked together to develop new gears/fishing techniques that have a lower impact on benthic habitats, to quantify the potential reduction of the physical impact as well as the negative effects on benthic communities, to weigh the socio-economic consequences of these changes against those of alternative management measures, *e.g.* closing of areas.

They focused on the development of modified towed gears. A generic approach was chosen in which cases (e.g. North Sea, Mediterranean) can be worked out. The overall ecological impact to benthic systems has been assessed by developing physical/biological models verified by tests at sea. This provides a tool to fisheries managers to identify gear and sediment type combinations which will minimise impact to the habitat. A group of experts worked to appraise the socio-economic consequences of the new gears and techniques. Gear types under study involved: otter trawls, beam trawls, pulse beam trawls and dredges. The project consisted of **six** work packages, as follows:

WP 1	Management and co-ordination
WP 2	Modelling and quantification of benthic impact
WP 3	Otter trawl modifications
WP 4	Beam trawl and Dredge modifications
WP 5	Economics
WP 6	Dissemination and implementation

The duration of the project was 44 months, starting on 01/02/2006, and ending on 30/09/2009. Special emphasis was given to consultation with and dissemination of the results of the work to the fishing industry through national Industrial Liaison Groups and an adequate implementation of alternative fishing gears and techniques.

2 Project objective(s)

2.1 Main objectives

- To develop new gears/fishing techniques that have a lower impact on benthic habitats,
- To quantify the potential reduction of the physical impact as well as the negative effects on benthic communities,
- To weigh the socio-economic consequences of these changes.

Practical tests should focus on areas with sensitive habitats and with potential for development of alternative and economically viable gears/fishing techniques.

2.2 Sub-objectives

- To develop alternative otter trawl components (*e.g.* doors and groundgear), modified beam trawls (electric stimulation, benthic release devices), and an alternative oyster dredge design to avoid sensitive habitats.
- To carry out flume tank tests on innovative designs.
- To carry out preliminary engineering feasibility trials on commercial fishing vessels.
- To involve the fishing industry in the development process from the early phases of the project through national industrial liaison groups, including a workshop.
- To carry out trials on a fisheries research vessel in a combined effort, and integrate where practical the gear modifications into one trawl.
- To develop a physical model and extend the biological model of gear impact on habitats developed in project MAFCONS to a gear component level.
- To measure and observe bottom impacts of conventional and modified gears.
- To verify the physical/biological models with these measurements and observations.
- To use these models to quantify the possible reduction of the physical impact as well as the negative effects on benthic communities arising from the new gears/fishing techniques developed.
- To compare the potential reduction of the physical impact as well as the negative effects on benthic communities of various existing conventional fishing gears and the innovative gears developed in this project.
- To appraise the economic performance possibility of various existing and innovative fishing gears and gear type changes.
- To disseminate the results to relevant sectors in the fishing industry, and contribute to implementation of the techniques developed above.
- To publish the results in scientific peer-reviewed fisheries magazines.

List of participants	
Partner No	**Organisation**
1	Wageningen Institute for Marine Resources and Ecosystem Studies - Department of Fisheries
2	Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Laboratory
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4	withdrawn
5	Institut français de recherche pour l'exploitation de la mer
6	Institute of Marine Research - Norway
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8	Vlaams Gewest
9	The Technical University of Denmark
10	University of Aberdeen
11	University of Portsmouth Higher Education Corporation - Centre for Economics and Management of Aquatic Resources
12	National Research Council - Institute of Marine Sciences, Marine Fishery Section
13	University of Liverpool

3 Specific project information

Country/Geographical area: North Sea, North-East Atlantic, Irish Sea, Mediterranean Sea.

Duration: 2006 – 2009.

Coordinating/Organisational body: Wageningen IMARES B.V. (former RIVO)

Funding instrument: EU STREP (Specific Targeted Research) under the 6th European Research Framework Programme.

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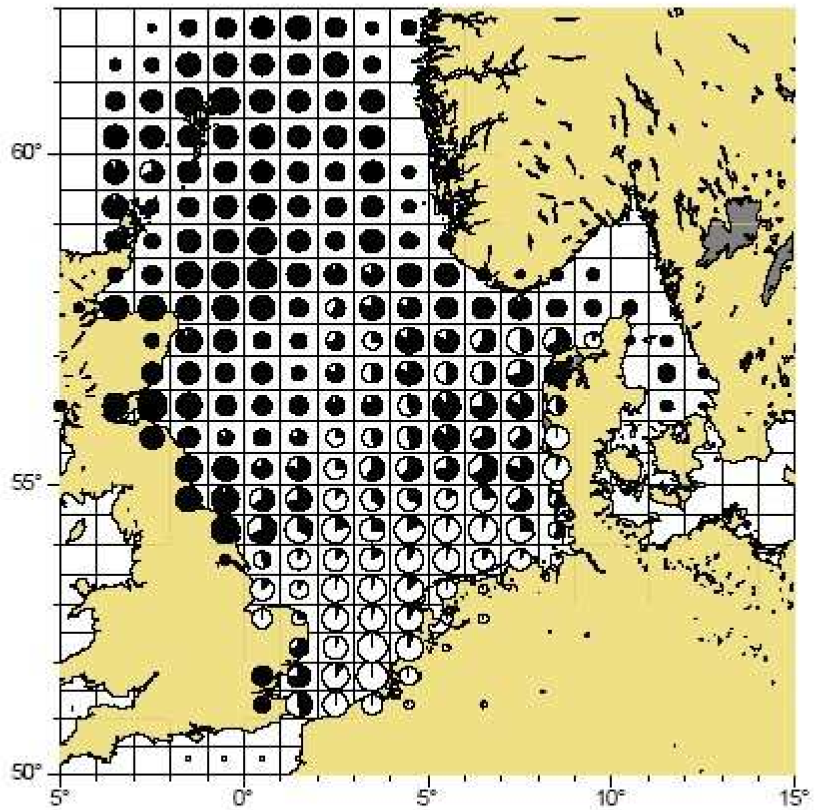
4 Problem description

4.1 Impact on benthic habitats

4.1.1 Nature of the problem

Concern over the possible effects of trawls on the seabed has existed almost as long as the fishing method itself, with early concerns being voiced by fishermen as far back as the 14th century (Graham, 1955; Gordon and Swinghammer, 1996; Lindeboom and De Groot, 1998). With the advance in technological developments of trawling gears (i.e. weight and size), particularly over the latter part of the 20-th century, the increase in the number of fishing vessels, engine power etc., these concerns are increasingly gaining international public and political importance. To help illustrate the level of effort now being deployed with demersal trawl gear, Figure 1 shows the extent of effort in the North Sea for 1998.

Figure 1 Distribution of bottom trawl (black) and beam trawl (white) effort (hours per year) for 1998 (data from Greenstreet, pers. comm., and Zuhlke et al., 2001).



International concern was formally voiced at the 58th meeting in Copenhagen in 1970 of the International Council for the Exploration of the Sea (ICES). Information was requested with regard to the possible impacts of trawls and dredges on the seabed and on the benthic fauna (Lindeboom and De Groot, 1998). Following an initial flurry of activity, member states reported on these effects (Anon., 1973). Then a drop-off in interest followed until the middle of the 1980's. In 1988, the ICES Study Group on the Effects of Bottom Trawling was convened in response to Council Resolution 1987/2:7 to collect information available since 1972 and to report on the developments in bottom trawling gear, existing literature, national research and proposals for co-ordinated research (Anon., 1988). The main conclusion related to the fact that the heavier gears in use, in the North Sea in particular, would have a greater impact on benthic communities (Anon., 1988). New observations on the possible effects of these gears on the seabed were therefore felt required at the time.

This led to renewed research interest with several countries undertaking systematic national studies (*e.g*. The Netherlands) into the direct effects of fishing activities on the benthos (Bergman *et al*., 1990; Bergman and Hup, 1992). Following on from these, multi-national studies were undertaken (IMPACT I and IMPACT II) which underlined the development in activities of the fishing industry within the participating states, but which also pinpointed a number of direct and indirect effects of trawling on the marine environment (see de Groot and Lindeboom, 1994; Lindeboom and De Groot, 1998). For instance the annual fishing mortality in the larger-sized invertebrate populations varied from 7 % to 48 % due to trawl fisheries in the Dutch sector in 1994, with half the number of species showing values of >25 %. The 12-m beam trawl fisheries caused higher fishing mortalities than 4-m beam trawl and otter trawl fisheries. Only in species restricted to the coastal zone, where the 4-m beam trawl fishery was much more intensive than in offshore areas, were fishing mortalities relatively higher and might even exceed those due to 12-m beam trawl fisheries (Lindeboom and de Groot, 1998, p. 371, ICES 2002).

Recommendations arising from such work indicated an urgent need for the introduction of management measures that centred on a reduction of trawling effort, on spatial restriction (e.g. zonation) of a particular trawling effort and on a reduction of the direct mortality rate through modifications in trawl design (Lindeboom and De Groot, 1998).

Although many studies were conducted for the North Sea, severe impacts of fishing occur also in the Mediterranean (Tudela, 2004; Sala et al., 2009), but one should realise that this statement also involves the effect on fish by discarding, and not only the effect on benthic communities. The effects vary from local effects on the sea bottom caused by trawler gears (Sala et al., 2009) to large-scale impacts on cetacean populations driven by driftnet bycatch. This variety – which makes the Mediterranean a unique global model for the implementation of the Ecosystem Approach to Fisheries – is due to four main interrelated factors: i) the huge diversity of fishing gears and practices; ii) the very high intensity of fishing; iii) a high diversity of habitats distributed from the shallow-waters to the deep-sea; and iv) the oceanic domain, and an important biological diversity.

The impact of fishing on the seabed concerns mostly the use of bottom-trawling gears: otter trawls, beam trawls and dredges. Trawling impacts on seagrass beds occur by both suspending sediments and directly damaging the vegetal mass, thus have the most dramatic consequences on *Posidonia* beds.

Seagrasses are exceptional seabed bottoms. The vast majority of Mediterranean seabed surfaces lack such a massive vegetal cover and are muddy, sandy or, in some places, rocky. These apparently modest habitats, far from being lifeless, are inhabited by complex biological communities, often part of fragile ecosystems. Current fishing practices, notably trawling on seabed sediments, profoundly disturb the physical support system and undermine the structure and functioning of the benthic ecosystem.

Evidence shows that the effects of fishing in the Mediterranean go far beyond the isolated impacts on overfished target species, vulnerable non-commercial groups or sensitive habitats. The ecosystem effects of fishing in the Mediterranean are also conspicuous at the systemic level, as highlighted by the massive ecological footprint of fishing or the marked effects on the foodweb structure. A holistic approach should therefore be adopted if the overall changes to the structure and the functioning of marine ecosystems caused by fishing are to be remedied.

Heavy fishing disturbs muddy and sandy bottoms, causing dramatic changes in the structure of both the physical support system and the related biological assemblages. As synthesised by Pranovi *et al.* (2000), "trawls and dredges scrape or plough the seabed, resuspend sediment, change grain size and sediment texture, destroy bedforms, and remove or scatter non-target species". The increase in the amount of suspended nutrients and organic matter can be added to these effects (Jones, 1992). Highly impacting bottom fishing (trawling, dredging, etc.) mainly affects shelf areas. In the Mediterranean basin deep trawling fisheries targeting Norway lobster or red shrimps also affects slope muddy bottoms. In general, muddy sediments, which form in high depositional areas with low external disturbance, are much more sensitive to trawling disturbance than more dynamic coarser sediments.

Deep slope fisheries targeting high value crustacean species operate out of Spain, Italy, Algeria and Tunisia, fishing down to a depth of 1000 m depth in the north-western Mediterranean red shrimp (*Aristeus antennatus* and *Aristeomorpha foliacea*) fishery. Although there is no information on the effects of deep sea trawling on muddy bottoms in the Mediterranean (or anywhere else in the world), the few authors touching on the subject warn of the extreme vulnerability of such sea beds to physical perturbations. It appears that recovery rates are much slower and the impacts of trawling may be very long lasting (many years or even decades) in deep water, where the fauna is less adaptable to changes in sediment regimes and external disturbances (Jones, 1992; Ball, *et al*., 2000).

The ecosystem effects related to the use of bottom gears may extend far beyond the direct, straightforward impacts discussed above. Eutrophic processes may be enhanced leading to hypoxia in sensitive soft bottom areas (as in the northern Adriatic) and the quantity of hydrogen sulphide released from sediments may increase (Caddy, 2000). The anthropic re-suspension of sediment enriched in organic matter can eliminate macrophyte, benthos and demersal fish approaching their hypoxia tolerance limit; the changed ecosystem structure favours species adapted or tolerant to hypoxic conditions. Trawling and dredging can also play a role affecting the intensity and duration of naturally occurring seasonal hypoxic crises in some places. These fishing practices, carried out in hypoxic conditions in the Adriatic Sea, can exacerbate the summer killings of young shellfish. Trawling can also remove large-bodied, long-lived macrobenthic species and subsequently reduce the bioturbation zone (Ball, *et al*., 2000). This could increase the danger of eutrophication and result in longer recovery rates (Rumohr, *et al*., 1996). On the other hand, studies carried out on muddy seabeds showed that otter trawling operations produce short-term changes in the biomass of taxa within the trawled area (Tudela, 2004).

A workshop on the Effects of Fishing Gear on Marine Habitats off the Northeastern United States was held in October 2001 in Boston, Massachusetts (Anon., 2002d). A variety of habitat characteristics were recognised, depending on topography and variability over time (Table 4-1). The impact of several gear types was then discussed by a panel of esperts, giving rise to a classification for otter trawl impacts on different habitats shown in Table 4-2. Several conclusions were drawn from this evaluation. First of all, gravel habitat was clearly considered to be most at risk, followed by sand and mud. Secondly, impacts to biological structure were of greatest concern, particularly in gravel habitat, followed by any physical impact to gravel habitat. Impacts to physical structure ranked third and removal of major physical features ranked fourth. Thirdly, otter trawls and scallop dredges were of much greater concern than other types of static gears such as clam dredges, gill nets and longlines, and pots and traps. Otter trawls and scallop dredges were judged to have the greatest impacts on gravel habitat. Additionally, otter trawl effects were of concern in all three habitat types, whereas scallop dredge effects limited to gravel and sand, and clam dredging impacts limited to sandy bottoms. Bottom gill nets and longlines were only of concern in gravel. Overall the panel stressed a theme throughout the workshop that in order to protect habitat from gear impacts three management measures deserve consideration: 1) effort reduction, as for many overexploited species, resource management measures which require reductions in fishing effort to maximize yield would have the added benefit of protecting habitat, 2) spatial closures seen as an important tool to minimize gear impacts on habitat, and 3) gear modification, which was mentioned as a possible way to reduce the impact of certain gears on critical or vulnerable habitats.

Table 4-1 Habitat Characteristics and Variability

HABITAT CHARACTER	VARIABILITY
TOPOGRAPHY	FEATURELESS-- FEATURES
SEDIMENT TEXTURE [and HARDNESS]	FINE -- COARSE ------------------------- [SOFT] --- [HARD] -------------------------- MUD ----------------------- SAND --------------- GRAVEL; SHELLS; BEDROCK
SUBSTRATE ROUGHNESS [and SURFACE AREA] · PHYSICAL · BIOLOGICAL	SMOOTH-- ROUGH [LOW] --- [HIGH] MUD ----------------------- SAND ---------------- SHELLS; GRAVEL; BEDROCK | --BURROWS-- | | ---------- BEDFORMS ------ | | --STRUCTURES (TUBES and ATTACHED EPIFAUNA) -------------------
SUBSTRATE DYNAMICS · PHYSICAL mud, sand, shells · BIOLOGICAL ---------------------------------- · PHYSICAL hard bottom · BIOLOGICAL	WEAK CURRENTS --- STRONG CURRENTS ------------------------------- TIDAL; STORM; OTHER -------------------------------- STABLE SUBSTRATE -------------------------------- UNSTABLE SUBSTRATE MUD ---------------- | SAND ---------------------- | ------------------ SAND and SHELL MOVEMENT ---- ADAPTED TO STABLE ----------- and/or ------MOVING SEDIMENT------------- STABLE SUBSTRATE -- GRAVEL MOUNDS, BEDROCK, GRAVEL PAVEMENT -------------------------- ADAPTED TO NON-MOVING SUBSTRATE
WATER COLUMN	STRATIFIED -- MIXED

PRODUCTIVITY WATER DEPTH	LOW --- - HIGH DEEP --- SHALLOW
HABITAT USAGE · by FAUNA · by FISHERS	SPAWNING, JUVENILE SURVIVAL, ADULT POPULATION ROUNDFISH, FLATFISH, BIVALVES (EPIFAUNAL, INFAUNAL) TARGET SPECIES and/or HABITATS using MOBILE GEAR, STATIONARY GEAR
FISHING IMPACTS · PHYSICAL · BIOLOGICAL	TOPOGRAPHIC FEATURES, TEXTURE, ROUGHNESS and SURFACE AREA, SUBSTRATE DYNAMICS ROUGHNESS and SURFACE AREA (TUBES and ATTACHED EPIFAUNA), BIODIVERSITY

Table 4-2 Impacts of Otter Trawls on Benthic Habitats

TYPE OF IMPACT	DEGREE OF IMPACT	DURATION	TYPE OF EVIDENCE	COMMENTS
MUD				
Removal of Major Physical Features	XXX (H) N/A (L)	Permanent	PJ	(H) in Mud refers to clay (i.e., tilefish burrows) in all cases
Impacts to Biological Structure	Unknown (H) XX* (L)	Months - Yrs	PJ	(L) opinions ranged from X-XXX
Impacts to Physical Structure	XXX* (H) XX* (L)	Months - Yrs	PR, GL, PJ	(L) opinions ranged from XX-XXX and unknown
Changes in Benthic Prey	Unknown			
SAND				
Removal of Major Physical Features	N/A	N/A	N/A	
Impacts to Biological Structure	XX* (H, L)	Months - Years	PR, GL, PJ	(H) opinion ranged from X-XXX (L) opinion ranged from XX-XXX
Impacts to Physical Structure	X* (H) XX* (L)	Days - Months	PR, GL, PJ	(H, L) opinion ranged from X-XXX
Changes in	XX* (H, L)	Months -	PR, PJ, GL	(H) opinions were

Benthic Prey		Years		XX or unknown (L) ranged from X-XXX and unknown
GRAVEL				
Removal of Major Physical Features	XXX (H, L)	Permanent	PR, GL, PJ	
Impacts to Biological Structure	XXX (H, L)	Months - Years	PR, GL, PJ	
Impacts to Physical Structure	XXX (H, L)	Months - Years	PR, GL, PJ	Rocks altered or relocated
Changes in Benthic Prey	Unknown			
KEY: X = Effect can be present, but is rarely large; XX = Effect is present and moderate; XXX = Effect is often present and can be large; N/A = Effect is not present or not applicable; Unknown = effects are not currently known; (H) = High energy environment; (L) = Low energy environment; PR = Peer reviewed literature; GL = Grey literature; PJ = Professional judgement. NOTE: Ongoing Canadian experiments will be able to provide additional information in the near future. * This does not represent a consensus among the panel				

Pursuant on these findings, it became clear that practical methods of reducing the identified effects of fishing gear on the benthos had to be found. While nets have been refined to reduce the by-catch of non-target and undersized commercial fish species, attempts to reduce the benthic by-catch or the potential damage of demersal fishing gears on invertebrate benthic species has only begun to emerge.

An example of such work is the REDUCE project (FAIR-CT97-3809), which aimed to identify and test alternative gear technologies which had the potential to reduce a number of direct and indirect effects of trawling on the marine benthic environment. Alternative techniques that could reduce the adverse effects of demersal trawls on marine benthic organisms were reviewed and those with most promise for further investigation were identified, in co-operation with the fishing industry. The practical feasibility of the identified alternative techniques was then investigated with respect to the following criteria: reduction of fish/benthos by-catch, effectiveness, economy, and acceptability to the fishing /scientific community. Selected alternatives were then further refined. At all times the selection process was driven by the requirement that catch levels could be maintained with the emergent new gear designs. In addition, the actual impact of the modified gear was assessed by taking representative benthos samples prior to and after its passage along accurately demarcated transects. As a result, the REDUCE project identified a variety of alternative gear technologies capable of reducing direct and indirect effects of demersal trawls on benthic marine organisms. However, there it was concluded that there was a need for these techniques and modifications to be further assessed as well as to determine the conditions under which these techniques could be successfully and safely implemented in the fishing industry. These techniques included: **electrical stimulation** and/or **drop-out windows** (beam trawling), and **adjusted foot-rope construction** with **roller balls** in combination with drop-out windows and **modified otter boards** with reduced ground contact (otter trawling).

In view of the development of an 'eco-system approach' in fisheries science, studies on the impact of fishing on the eco-system were reviewed by ICES WGECO in 2002. A number of mitigation measures were identified as a function of habitat type. Gear modifications were recognised as possibilities for reducing otter and beam trawl impacts for the sensitive habitat types defined as 'structural benthic epifauna', 'benthic infauna' and 'mollusc beds' (ICES 2002, Table 4-3)

Table 4-3 Matrix of fishing gear/habitat type and mitigation measure (after ICES, 2000 ; Gubbay, 2001).

Fishing Activity	**Sensitive Habitat Type (from Gubbay, 2001)**						
	Deep-water biogenic habitats	Structural benthic epifauna	Benthic infauna	Mollusc beds	Nearshore communities	Intertidal mudflats	Mearl beds
Otter trawling	AC	AC, GM	GM	AC	AC	N/A	AC
Beam trawling	N/A	AC, GM	GM	AC, GM	AC	AC	AC
Pelagic trawling	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Drift/gill netting	AC	N/A	N/A	N/A	N/A	N/A	N/A
Bottom longlining	AC	AC, GM	N/A	N/A	N/A	AC	N/A
Pelagic longlining	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tangle netting	AC ?	GM ?	N/A	N/A	AC	AC	N/A
Pot fisheries	N/A	AC, GM	N/A	N/A	AC/R	N/A	N/A
Dredging (Epibenthic)	N/A	AC	AC	AC/R	AC	AC	AC
Dredging (Hydraulic)	N/A	AC	AC	AC/R	AC	AC	N/A

Key to mitigation measures :

AC	Area Closure	R	Reseeding/restocking
GM	Gear Modification	N/A	Fishing activities thought to have no effect

In a recent review Løkkeborg (2005) stated that two types of impact studies exist, *i.e.* studies in which experimental trawling is conducted and the responses of the benthic community are assessed, and studies in which historical effort data are used and fishing grounds subjected to low and high fishing intensities compared. The advantage of the first type is that this method provides exact data on the disturbance regime, but the disadvantage on the other hand is that the temporal and spatial aspects of experimental trawling do not truly reflect the large-scale and long-term disturbances that occur in real fisheries. Consequently such studies, having no replication at the appropriate spatial scale, run the risk of overestimating effects of trawling disturbance. Impact studies based on historical effort data reflect disturbances imposed by commercial fishing, but the actual intensity of disturbance is not know and suitable control sites seldom exist.

At this juncture it is also interesting to compare the work in Europe with work done in the United States and Canada. A recent review of impacts of ten classes of fishing gears in US-waters rated bottom trawling as top of the list in terms of severity and need for policy response (Chuanpagdee *et al*., 2003, Table 4-4).

Table 4-4 Scale of relative severity of collateral impacts of ten fishing gears and possible policy responses (Chuanpagdee *et al.*, 2003)

Gear Type	Impact rating	Policy response
Trawl-bottom Gillnet-bottom Dredge Gillnet-midwater	High	Very stringent
Pots&Traps Longline-pelagic Longline-bottom	Medium	Moderately stringent
Trawl-midwater Purse seine Hook&Line	Low	Least stringent

4.1.2 State of the art concerning physical and biological modelling of fishing gear and quantification of benthic impact.

Impacts of towed fishing gears on benthic habitats and communities have been investigated in many studies (reviewed by *e.g.* Jennings and Kaiser, 1998; Auster and Langton, 1999; Hall, 1999; Collie *et al.*, 2000). However, a large proportion of these studies have failed to demonstrate the long-term ecological changes that can be unambiguously attributed to trawling disturbance (Løkkeborg, 2005). This is often because there has been a delay between the trawling impact and subsequent sampling of the disturbed benthos, allowing for other drivers, which may include biological (*e.g.* predation by scavengers), physical or climatic factors (*e.g.* Clark & Frid, 2001 & Bergfeld & Kroncke, 2001 for reviews of long-term trends), to occur. Thus our knowledge of the long-term response of the benthos to impacts from trawling is still rather rudimentary (Currie and Parry, 1996; Freese *et al.*, 1999). If we are to further our understanding of long-term changes, it is critical that we are first able to quantify the immediate disturbance of fishing in terms of mortality and change in habitat. We must also be able to distinguish this from changes that occur due to other drivers (e.g. natural mortality or habitat alteration due to a storm event).

Based on a meta-analysis of those studies that have quantified mortality and injury post impact (e.g. Bergman & Hup, 1992 ; Bergman & van Santbrink, 2000 ; Van Marlen, 2001) it is possible to draw a number of conclusions about the short-term change in population and community that results from trawling. Evidence from these studies supports the theory that there is a relationship between the living habit (*e.g.* position on or within the seabed), morphology and mobility of an animal and its' inherent vulnerability to towed gears. Reviews of studies on the alteration of habitat that occur in the path of gear also allow a number of assumptions to be made about the likely change in generic habitat types (*e.g.* sand, mud, gravel, coral) (e.g. Auster *et al.*, 1996; Auster & Langton, 1999; Johnstone, 2002). Using this information, efforts are now being made to model the immediate ecological disturbance of towed fishing gears to benthic systems (including invertebrates, habitats and demersal fish) (Piet *et al.*, 2000; Piet *et al*., 2004; work being undertaken in EC 5th framework project MAFCONS (QSRS-2002-00856)).

In the MAFCONS model, benthic communities are subjected to a particular number of hours fishing over a specified time period and area. The resultant change in the community depends on the vulnerability of the species making up the impacted community. Generic "species" are assigned a level of vulnerability, which determines the proportion of the population that would be killed by a single passage of a gear in a given area. Communities may be made up of invertebrates, fish or a combination of both, but at present the most work has been done on the invertebrates. Vulnerability depends on a number of characteristics of the species based on its' ecology and morphology. At present vulnerability is assigned based on the meta-analysis described above. It is clear from the literature that vulnerability varies with gear type because of the different seabed/gear interactions found. However, at this stage the available literature does not enable us to resolve vulnerability to individual gear types.

In this proposal we will study in greater detail the physical processes associated with the interaction of the gear components and the seabed. This will permit a refinement of the input data to the MAFCONS model and allow a quantification of the ecological disturbance to the benthos resulting from the passage of the different components of any given towed fishing gear. Ultimately, using spatially and temporally resolved information on fishing effort and seabed sediment types, the ecological disturbance to the benthos resulting from the physical impact of towed gears for a given area will be quantified. In this project one of the main objectives is to develop new or modified gears that have low impact on the benthos. Given that the MAFCONS model updated in this project will be based on individual gear components, it will be possible to predict ecological disturbance for any towed gear combination and thus the new gears developed in this project. The ultimate aim will be to provide a management tool that can be used to compare different gear/seabed combinations in order to make decisions on how to continue fishing with the minimal impact to benthic systems.

In order to make a truly generic tool that can be applied to any gear, it is essential that the physical processes involved in the interaction of gears with the seabed be quantified for the individual components that are in contact with the seafloor. This will allow for the development of physical models that can then be built up to represent any overall trawl system. It is proposed that the physical modelling aspects of this work be subdivided into two main areas; the modelling of a tool, in this case a trawl gear component, on the sea bed and the modelling of the overall trawl system. To be able to fully model the trawling process and use this as an input to the MAFCONS ecological disturbance model, it is necessary to be able to predict the overall motion of the trawl gear and its interaction with the seabed, the effect of each trawl gear component on the seabed and then the combined effect of the complete trawl system.

A number of papers have been written on the modelling of nets for trawling (Theret, 1993; Makarenko *et al.*, 1998; Bessonneau and Marichal, 1998; Priour, 1999) and commercial codes for net design are available (*e.g.* DynamiT). However, even where these models take the seabed into account for the deformed shape of the net, they do not provide information on the detailed interaction of the gear components and the seabed. Several researchers have examined the interaction between a tool and a granular material. Bohatier and Nouguier (2000) looked at a problem related to cutting processes using numerical simulations where the soil is modelled as a dry granular material and the tool was moved at a constant velocity. For that purpose the Contact Dynamics (CD) method based on discrete elements was used. Two different physical inclusions, inertia and gravity were considered where both parts were shown to be dependent on the cutting constraints; cutting height and shape of the tool. The results from this model suggest that most of disturbance of soil occurs along a line of soil passing through the bottom of the tool. Further study was undertaken on sand with grains of different diameters and statistical analysis of the force supported by the tool around a mean force is shown to be the same for all cases. Research undertaken by Zhao and Miedema (2001) concentrated on the finite element method where the cutting forces in saturated soils were simulated.

Laboratory based experiments were carried out in the EU-funded study TRAPESE. These focused on morphological changes in the upper sea bed layers due to beam trawl gears (Paschen *et al.*, 2000). A series of tests using the laser measurement technique were undertaken on a purpose-built test bed where investigation on the interference of the upper sediment layers by towed elements of beam trawl gear. Results show that with higher resting pressures the penetration depths increases. Maximum penetration depths, between 20-35mm were found for the strongly digging trawl head model at resting pressures higher than 1.03N/cm2. It was also shown that the sediment height as an indication of the vertical force differs between Baltic and North Sea sediment. The difference of 20% was explained to be due to the difference in grain composition. The range of penetration depths found from Box-corer samples taken from the tracks of commercially sized beam trawls varied from 10mm to 80mm depending on the gear weight, the towing speed and the type of substrate.

In this project the important physical processes involved in towing a fishing gear across the seabed will be modelled. This will involve the development of (i) a finite element model of the gear components/sediment interface that will predict the penetration depth, sediment displacement and the pressure field associated with each gear component and (ii) a dynamic lumped parameter model to predict the movement of the gear components. These two models will be coupled to provide a dynamic model of the interaction between gear components and the seabed. The finite element (FE) analysis will be used to provide detailed analysis of the local deformation of the seabed around a component, while the dynamic rigid body model will be used to predict the motion of the gear components. The output of these models combined will provide the depth of penetration of gear components, the volume and the behaviour of disturbed sediment and the pressures and stresses during contact of the components with the seabed. The development of each physical model component will be underpinned by laboratory experiments and sea based trials. During the sea based trials biological core samples will also be taken across the areas of gear/seabed interaction in order to validate the inputs to the MAFCONS ecological disturbance model. These will help to assess the a priori predictions about which species will be vulnerable to particular physical impacts based on their ecology and morphology.

The work described so far will all be undertaken in Work Package 2 of this project. This will allow an overall global assessment of the impact of any gear or gear combinations on benthic habitats and communities. However, throughout the project the participants will also fully co-operate with colleagues in Work Packages 3-4 so that an assessment can be made of the benthic impact of the modified gears specifically designed and tested in this project. In the field, modified and existing gears will be assessed with a number of easy to collect and interpret physical and biological indicators. Such indicators should not be affected or masked by the complexity and natural variability of benthic systems. They will include measures such as (i) the levels of sediment suspension; (ii) the visual alteration of relief and topography; (iii) the pressure exerted on the bottom; (iv) the alteration of acoustic properties; (v) the bycatch, and (vi) the damage to invertebrates. Methods are available to collect these indicators such as turbidity-meters, transmissometers, sediment traps, grab and core samples, side-scan sonar and video recordings, pressure sensors and tension meters mounted on the gear.

Based on the precautionary principle, a reduction in the physical and/or biological impact of modified gears to those of existing gears should be sought. In essence, the point of a precautionary principle is to make decisions so that any error in understanding or action is likely to favour environmental well being (Underwood 1996). The quantification of the ‘easy to measure’ indicators will, therefore, be used as a method of determining whether the modified gear does have a reduced benthic impact. At the same time, however, the MAFCONS ecological disturbance model will be run using the described dimensions of the modified gears to assess the overall ecological disturbance caused. It will then be possible to compare the conclusions drawn from each exercise. Finally, the indicators will also act as independent validation measures for the physical and biological model inputs to the MAFCONS model. It should be possible to compare measures such as the level of sediment suspension for both modelled values and actual field measurements from modified gear sea trials.

4.1.3 Economic impacts of adopting new fishing gears

Relatively few studies have been undertaken to assess the economic impact of adopting environmentally friendly fishing gear. Previous studies have largely considered the additional costs imposed on fishers through the introduction of bycatch reduction devices (e.g. Griffin and Oliver, 1991; Hendrickson and Griffin, 1993; Matsushita and Shida, 2001). These were mostly reductions in catches as a result of using the gear. Ward (1994) and Pascoe and Revill (2004) also considered the benefits to other fisheries from reduced bycatch in a particular fishery. The latter studies have employed bioeconomic models to estimate the transfer of benefits to the other fisheries.

A main feature of this study is that gear is also being developed that will lead to a reduction in habitat damage. No previous studies have been undertaken to determine the economic impact of such an environmental benefit in fisheries, although adoption of management strategies and technologies to improve biodiversity in agriculture (*e.g.* Wynn, 2002) and protect endangered species in forestry (*e.g.* Marshall *et al*., 2000) have been considered through the use of cost-effectiveness analysis. An implicit assumption of such an analysis is that the environmental benefits do outweigh the costs, and the emphasis is then on achieving the greatest environmental benefit (in terms of reduced impact) at the lowest cost to the industry.

4.1.4 State of the art concerning gear types and mitigation of impact

Beam trawling - effects
Beam trawling, or the concept of opening a trawl with a boom or spar, has been in existence since the 1400's. It became more important in the 1960s as a replacement for otter trawls where chains had been added between the two otterboards to enhance flatfish catches. The spreading force of the boards limited the number of chains that could be used. In the intervening years, beam trawl efficiency for catching flatfish has been enhanced with weight, number of chains and size.increasing. However, since 1988 the beam width has been limited to 12m.

The penetration depth of a beam trawl depends on the weight of the gear and the towing speed, but also on the type of substrate and ranges between 1 and 8 cm (Paschen, Kopnich and Richter, 2000).

Beam trawling reduces the biomass, production and diversity of benthic communities (Lindeboom and de Groot, 1998; Kaiser and de Groot, 2000 Paschen, Richter and Köpnick, 2000). Changes in communities following beam-trawling result from the direct mortality caused by the trawl and also the indirect effects of this mortality on species interactions (Ramsay *et al*., 1997; Jennings *et al*., 2002). Beam trawls cause direct mortality in two ways. Firstly, the shoes, tickler chains or chain mat impact on animals on the seabed (Bergman and Van Santbrink, 2000) and secondly, animals are caught in the net and die from sustained injuries, during hauling or when the catch is processed and discarded (Lindeboom and De Groot, 1998).

The mortality caused by beam trawls hitting benthic invertebrates was measured by Bergman and van Santbrink (2000), who compared the densities of animals before and after trawling. For gastropods, small and medium-sized crustaceans (typically 5-40 mm length) and annelid worms, direct mortalities following a single pass of a 12m-beam trawl were typically 5 to 40%. For bivalve species, mortalities ranged from 20 to 65%. The mortality rates of invertebrates that are caught and discarded can also be high, ranging from 26-88% for bivalves, 25-67% for crustaceans and 11-21% for starfish in North Sea studies (Fonds, 1994; Lindeboom and De Groot, 1998). However, since the catch efficiency of beam trawls for invertebrates is generally less than 10% (Lindeboom and De Groot, 1998), the total mortality caused by the trawl gear hitting animals is typically 5 to 10 times greater than the mortality of invertebrates that are caught and discarded.

Beam trawling – mitigation of effects

Several potential mitigation measures have been looked at over the last 30 years to reduce the impact of beam trawling on the benthic environment, but the two that provide the best potential solutions have undoubtedly been the development of electric fishing techniques and the use of benthic release panels.

Electric fishing

Research into the potential for electrical beam trawling began in shrimp fisheries where the typical jumping behaviour of the animals to electrical stimulation was noted. Later similar potential was identified for catching flatfish, especially for catching sole, and a great deal of research effort was dedicated to this technique in The Netherlands, Germany, the United Kingdom and Belgium in the 1970s and 1980s. Typically, a relatively large number of tickler chains are used in conventional beam trawls to catch sole, in particular and the key objective of the work was to decrease the gear drag by replacing the tickler chains by a system of parallel electrodes, and thus improving the fuel economy of beam trawlers, an issue of great importance in the early 1970s, but now again an issue due to the steep rise in fuel prices. The designed system, originally tested consisted of an onboard pulse generator, connected through a cable to a capacitor discharge unit built inside the beam and an array of electrodes placed in front of the ground rope. In The Netherlands the development was stopped in 1988 for political reasons, *i.e.* the fear by public authorities of a further and undesired increase in fishing capacity.

Similar electric tickler systems following the Dutch example were developed in Germany (Horn, 1976), Belgium (Vanden Broucke, 1973), and the United Kingdom (Stewart, 1978-1979; Van Marlen, 1985; Lart and Horton, 1996) although the design philosophies in the various systems diverged. All the research activities were carried out on a national basis, there were no European research funds in the fisheries sector at the time, but regular contacts between the various research workers existed. By the mid-eighties more elaborate co-operation emerged, the performance of the Dutch and the German system was compared during a trip on RV ISIS. An economic analysis showed that the effect of parameters such as fuel price, principal investment, and catch level on the payback period for a complete electric fishing system can be large, and that the system could only earn its investment in relatively short time with increased catch rates (Van Marlen, 1988).

Since 1992, however, a private company (Verburg-Holland B.V. of Colijnsplaat, The Netherlands) has developed a system after contact with the Dutch Directorate of Fisheries. IMARES became involved in this work in 1998 and considerable progress has been made in the intervening period. Initially a prototype with a beam length of 7 m was tested in 1998 and 1999 in EU-project REDUCE (FAIR-CT97-3809). The results showed a clear potential of the electrified trawl to reduce the by-catch of benthos by some 40%, while the median direct mortality of invertebrates (15 taxa) dropped from 36% for the conventional tickler chain gear type to 24% with the electrified beam trawl (Van Marlen *et al.*, 2001; Van Marlen *et al.*, *submitted*). In 2000 the system was scaled up to 12 m (See Figure 2 below), the most commonly used beam width in the Dutch fleet. A range of technical trials followed, and in 2004 a commercial beam trawler has been fully equipped with two electrified gears and winches, with extensive field tests due to begin in 2005 under a Dutch national research project. The biological and economic performance of this system will be monitored and compared to vessels equipped with conventional beam trawls. An extension of this work with an increased number of vessels is foreseen, and further biological and economic monitoring is proposed here, and is supported by the Dutch Ministry of Agriculture, Nature Management and Food Quality.

Figure 2 Prototype of a 12m pulse beam trawl tested on RV "Tridens" in 2004.

Benthos release panels

Benthos release panels (also known as drop-out panels) have the potential to reduce the environmental impact of beam trawling. Considerable developmental work has already been undertaken on benthos release panels in a previous international project (EU-project REDUCE (FAIR-CT97-3809)) and more recently in a UK DEFRA funded research national programme to develop more environmentally friendly fishing gears. These works have shown that commercially acceptable designs of benthos release panel are close to fruition. Results to date indicate that reductions in benthic invertebrate by-catch rates of 75-80% are readily achievable without loss of commercial target species. It is estimated that benthic release panels could potentially reduce the overall environmental impact of beam trawling by around 10% without any commercial penalty for the fishermen (Revill and Jennings, 2005). This figure is however a rather crude estimate using scant data and it may in fact (as suspected) be an underestimate. Further work is required to specifically quantify the overall reduction in environmental impact of benthos release panels when used in beam trawls. Some further developmental work is also required to ensure that the release panel technology successfully developed sofar, can be effectively transferred and adapted for use across the broad range of seasonal conditions and fishing grounds associated with the EU beam trawl fishing fleets.

While benthos release panels can potentially release a substantial majority of benthic invertebrates caught in the beam trawl, they do little to release many of the small non-target juvenile demersal fish species. Such fish are an integral feature of marine benthic communities. Cod-ends / panels constructed from T90 mesh may offer a simple potential solution which release substantial numbers of small non-target benthic fish species (see following section). T90 mesh can also potentially be used in combination with a benthos release panel to achieve a much greater overall reduction in the environmental impact of that fishing gear.

T90 cod-ends

Cod-ends / panels constructed from T90 mesh (mesh turned through 90°) have a more open mesh than conventional diamond mesh. Unlike diamond mesh, the opening of a T90 mesh is maintained under strain and can therefore allow small fish and invertebrates to escape through the meshes throughout the complete towing cycle. Preliminary trials conducted by Moderhak (MIR), and Revill (CEFAS) have shown that T90 cod-ends can potentially substantially reduce the by-catch of non-target / undersized fish without loss of commercial target species. Provisional pilot trials with a T90 cod-end have been undertaken in the UK English Channel beam trawl fishery (June 2004) and also the UK Farne Deeps Nephrops fishery (Oct 2004). T90 cod-ends can potentially be used in combination with a benthos release panel in order to greatly reduce the impact of many towed fishing gears upon benthic communities. Further testing and evaluation of T90 cod-ends /panels is required as studies to date in this field are extremely promising, but limited.

Figure 3 T90 cod-end under pilot testing on a UK beam trawler

Figure 4 Example of typical comparative catches from paired hauls during previous UK twin beam trawl trials

Otter trawls – effects

As described by Rose *et al.,* 2000, traditional otter trawls have several components that contact or approach the seabed and variations in the design of these components determine their effect on the seabed. According to Brylinski *et al*., 1994, up to 12% of the seabed in the path of an otter trawl during tests carried out in the Bay of Fundy was noticeably changed. The most prominent effect of otter trawls on the sea bed is the furrows caused by the otter boards, which may extent to about 20 cm depth (Brylinsky *et al*., 1994; Sanchez *et al*., 2000; Sala et al., 2009). Other components that have an impact are the sweeps, the groundrope, especially when made of a heavy construction, such as bobbins and these components can leave narrow scrapes or compressions depending on weight and bottom type.

Trawl door marks are the most recognizable and most often observed effect of otter trawls (Caddy 1973, Friedlander *et al*., 1999; Sala et al., 2009), producing narrow but nonetheless deep swaths. Doors travel across the seabed orientated at an angle to the direction of tow with the resulting marks consisting of an area of seabed scoured by direct contact with consequential sediment disturbance. The extent of these marks is directly related to the downward force exerted on the seabed and the width of that contact. Generally the vertical attitude of the bottom trawl door is adjusted so that hydrodynamic forces have a small downward component, increasing the force of seabed contact (Seafish *et al*., 1993) but the design of door can influence the degree of contact significantly.

Bridles and sweep arrangements that connect the doors to the net may be in contact with the seabed for part or all of their length. When using long bridles in fact to target herdable species such as flatfish, the bridles contact more seabed than any other trawl component over the duration of a tow. The force of contact of these sections with the seabed results from their weight per length and unless heavy chain or supplementary weights are added, this limits the action of bridles to skimming the surface of the seabed. Small scale vertical features, particularly on soft substrates can be flattened by this action, while emergent organisms can be vulnerable to penetration or undercutting by bridles.

Similarly footropes of trawls cover a large swept area, with the proportion of that covered by the footrope dependant on the relative length of the bridles, Footrope effects on the seabed 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 centre section. Some protective footrope designs i.e. Rockhoppers are designed specifically not to roll but rather to turn back under the belly netting and lift over an obstruction. The large diameter of the rubber discs used in rockhopper footrope construction also produces a vortex in their wake, contributing to sediment suspension. Such footropes are less likely thus to undercut emergent organisms or to penetrate the substrate, but more inclined to run over or flatten them. The down force on the seabed exerted by the footrope is dependent on the weight per unit length and the lift from the netting and floats of the trawl to which it is attached. Generally the overriding design criteria for footropes is to ensure that it has sufficient positive restoring down force to maintain seabed contact when disturbed from equilibrium by an obstruction or change in topography.

Depending on fishing operation auxiliary weights may be added to trawl gear to increase downward force at different points along the gear. Weights installed at the lower wingends of pelagic trawls, for instance, may contact the seabed when these are fished close to the bottom. Similarly for demersal pair trawling operations weights are used to sink the gear to the seabed rather than doors. Clump weights are used to depress the centre bridles of a multi-rig. 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.

The most serious effects of trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna. Erected organisms such as sponges, anthozoans and corals have been shown to decrease considerably in abundance in the path of groundgear (Freese *et al*., 1999; Moran and Stephenson, 2000). Such habitats may thus be severely affected by fishing operations. A few studies have been conducted to determine the impacts of experimental trawling on sandy bottoms of offshore fishing grounds (Prena *et al*., 1999). These studies showed decline in the abundance of some benthic species, but trawling disturbances did not produce large changes in the benthos communities. These habitats may be resistant to trawling but because they are subjected to high degree of natural disturbances such as strong currents and large temperature fluctuations. Several studies have been conducted on the impacts of shrimp trawling on soft sediments (Hansson *et al*. 2000; Drabsch *et al*., 2001; Sparks-McConkey and Watling, 2001.) However, clear and consistent effects of trawling disturbances have not been demonstrated in these studies. On the other hand, soft-bottom habitats show pronounced temporal changes due to natural variability, and potential changes attributed to trawling may be masked by this variability and therefore difficult to demonstrate.

Bottom trawling fleets predominate in many Mediterranean fisheries, being responsible for a high share of total catches and, in many cases, yielding the highest earnings among all the fishing sub-sectors. The high profitability of this fishing practice is largely due to its low selectivity with respect to sizes and species caught, and to the high harvests generated. Trawlers have dramatic effects on the ecosystem including physical damage to the seabed (Sala et al., 2009) and the degradation of associated communities, the overfishing of demersal resources, and the changes in the structure and functioning of marine ecosystems derived from the depletion of populations and the huge amount of bycatches and associated discards.

The effect on marine communities is twofold: i) at a single-species level, the population dynamics of a species are altered, and ii) at the ecosystem level profound changes occur because of the disruption of food webs. Ecosystem modifications are triggered by the change in the biomass and demographic structure of the different species as well as by the increasing food supply for scavenger and opportunistic species. It is worth noting that the latter can result in the trophic connection of separate sub-systems (i.e. pelagic and benthic), making ecosystem consequences even more dramatic.

Although bottom trawling is inherently rather unselective, bycatches and discards can be minimized. Trawling can be limited and technical measures can be introduced to improve selectivity. Trawl selectivity within an area depends on many factors, ranging from the depth exploited or the kind of bottom, to the season. Most impacting scenarios could be avoided by restricting trawling both spatially and temporally. In this context, current provisions banning trawling in coastal waters less than 50 m deep or three miles offshore should be enforced effectively. Trawling gears could be made more selective by using higher mesh sizes or incorporating special excluding devices, such as those based on rigid grids. The former solution may be difficult to apply in Mediterranean waters for social and political reasons, but the development and compulsory use of excluding devices increasing selectivity (such as those in use in some North Atlantic waters) deserve attention. Alternatively, the use of a square mesh can also improve selectivity. It is convenient to mention here that shorter trawling hauls are known to reduce discard rates (Stergiou *et al*., 1998, Moranta, *et al.*, 2000).

Partial solutions and technical improvements notwithstanding, the banning of bottom trawling in large marine protected areas throughout the Mediterranean Basin appears to be the only way of maintaining a sample set of demersal ecosystems free of the damage caused by this widespread fishing practice. These areas would moreover be very useful as a basic reference guide to healthy bottom communities in the context of a future ecosystem-based management of Mediterranean fisheries.

Whilst the problems related to the capture of undersized individuals, bycatches (and subsequent discards) of particularly vulnerable species or groups by Mediterranean unselective trawling fleets, there is compelling evidence that the physical impact of Mediterranean bottom trawling on Posidonia beds and soft bottoms is significant: trawl doors penetrate them more deeply than other sediments, with potentially greater effects on infaunal species (Ball, *et al.*, 2000). The ecosystem effects of trawling on deep muddy bottoms, *i.e.* in red shrimp or Norway lobster fisheries, also deserves special attention given the high vulnerability of deep muddy bottom communities to external perturbations.

Otter trawls – mitigation of effects

Gear modifications to otter trawls to reduce seabed impact have been reported by Carr and Milliken 1998, Valdermarsen and Suuronen 2003, Rose *et al.* 2000, CEFAS 2003 and He *et al.,* 2004. These modifications include reducing the weight of groundgear, reducing bottom contact (e.g. semi-pelagic trawling), using "sweepless" trawls with drop chains and no or limited groundgear and more novel approaches such as the use of kites, depressors or other flexible devices and "Active" or "Auto" trawl systems. The following are some of the mitigation measures developed:

Lighter Groundgear

In 1999, as reported by He and Foster, 2000, the Fisheries and Marine Institute in St. John's, Newfoundland and Fishery Products International Ltd. jointly initiated a project to evaluate and to reduce seabed impact of offshore shrimp trawls. This work involved model flume tank testing as a well as sea trials and aimed to establish whether it was possible to reduce seabed contact through a reduction in the number of footrope bobbins, without significantly altering the performance and catching efficiency of the gear. A number of options were tested and the results were positive in terms of geometry and stability of the experimental trawl, however, reduced catch rates and gear damage were experienced.

Other similar developments include research in the Faeroes to reduce seabed impact by replacing tickler chains with brushes (K. Zachariassen, *unpublished*) and also replacing rockhopper footropes with wheels or rolling gears (K. Zachariassen, *unpublished*). The object was to develop modifications that could roll in the towing direction. The most successful configuration tested consisted of a single 22cm wide rubber disc with a steel axle attached to a bracket. The brackets were then attached to the footrope with a steel pin. Between the wheels, there was a combination of discs and rollers that were smaller in diameter than the wheels. Each wheel rotated independently and maintained orientation in the tow direction. This design seemed to be workable and practical and further work is planned in the Faeroes and also in Norway. Similar research in Ireland (Ball *et al.,* 1999) tested whether the rubber disc groundgear of an otter trawl could be replaced with a series of weighted rollers. The purpose of the design was to allow the trawl to move over, rather than plough the seabed. Preliminary results were promising with the system developed.

Semi-pelagic Trawls

Species such as shrimps, *Nephrops* and fish species such as monkfish are not herded by the sand clouds generated by the bridles and doors due to poor swimming ability and inability to react to fast moving trawl components. The mouth area of the trawl designs used to target these species therefore, determine to a large degree the amount caught. Taking this principle a number of experiments have looked at using trawling system with the doors off the bottom to reduce bottom impact whilst maintain commercial catch rates. As reported in He *et al.*, 2002; He and Littlefield, 2003, Delouche and Legge, 2004 and He and Delouche, 2004 two experiments have been carried out in the Gulf of Maine and in two locations off Newfoundland. In both experiments, the primary control of the door height was achieved through the shortening of warps and monitored through the use of door height monitoring devices. Results from the trials again showed potential for semi-pelagic trawling for shrimps in this case, although it was concluded that further work was required to design a more robust system to better control the doors.

Sweepless or Raised FootropeTrawls

The “raised” footrope trawl was developed for the Gulf of Maine silver hake *Merluccius bilinearis* fishery to avoid catching flatfish and other bottom-dwelling organisms by raising the height of the fishing line 0.5m above the seabed (Pol, 2003). The fishing line was raised by the attachment of a sweep chain to the fishing line by a number of drop chains. The raised footrope trawl has been very successful and has become mandatory in the fishery. The sweepless trawl, however, represents several improvements being easier to rig and enforce as well as having less impact on the seabed, because contact is reduced to a limited number of points, instead of from wingend to wingend. The sweepless trawl has no chain sweep and additional weight to replace the weight of the sweep is provided either by increasing the link size of the drop chains, or by hanging two chains at each attachment point. Some fishermen in the US have adopted the sweepless trawl voluntarily because of its advantages, although concerns have been raised about loss of target species. Efforts are continuing to promote the use of the sweepless trawl.

Kites, depressors and other flexible devices in trawls

Goudey, 1999 has investigated the use of kites and other flexible devices such as depressors. A narrow fabric-depressing panel was installed between the fishing line and groundgear, along with kites installed at various locations in the trawl. Parafoil doors instead of standard doors were also tested. However, the devices were only tested in a flume tank and no subsequent sea trials are reported. A more interesting development is the “self-spreading” groundgear consisting of ‘sheering plates’ being developed by SINTEF and IMR, Norway (SINTEF, 2004; Figure 5). In this design, a series of rubber plates were mounted under the fishing line. Flume tank tests and half-scale field trials showed the new groundgear to increase wingend spread by 10-15% and suggested door weight could be reduced. In addition, because the individual plates can flip horizontally in reaction to rocks and other obstructions, this gear appears to react to obstructions more dramatically compared to standard rockhopper gear.

Figure 5 Sheering plates to replace rockhopper ground gear

"Active Trawl" and "Auto-Trawl" Systems

The concept of the Active Trawl System was developed by Shenkar (1995, 1996) to overcome difficulties in improving the performance of trawl doors and active control of the doors. The Active Trawl System developed spreads the trawl by using "variable thrust vector devices" (VTDs) powered from the ship. The system is designed to have a "bottom-contour" mode in which the VTDs maintain light contact with the bottom or operate at a set height above the seabed. Although this system is still in development stage, it does provide the potential for a doorless otter trawl in certain fisheries, where herding is not a pre-requisite to catch the target species. SCANMAR in Norway has carried out similar developments using acoustic control of the trawl door's vertical and horizontal positions. This is a part of more comprehensive research and development work into "Auto-Trawl" systems, which is ongoing. It is reported that acoustic manipulators fitted onto the doors and fired by means of an acoustic link can control the position of doors.

Proposed mitigation measures

Rationale of the approach

The approach adopted in the proposal is :

(i) to develop towed gears with reduced impact, and
(ii) to develop static gears or more targeted fishing with towed gears to direct effort away from areas of sensitive habitat.

The majority of the area fished in EU waters is not considered to be sensitive habitat, being largely made up of soft sediments and gravel, nevertheless, the ecological disturbance to the benthos in these habitats is well documented. We believe that for these areas it is possible to reduce the benthic impact of fishing by modifying the design of existing towed gears. At the same time, valuable fisheries do exist in areas of recognised sensitive habitat such as cold water corals and maerl beds. To protect these areas we believe it is necessary to prohibit fishing with towed gears and to redirect effort to static gears.

To assess the impact of these gears we employ a range of 'ready to use' indicators measured in the tow path that account for both physical and biological effects of the gear.

We also assess the overall ecological impact to benthic systems by refining an existing model of the disturbance of fisheries. Ultimately this will provide a tool to fisheries managers that could be used to identify gear and sediment type combinations which will minimise impact to the benthos.

The core of the proposed work will be the development of new fishing gears that have a lower impact on benthic habitats and communities (WP 3 and WP 4). With generic models, based on gear components, to be developed in WP 2 Modelling and quantification of benthic impact, the effects both in physical sense, as on benthic communities will be evaluated. In addition the economic viability of using these new gears and the economic potential of alternative tactics or gear types such as static gears will be investigated (WP 5).

Modifications to towed gears

Otter trawls

The most important components of otter trawls causing impact on the sea bed are the otter boards and the groundgear, which will be addressed in WP 3 Otter trawl modifications. A strong candidate is the replacement of rockhopper groundgear with 'self-spreading ground', which uses sheering plates arranged along the fishing line instead of rockhopper discs that, particularly along the wings are rigged transverse to the towing direction and thus creates significantly less drag and ground friction. Similarly roller footropes, which have been the subject of research in the Faeroes and Ireland and are designed to move over, rather than plough the seabed are also considered. Several different configurations have been tested, with the most promising incorporating pairs of rubber discs with steel axles, which can rotate independently of each other and maintain orientation in the towing direction.

Trawl Doors

Many existing Trawl door designs can be rigged to have less bottom impact through alterations to warp:depth ratio or towing point, e.g. Morgère Polyfoil and Oval doors, while other doors are specifically designed to have minimal bottom contact with high lift-to-drag ratios *e.g.* Faeroese Injector doors or Poly-Ice El Cazador doors. CNR-ISMAR, in collaboration with Grilli sas and Prosilas sas in Italy, has recently designed an experimental "low impact" door which is designed to reduce hydrodynamic drag coefficient and increase spread. This prototype door design is based on the most advanced hydrodynamic concepts in improving the water flux on the upper part of the trawl door to avoid vortices, which are the cause of increased drag and cavitations. This results in better efficiency in terms of reduced fuel consumption but more importantly less ground contact. The initial review and modelling work (using commercial software 'Fluent') will consider these alternatives as well as research into developing hydrodynamic efficient trawl doors with less ground contact, or no ground contact at all currently being undertaken in France by the door manufacturer, Morgère and in Iceland by Hampidjan using light "plastic" doors. This objective can be reached through mitigation of the excess reaction force of the door to seabed, which can be achieved by weight reduction, performance improvement and/or the use of hydrodynamic devices that will maintain the door off the bottom or with a low intensity contact on the bottom.

Beam trawls

The most successful modifications developed so far are the pulse trawl, and the benthic release panel, which will be studied further in WP 4 Beam trawl and Dredge modifications. In addition a square mesh codend will be studied for the Mediterranean. Prior research has shown that the bycatch of benthic organisms can be substantially reduced, and in the case of the pulse trawl the direct mortality of a range of benthic invertebrate species was found to be lower. Concerning the state of development of the pulse trawl and the benthic release panel, it is expected, that these innovations can be successfully implemented. The proposed work serves to support this objective.

Dredges

An alternative Danish oyster dredge design to reduce impact will be studied in WP 4 Beam trawl and Dredge modifications.

Alternative gear types.

It is conceivable that changes in gear type (e.g. from a mobile to a stationary gear) will serve to protect habitats and components of the eco-system.

Proposed gear replacements are:

- Replacing beam trawling for flatfish by gill-nets, for which an economic study will be done in WP 5.

5 WP2 – approach and results

5.1 Finite element (FE) modelling (Task 2.1)

Finite element (FE) modelling of both full scale and lab scale components has been undertaken using the ABAQUS software package. Simulations of the roller clump, the trawl door and some rock hopper gear used during the sea trials of participant 3 have been run to provide correlation with full scale trials, while a scale model trawl door and roller clump have been simulated to correlate with the lab tests. Some of this work has been published. [1, 2]

5.1.1 Full Scale Trawl Models

The first component simulated was a roller clump from a twin trawl. This was simulated as a rigid body penetrating/rolling over a deformable seabed. Figure 2.1 shows a diagram of the seabed and roller clump prior to the start of the simulation.

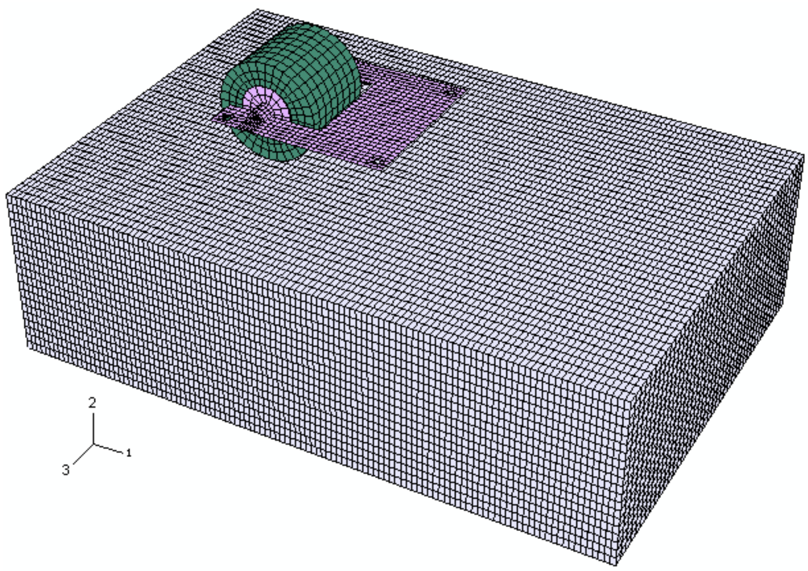


Figure 2.1 An FE model of the seabed and a roller clump

The simulations involve dropping the component onto the seabed and then towing along the seabed at constant velocity. After initial simulations it was found that the best results were obtained with the use of adaptive meshing and an hour-glass effect available in ABAQUS. The adaptive meshing feature updates the mesh after a number of time steps to ensure that the mesh does not become too distorted as this reduces accuracy. The hour-glass effect allows for additional modes of deformation which allows the material to “flow” better. This was used to permit the loose sediment to flow around the trawl component. This method initially proved highly effective in producing penetration depths and trench shapes very similar to those found in the sea trials as is shown in Figure 2.2 [1]. Figure 2.3 shows a typical result for this type of simulation from FE simulation.

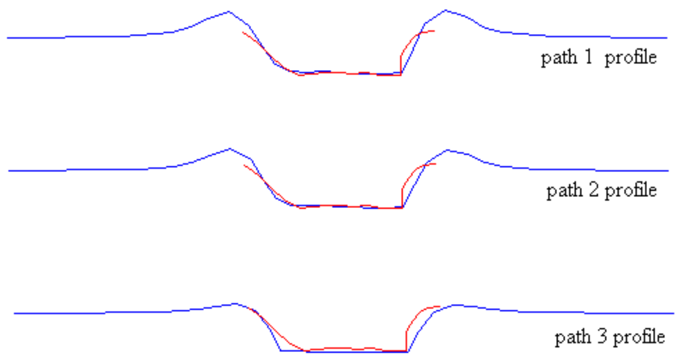


Figure 2.2 Image across the trench formed by towing a 1.2t roller clump over the mud soil obtained from FE and sea trials. (blue line is from the FE simulations and red is from the sea trials)

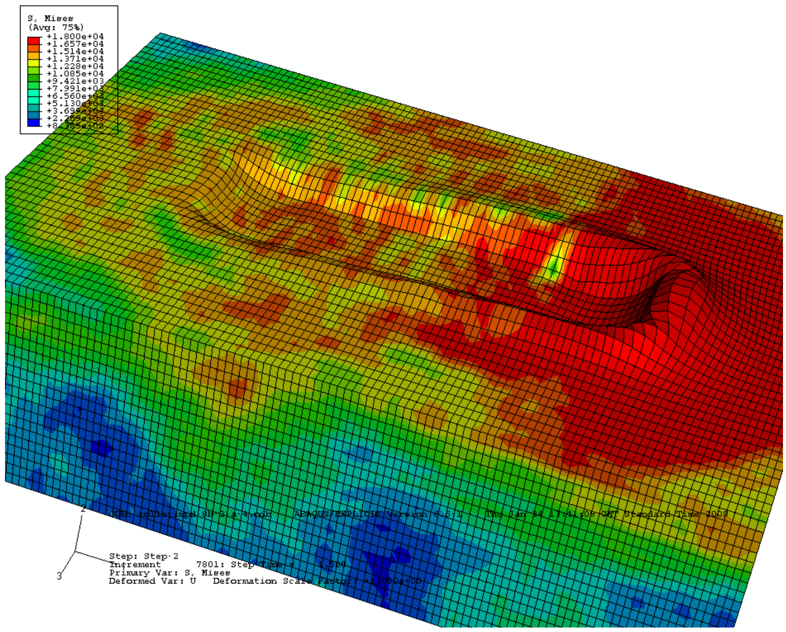


Figure 2.3 An image from the FE simulation after towing a 1.2t roller clump over the mud soil

Similarly, the results between the numerical models and the sea trials compare well for the case when the otter door was towed. These validations are reported in (1) and (2) and a typical comparison with the sea trials shown in Figure 2.4.

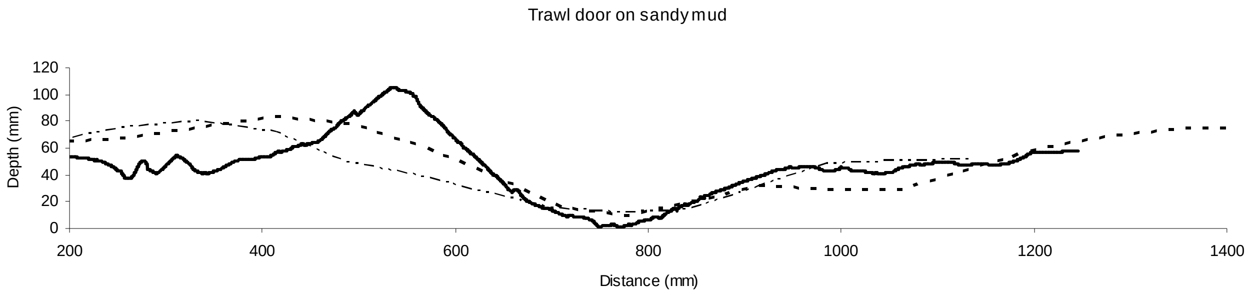


Figure 2.4 Image across the trench formed by towing a Morgère WS trawl door over the mud soil obtained from FE and sea trials (dashed lines are from the FE simulations and the solid one is from the sea trials)

During validation of the drag incurred during the towing action, however, it was found that the hour-glass effect appears to modify the contact stresses, and so the drag force. As a consequence some simulations are now being run with the adaptive meshing feature but without the hour-glass option. The FE simulations with this new approach produce higher penetration depths than was the case with the previous set up which included the hourglass effect. Regardless, this approach is still deemed valid for sandy mud soil, which is believed to experience more plastic deformation during the towing of the element.

Currently simulations have been run for the Morgère door used by FRS for its sea trials. These simulations were run with the adaptive meshing feature. Simulations were run for a variety of downforce on the door and pitch angle but for only one pitch angle, 35° which is close to the nominal angle for the FRS sea trials. In discussion with FRS it was decided that the range of this angle would be small and so to reduce computational effort only the nominal angle was chosen. The details of the simulations and the parametric values are shown in Table 2.1.

Table 2.1 Parameter values for the parametric study

Otter door			
	weight	**pitch angle (°)**	
velocity 0.1m/s angle of attack 35°	0.5w	0, 5, 10	For all combinations the following relationships are required: - penetration vs. vertical force - penetration vs. velocity - drag force vs. displacement - drag force vs. velocity
	w	0, 5, 10	
	1.5w	0, 5, 10	
velocity 0.2m/s angle of attack 35°	0.5w	0, 5, 10	
	w	0, 5, 10	
	1.5w	0, 5, 10	
velocity 0.5m/s angle of attack 35°	0.5w	0, 5, 10	
	w	0, 5, 10	
	1.5w	0, 5, 10	

The relationships of drag force to penetration and velocity and contact force to penetration and velocity could then be generated and are shown in Figures 2.5 and 2.6 respectively. It should be noted that the surfaces shown in the figures were obtained using 0.5w, w and 1.5w for the weight of the otter door, where w is the nominal weight of 4.5kN and for three different velocities of 0.1, 0.2 and 0.5 m/s. It is clear from both graphs that with an increase of the weight the contact and drag forces increase. It is interesting to observe that the pitch angle has an influence on the drag and contact forces obtained. It appears that when there is no pitch angle the door performs more like a sledge and therefore does not show a linear increase in force with an increase in weight as is apparent for the surfaces corresponding to a pitch of 5 and 10 degrees.

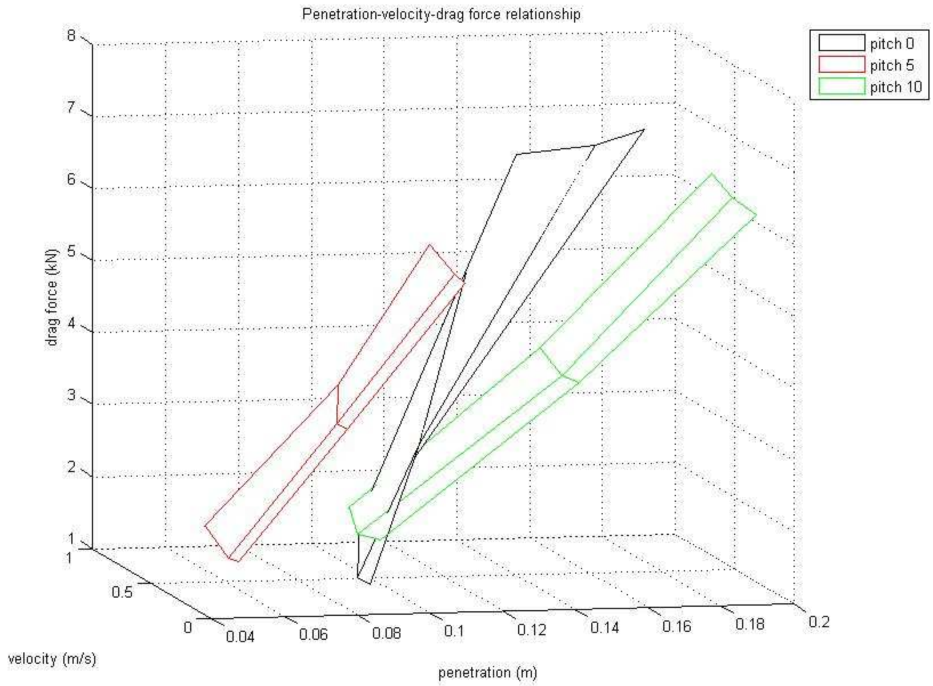


Fig. 2.5 Relationship between drag force and penetration- velocity obtained from FE model

Further observations show that the penetration produced by the door with a pitch angle of 5 degrees is less than when the door is kept horizontal during the towing process. At the same time the drag force is also smaller which may be explained by the reduced surface in contact with the seabed due to the pitch angle of the board. This implies that a higher pressure will be present towards the rear of the door. With a further increase of the pitch angle the drag force becomes higher as the heel of the door penetrates more and builds up the sand in front of the door. The heave produced increases the force (amount of energy) needed for the trawl to be towed. These results suggest that pitch angles between 0 and 5 degrees are sensitive. Either the contact has not been fully established or the pitch angle is not high enough to produce an amount of soil in front of the door sufficient to increase the resistance of the soil and therefore drag force higher than for 0 degrees pitch angle.

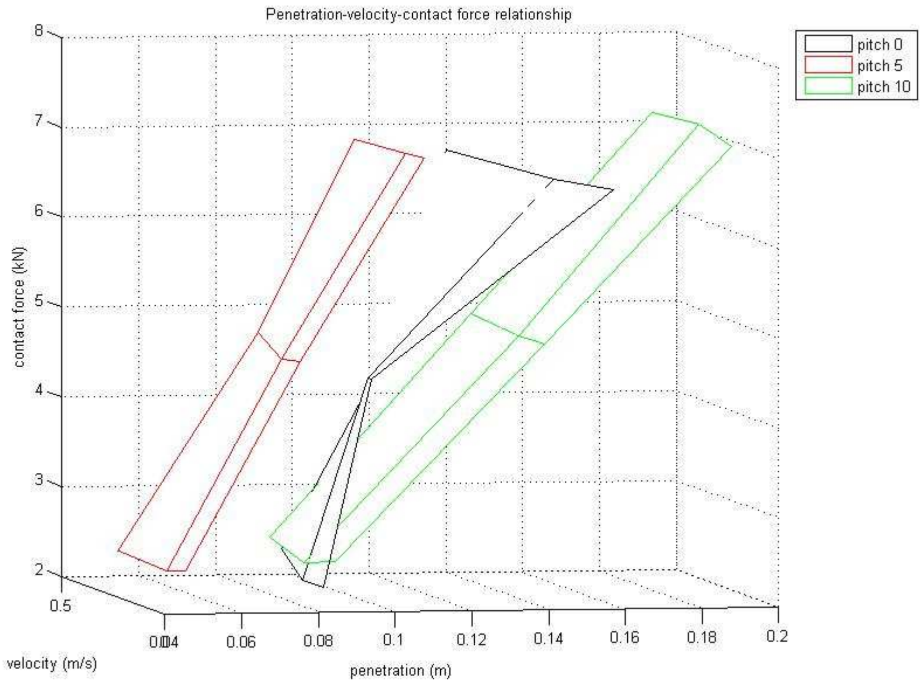


Fig. 2.6 Relationship between contact force and penetration-velocity obtained from FE model

Similar relationships are to be generated for other gear components such as the roller clump and ground gear discs. All these components are in direct contact with the seabed and therefore important to be observed and any potential disturbance noted.

The results of the FE analysis will be used for a dynamic numerical model, which is able to predict the dynamic behaviour of different trawl gears and help assess the possible disturbance they may cause to the seabed. In order to define the contact between the seabed and gear components within the dynamic model (Figure 2.7) the relationships defined in the FE study will be used. A curve fitting method was used to establish a function which desribes the relationship between penetration, velocity and drag force required for the dynamic model.

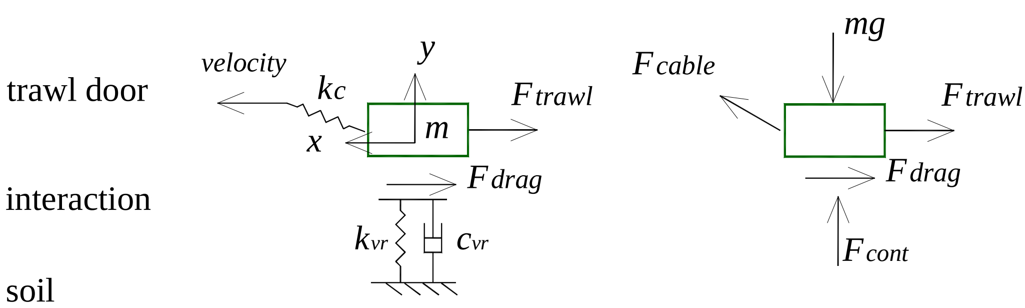


Fig. 2.7 Contact between the soil and the gear component dynamic system and the free body diagram

The relationship between these variables gives encouragement that similar relationships can be obtained for other gear components. Simulations are currently under way for the rock hopper gear used in the FRS sea trials and the bobbins for the new plate gear proposed by IMR as part of Work Package 3. A similar approach can be used for the scaled models used in the laboratory allowing for different soil properties to be investigated.

5.1.2 Laboratory Scale Trawl Models

FE models have also been run for the scale models investigated in the lab. In particular a roller clump and simplified model of a trawl door have been investigated [2]. The main purpose for the laboratory tests was to validate the FE model which will then be able to be used for modelling the sea trials. An FE image of the displaced soil across the trench formed by towing the scaled laboratory roller clump over the soil is shown in Figure 2.8.

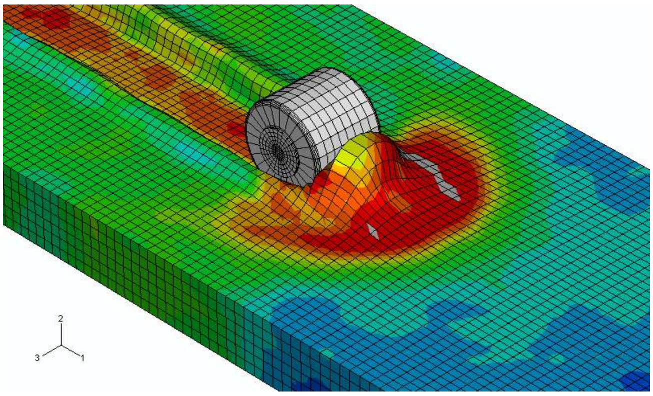


Figure 2.8. Image of the scaled roller clamp using the FE model.

5.1.3 Laboratory Scale Testing

The lab tests were run in a purpose built channel, which incorporates a frame and moving trolley on which the component is mounted. The channel is 4.8m long, 50cm wide and 20cm deep and the trolley which runs on the frame is designed in such way that different trawl components can be easily attached and tested. This is shown in Figure 2.9.

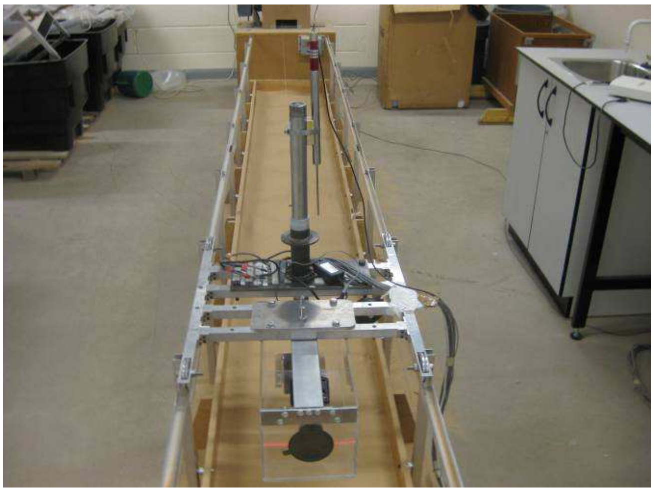


Figure 2.9. Laboratory sand tank

The channel was filled with a sand of similar particle size to one of the tests run by FRS. The trolley is pulled along the channel at constant velocity by a winch system. The speed and position of the trolley are monitored by a wireline displacement measurement device. The component is free to move vertically relative to the trolley and the drag force and depth of penetration are monitored by a load cell and LVDT respectively. Pressure transducers can also be used to measure the pressure in the sediment during a test or in the case of the trawl door, on the front and lower surface of the trawl door shoe. A laser camera scanner has been built specifically to measure the trench formed by towing a gear component through the sand. This technique allows for the laser profile of the difference between the undisturbed and disturbed sand bed to be obtained. The technique is a powerful tool, allowing clear and elegant measurement of the contour of the trench after the tow rather than using manual measurements. The details of the laser and camera are described comprehensively in OMAE 2009. A close up view of the camera and laser is shown in Figure 2.10.

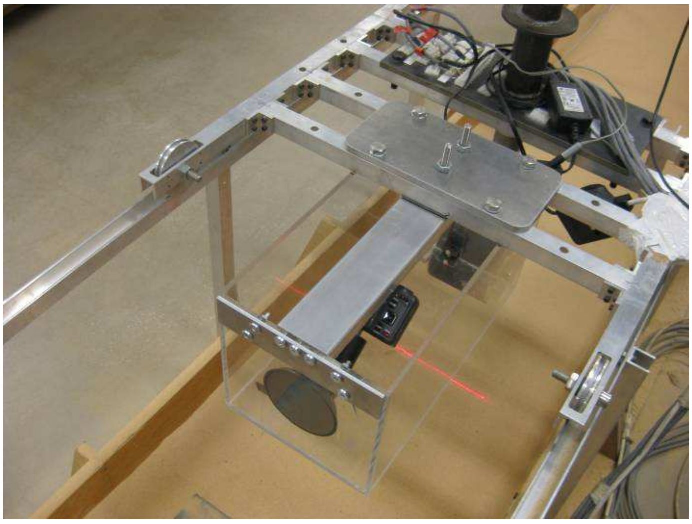


Figure 2.10. Close up view of the camera and the laser set up.

A typical profile is shown in Figure 2.11.

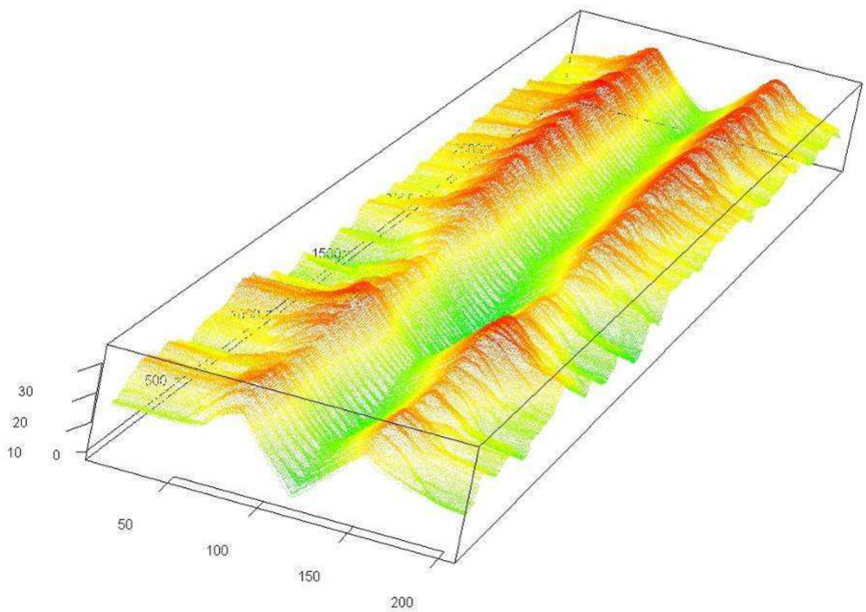


Figure 2.11. An image obtained from the camera and the laser set up.

An extensive series of tests were undertaken on the trawl door and the following conclusions were drawn:

- Over the range of velocity examined (0.1, 0.2 and 0.5m/s), the drag force does not seem to depend on velocity. The fluid drag due to the water will however.

- The drag force increased with increasing attack angle to a certain point and then decreased slightly. The peak was found for the tests run at 20°

- The depth of penetration of the trawl door is sensitive to the pitch angle. During initial experiments a small negative pitch was present (nose down). These negative pitch angles produce deeper penetration than positive angles (nose up). The shape of the nose of the shoe was also found to be important. The small radius, 10mm, used initially was found to produce deeper penetrations than a larger radius, 42mm, used in later experiments. With this radius the scale model door is effectively a 1/10 scale model of the Morgère door in terms of geometry and scaled mass.

A series of experiments have also been undertaken with the roller clump

- Over the range of velocity examined (0.1, 0.2 and 0.5m/s), the depth of penetration starts with a rapid penetration and then levels out to a steady state within similar distances from the start of the test. When the results are compared with the simulations undertaken by FE analysis it is shown that the penetration obtained from the experiments is higher which can be explained by the fact that the surface layer of sand is looser in the experiment than can be modelled easily.

- The drag force becomes constant after 2.4 m showing that a steady state has been achieved. (See Figure 2.12) The results show that both the drag force and penetration increase with velocity. However, it should be noted that relative increase in force with increasing velocity is greater than the relative increase in penetration with velocity. This suggests that although the force is affected by the depth of penetration, the velocity has a substantial additional effect as well over the speed range examined for this component. This is an important aspect in terms of producing a model which can be included in a full dynamic model of a trawl system interacting with the seabed.

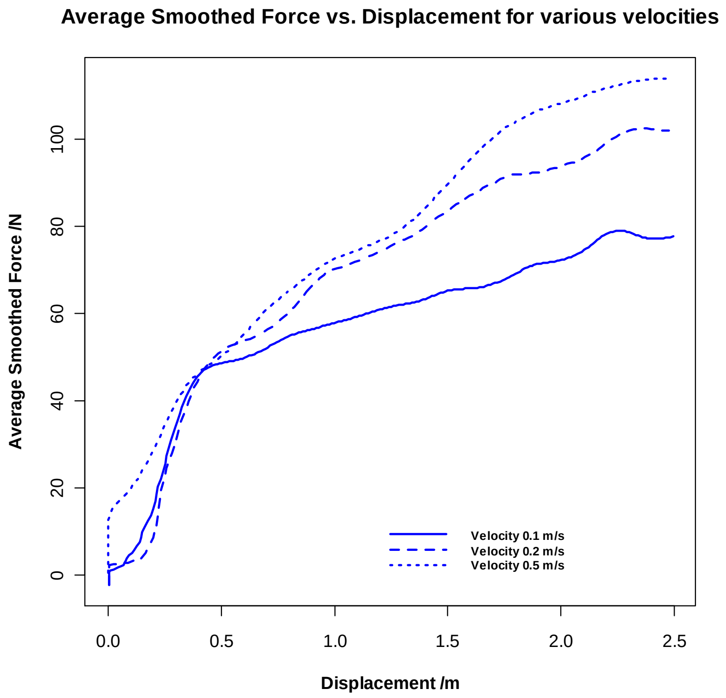


Figure 2.12 Force vs. displacement obtained from the experimental set up for different velocities

5.2 Dynamic models of complete trawl gear systems (Task 2.2)

5.2.1 Introduction

The aim of the dynamic modelling task of WP2 was to produce dynamic models of complete trawl gear systems, which could be used to simulate the motion of the trawl as it was towed over the seabed. The models should be able to predict the depth of penetration and as well as the volume of sediment disturbed at different depths. This data can be used by the biologists in the team to predict the mortality of the infauna and epifauna and so estimate the ecological impact of the trawl.

Although a number of models of trawling and netting have been developed previously by researchers [4-16], most of these have been aimed at estimating the shape of various designs of trawl net and particularly the cod end [10-16], the shape and motion of which affects the escape of fish [17-19]. One of the most comprehensive models, the DynamiT package produced by IFREMER, provides net manufacturers with a means to check the geometry of a proposed trawl design [20]. This includes spread of the net, net shape, drag etc. Although the package makes allowance for contact of the trawl and trawl doors with the seabed as a constraint, no quantification of the disturbance of the benthos can be made.

To address these issues, two models have been developed within the project:

- Simple 3 mass model comprising 2 trawl doors and the trawl
- Full multi-mass model of a complete trawl with detailed, warps, doors, sweeps, bridles, ground gear and net.

The former of these has been completed and the latter is in the final stage of development. The two models are discussed in more detail in the following sections.

5.2.1 Simply 3 Mass Model

Description

The aim of producing the simplified 3 mass model was to prove the various modelling principles before proceeding to the detailed model of a full trawl system. A schematic of the 3 mass model is shown in Figure 2.13.

The coordinate system used is *x* is forward along the trawl path, *y* is vertical upwards with the seabed as the datum and *z* is lateral, with starboard as positive.

The motion of the system is driven by the motion of the vessel. This is assumed to have a mean velocity in the *x* direction but heave and surge motion due to waves can also be included to assess the effect of these on seabed disturbance. The trawl doors are connected to the vessel by massless springs, which model the warps. These are attached to the vessel at the appropriate height above the sea level and at the correct width for the beam of the vessel. Each trawl door has three degrees of freedom, allowing motion in the *x*, *y* and *z* directions. The trawl net is modelled as a separate mass and is attached to the two doors by sweeps and bridles, which again are assumed massless but have stiffness. The length of the warps can be increased or decreased with time to allow shooting or hauling of the trawl if this is needed.

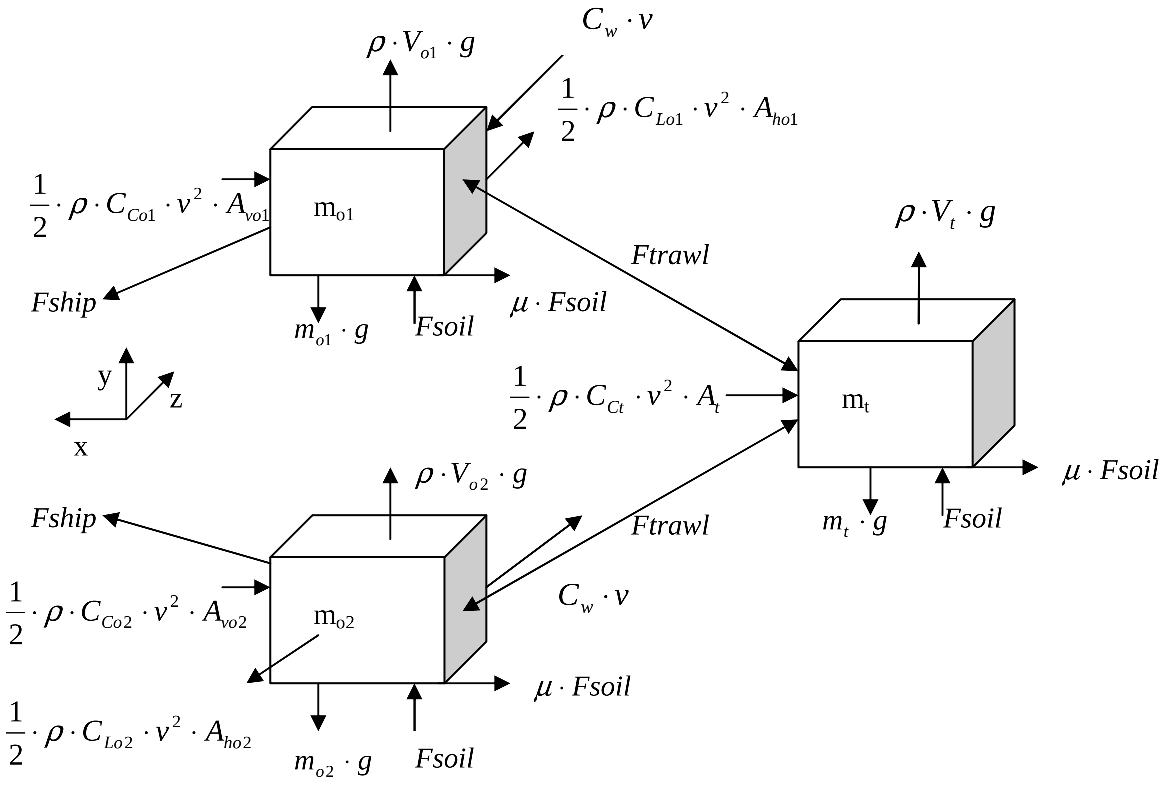


Figure 2.13 Schematic of the 3 mass trawl model

The models of the trawl doors include buoyancy, hydrodynamic lift and drag and contact with the seabed. The seabed contact model incorporates a simple linear Winkler type model of the stiffness of the seabed and Coulomb friction between the trawl doors and the seabed. The model was coded in Matlab and solved using the ode solver functions typically using ode15s or ode45.

Supporting Work – Fluid Simulation
Although Morgère publish drag and lift coefficients of 1.3 and 0.9 for the WS door used in the sea trials, the values used here for the drag are slightly lower as they are solely due to the fluid drag and lift while the published data take account of bottom contact. Simulations were run using the COSMOS FloWorks package to find the fluid drag, using a solid model supplied by Morgère. Figure 2.14 shows the trawl door model. Figures 2.15 and 2.16 show the flow vector and dynamic pressure results for one of the simulations with an attack angle of 40°. A wide range of simulations was undertaken to characterise the door. Other doors can be treated in a similar manner.

The resulting data used in the model for the trawl door are listed in Table 2.2.

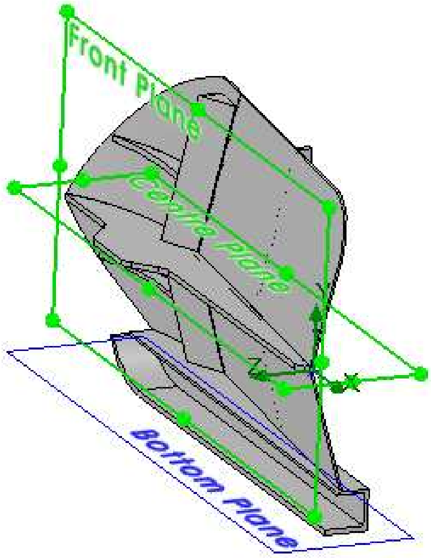


Figure 2.14 Detail of the trawl door model

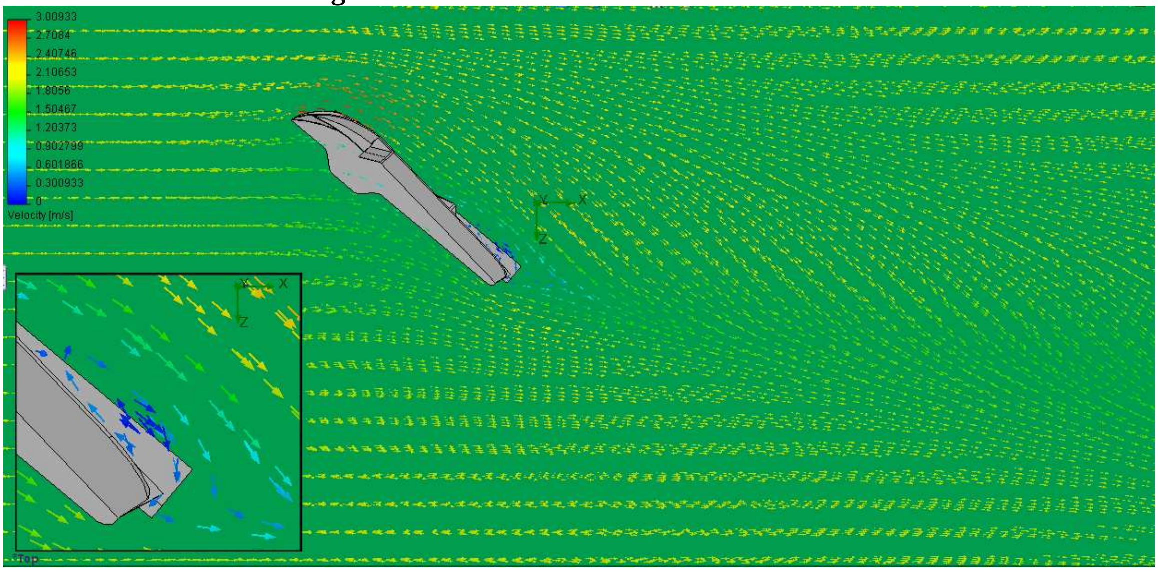


Figure 2.15 Flow pattern around the Morgère door at 40° attack angle

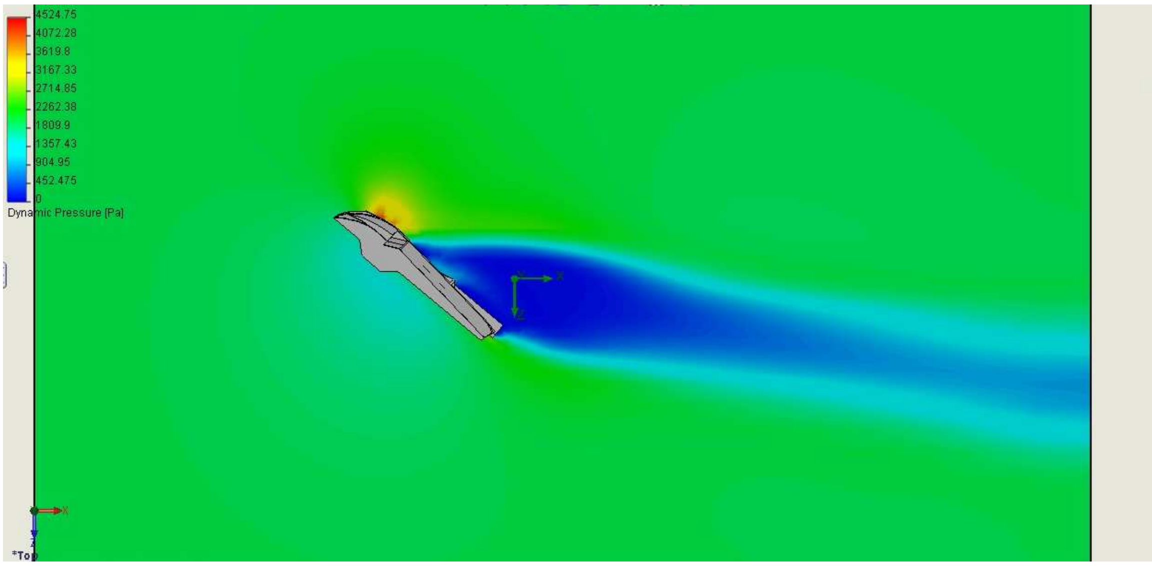


Figure 2.16 Dynamic pressure around the Morgère door at 40° attack angle

Table 2.2 Parameters of the Morgère trawl door

Parameter	Value
Trawl door mass (kg)	445
Submerged weight (kN)	3.8
Lift coefficient CL	1.3
Drag coefficient CD	0.8

Simulation Results

Simulations were run for the series of sea trials undertaken off the Moray coast and in the Clyde for the DEGREE project. Table 2.3 shows the values of the main parameters used.

Table 2.3 Parameters of the Alba/Clupea trawl simulation

Trawl Model	Alba/Clupea
Warp Length (m)	75m
Sweep/bridle length (m)	62.5m
Water depth (m)	20m
Trawl/catch mass (kg)	1000kg
Ship beam (m)	6m
Net opening (m)	12m
Velocity (m/s)	1.5m/s (2.9kt)

A number of simulations have been run using the model. Figure 2.17 shows deployment of the trawl doors. This was used to check whether the spread of the doors was correct when compared to the trials undertaken by Marine Scotland (Previously FRS Marine lab). The measured spread was reported as 36-40m and this is replicated accurately by the model.

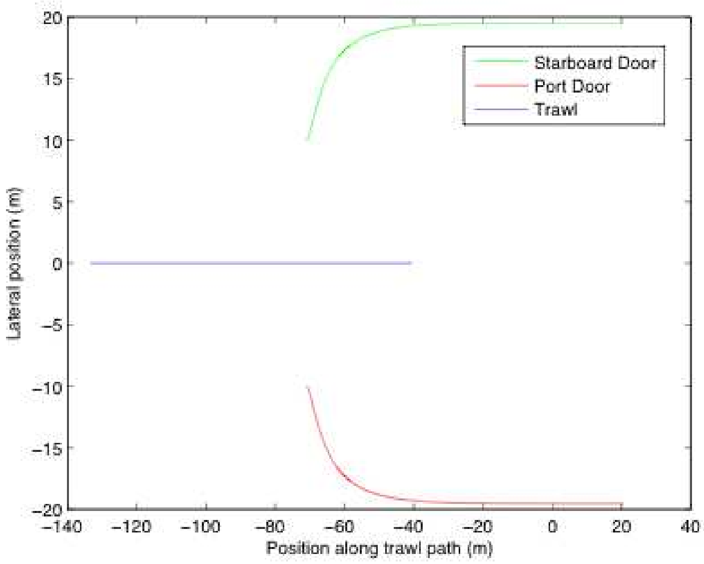


Figure 2.17 Trawl door deployment over a smooth seabed.

Figures 2.18 - 2.20 show the results of simulations from the model for different seabed conditions. In all three cases the seabed soil parameters, the trawl velocity and the masses of all components are held constant, the only variable is the seabed profile. The blue line represents the motion of the trawl door and the red lines depict the seabed surface and layers 5cm, 10cm and 15cm below the surface. These are included to show more clearly the penetration.

Figure 2.6 shows the penetration of the trawl door for the case of a smooth seabed with steady motion of the vessel. It can be seen that the penetration into the seabed is small, of the order of 2cm. Figure 2.7 shows the effect of small seabed ripples on the penetration. The ripples are 50mm high and have a wavelength of 250mm. This seabed condition is similar to that found in the Nairn/Lossiemouth sea trials. It can be seen that the trawl door cuts through the ripples and penetrates to depths of about 2cm below the mean seabed surface.

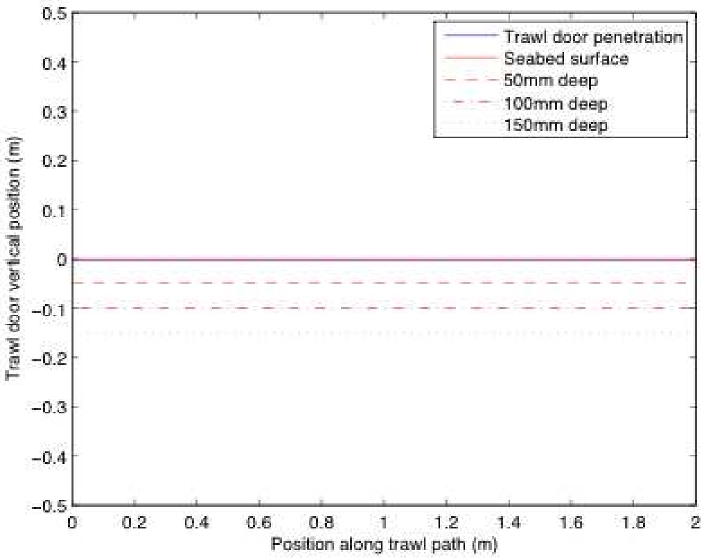


Figure 2.18 Penetration of the trawl door into a flat seabed as calculate by the 3 mass model.

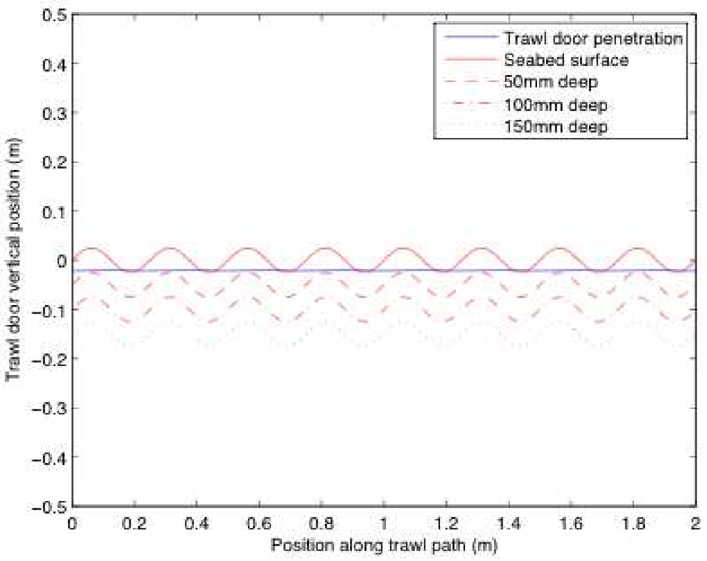


Figure 2.19 Penetration of the trawl door into a seabed with 50mm high ripples of 250mm wavelength, as calculate by the 3 mass model.

Figure 2.8 shows the effect of large, long wavelength seabed ripples on the penetration. The ripples are 0.2m high and have a wavelength of 5m. This seabed condition was not encountered during the sea trials, but is included here as a possible scenario for comparison.

In this case, the trawl door impacts the leading face of the ripple, ploughs into it but then rises, exits the ripple and slides down the rear face before impacting the front of the next ripple.

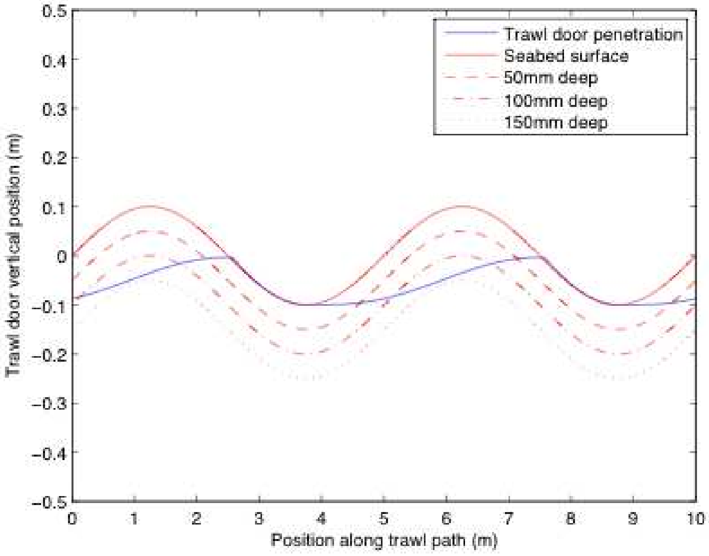


Figure 2.20 Penetration of the trawl door into a seabed with 200mm high ripples of 5m wavelength, as calculate by the 3 mass model.

For completeness Figures 2.21 and 2.22 show the effect of vessel surge motion on motion of the trawl door and its penetration into the seabed. The motion simulates approximately, the effect of a 1m 10 sec period wave on the vessel resulting in heave motion and variation of the vessel's speed.

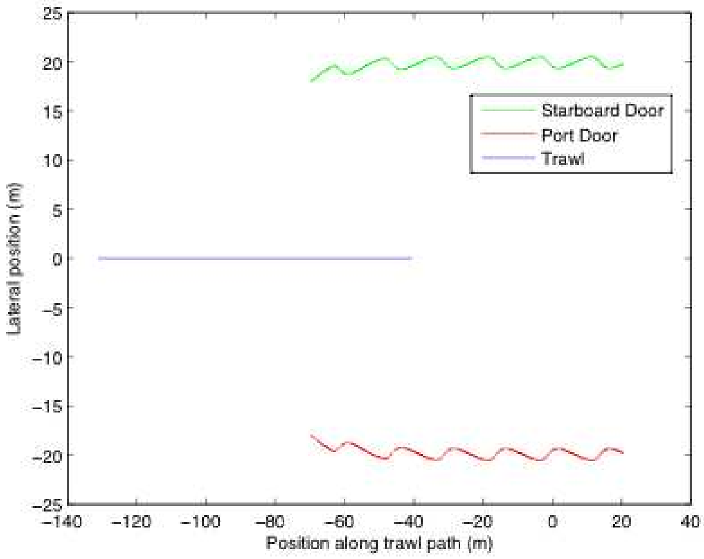


Figure 2.21 Trawl door penetration over a smooth seabed.

Figure 2.9 shows lateral motion of the doors as due to the wave motion. Figure 2.10 shows the penetration due to this motion. It is clear that the penetration is less than for the cases with ripples despite the door lifting off the seabed and then making contact again.

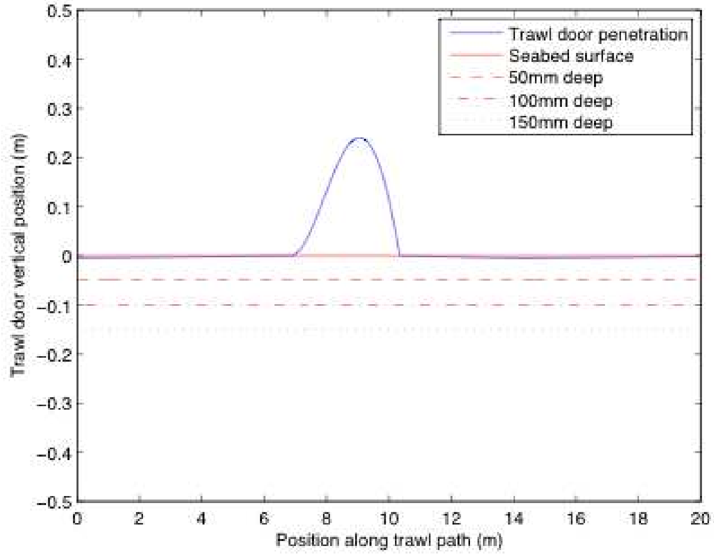


Figure 2.22 Trawl door penetration over a smooth seabed with vessel surge/heave motion.

Tables 2.3 and 2.4 show the relative effect of the four scenarios in terms of sediment disturbed. It can be seen that trawling over ripples results in more sediment disturbed and deeper peak penetrations.

Scenario	Average Penetration Depth	Relative Volume Displaced
Smooth Seabed	0.26cm	1
50mm ripples with 250mm wavelength	2.1cm	8.1
200mm ripples of 5m wavelength	5.8cm	22.3
Smooth Seabed with vessel surge motion	0.2cm	0.8

Table 2.4 Comparative results of simulations.

Scenario	Relative Volume Displaced in range 0-5cm	Relative Volume Displaced in range 5-10cm	Relative Volume Displaced in range 10-15cm
Smooth Seabed	1	0	0
50mm ripples with 250mm wavelength	8.1	0	0
200mm ripples of 5m wavelength	11.5	7.6	3.2
Smooth Seabed with vessel surge motion	0.76	0	0

Table 2.5 Comparative results of simulations.

5.2.1 Full Dynamic Model

The full dynamic model was developed from the simpler 3 mass model. The aim was to produce a model, which allowed the effects of all gear components, not just the trawl doors to be assessed. This requires that the door, sweeps, bridles and ground gear are modelled in detail. Although the net itself does not need to be modelled in detail, the net model must reproduce the correct drag, opening and foot rope/ground gear geometry for the model to be useful. This was therefore the objective of the second model.

Description

The model is a lumped parameter model, i.e. any continuous component like a warp rope, is subdivided into a number of discrete elements, with mass, damping and stiffness properties, which are interconnected. Discrete components e.g. the trawl doors and ground gear are modelled individually. The model comprises the following:

- Ship motion
- Variable length warps
- Variable position connection point to the front of the trawl door. 2 or 3 point connection is possible
- Trawl door with 6 degrees of freedom, *x*, *y*, *z* motion and pitch roll and yaw angles.
- Variable position connection point to the rear of the trawl door. 2 or 3 point connection is possible
- Variable length sweeps and bridles
- Variable number and type of ground gear
- Variable net geometry

The preliminary version of this model has been run with the geometry of the trawl gear used on the sea trails undertaken by FRS Marine Lab on the Clupea and Alba na Mara research vessels but with a simplified trawl net. Figure 2.23 shows the initial position of the entire trawl system at the start of the simulation. Figure 2.24 shows the relative positions of the trawl region and trawl doors in more detail. In Figure 2.24 the group of circles in the upper right corner of the figure represent the trawl door, the connection points to the warp and sweeps and the sweeps themselves which is this case are very short, about 7.5 m.

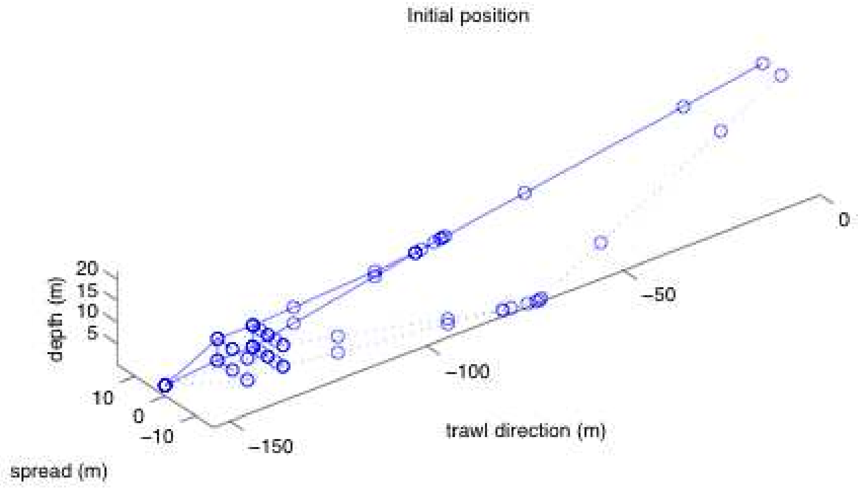


Figure 2.23 Initial position of the Clupea trawl at the start of simulation

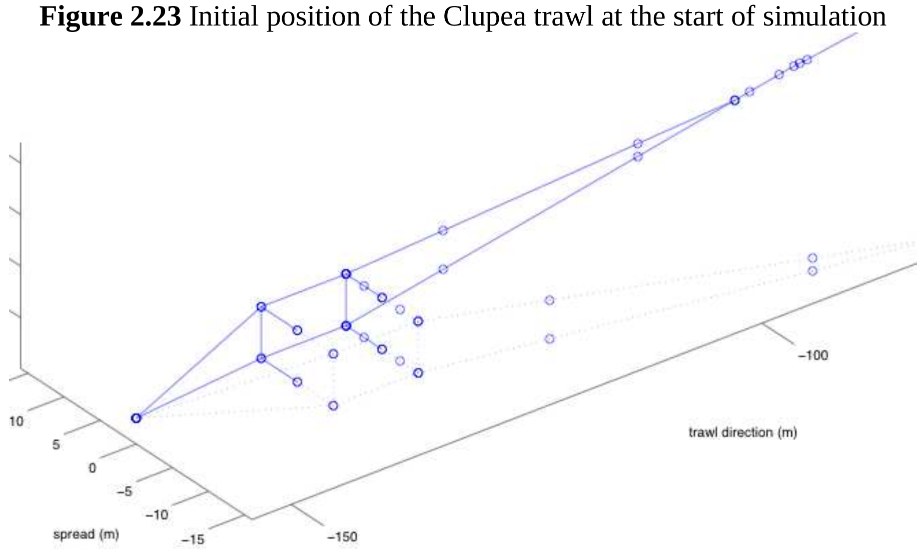


Figure 2.24 Detail of the position of the Clupea trawl at the start of simulation

The model contains a more complex bottom contact model with nonlinear stiffness and drag terms. The parameters for this are being extracted from the series of parametric simulations run on the various gear components, which contact the seabed as described earlier in this report. Once these functions are derived they will encapsulate in the dynamic model.

Supporting Work – Fluid Simulation

One of the new trawl gear components proposed within DEGREE is a plate gear set up instead of the more usual rock-hoppers. Because of the larger frontal area of these plates, fluid simulations were also undertaken on these to allow them to be included in the model at a later date. Because the angle of attack of the plates changes around the footrope as shown in Figure 2.25, simulations were run for the four groupings shown. Figures 2.26 and 2.27 show the flow patterns in the horizontal (seabed) plane and a vertical plane around the segment of the new gear closest to the centre line of the trawl (group 1 in Figure 2.25). The high level of turbulence seen in Figure 2.27 behind the plates may result in sediment disturbance in softer/looser sediments. Simulations of the individual groupings of plates and the entire group of plates have been run.

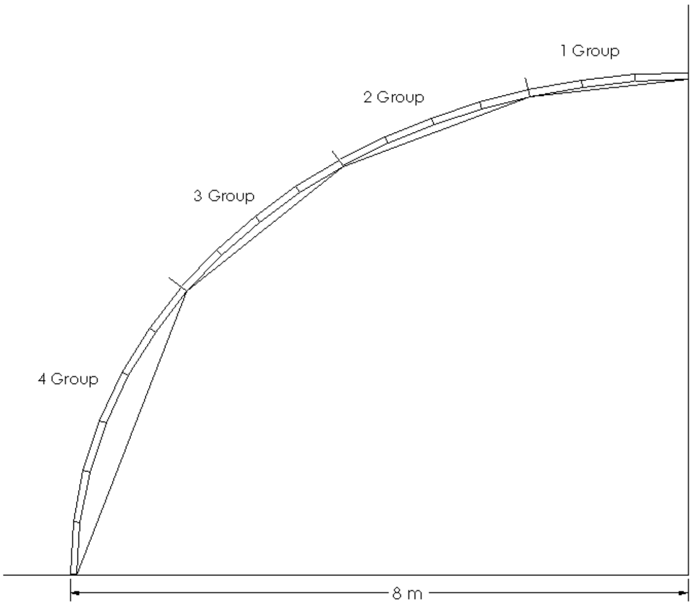


Figure 2.25 Positions of the plate groups simulated.

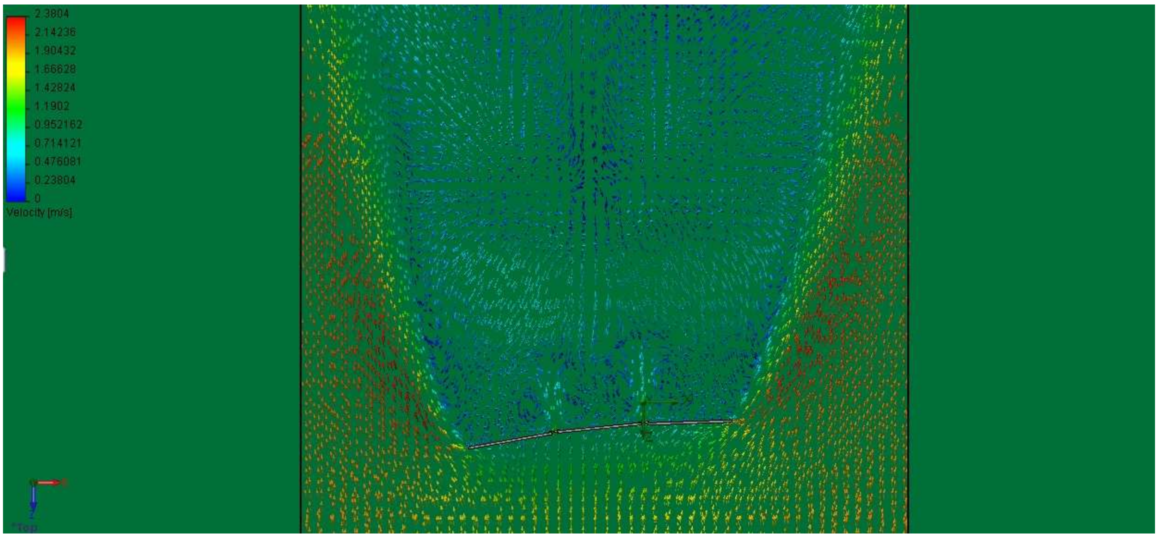


Figure 2.26 Flow pattern around the centre section plate gear in the horizontal plane (Plan view)

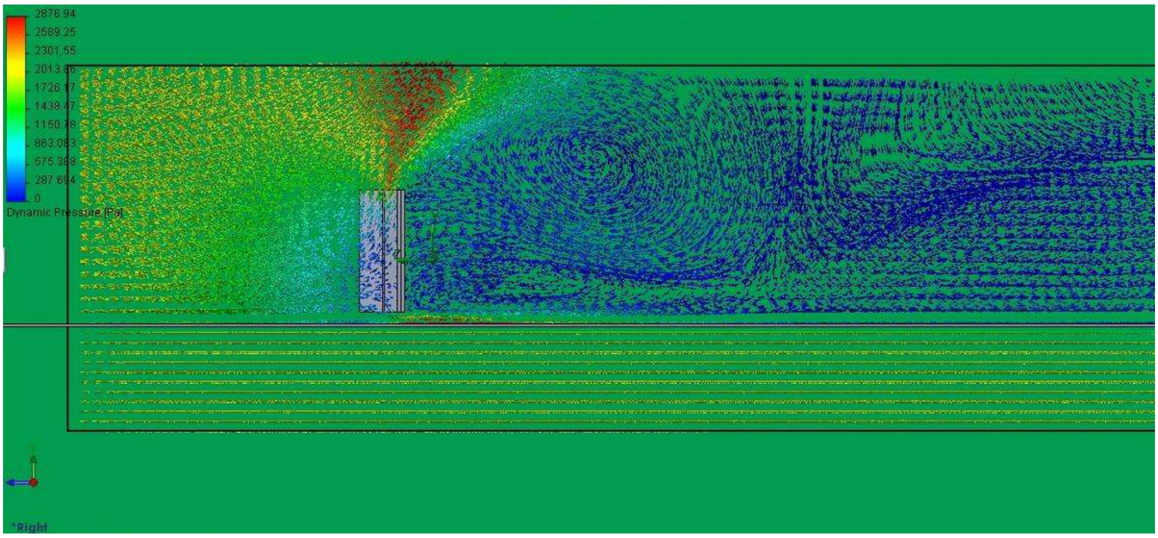


Figure 2.27 Flow pattern around the centre section plate gear in the vertical plane (Lateral view)

Current Level of Development of the Full Trawl Model

The full model is currently being developed to incorporate the data from the fluids models presented in the section above and those generated by the FE modelling to produce a comprehensive model including bottom contact and the potential for including novel items e.g. plate gear. The forces induced on the plate gear and trawl door from the fluid flow and the forces induced on the ground gear and trawl door from the bottom contact will be formulated as functions and added to the current model, replacing the simpler models already included. The net model is also being generalised and a simpler interface introduced.

5.2.1 References

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5.3 Sea trials to verify models (Task 2.3)

5.3.1 Introduction

The aim of Task 2.3 was to verify the models of Tasks 2.1 – 2.2 through two sets of sea trials. In each case divers would measure the physical impact of the gears and take biological core samples, which would later be analysed to quantify the ecological effects of the modelled gears. The field sampling methodology and results of the analyses of physical effects are described below in sections 5.3.2-5.3.3. The results of the BACI (Before/After, Control/Impact) study on ecological effects are described in section 5.3.4 (this work is currently being prepared for publication). Some broad conclusions are given in section 5.3.5.

5.3.2 Instrumentation development

The laser-camera sea bed profiler system developed during the first 18 months was remounted on a new frame for further ease of use (Figure 2.28). The system has been shown to be accurate to within 0.5mm and has been successfully used to measure the physical impact of the sea bed in the aftermath of a towed gear. This work has been accepted for publication in a peer reviewed journal (O'Neill et al., 2009) and a copy of it is presented in Annex 2.5.

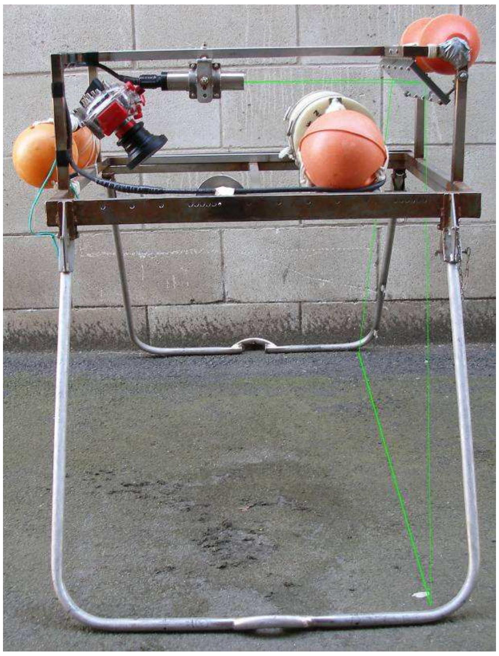


Figure 2.28. The underwater laser stripe seabed profiler used to measure the physical impact of towed gear components on the seabed. Divers position the apparatus over area of interest. The laser stripe is reflected off the mirror (top right in the figure) on to the seabed and the divers take a picture with the camera (top left in the figure)

The divers' towed underwater vehicle (TUV) provides a safe working platform for divers to be towed alongside and to work in close proximity to towed fishing gears (Figure 2.29). For the trials described herein, the LISST 100X was attached to a 'wing' on the port side of the TUV which allowed the TUV pilot to 'fly' it into the sediment plume in the wake of the trawl doors. The LISST 100X is an in situ particle sizer that uses the laser diffraction principle to estimate particle size (Figure 2.30). The laser diffraction method determines size distribution of an ensemble of particles, as opposed to counting type devices that size one particle at a time. It emits a laser beam which scatters in all directions on encountering particles and records the scattering intensity over a range of small angles using a specially constructed multi-ring detector. At these small angles, light scattering is determined almost entirely by light diffracted by the particle and the multi-angle scattering can be converted to a size distribution. The resulting concentration of particles (measured in μl/l) is presented in 32 logarithmically increasing size ranges between 2.5 and 500 μm (microns).

Figure 2.29 The divers towed underwater vehicle (TUV)

Figure 2.30 The LISST 100X on a frame extending from the divers towed underwater vehicle (TUV)

The high frequency loggers for the uni-axial load cells and the six-component door sensors and the associated logging and downloading software were completed.

5.3.3 Experiment to assess the immediate physical, ecological and environmental impact of a demersal trawl gear.

Two experimental cruises were carried out during 2007 and 2008 to assess the immediate physical, ecological and environmental impact of a demersal trawl gear. The first, in September/October 2007, was carried out on board the RV Clupea at sites in Nairn Bay and between Lossiemouth and Burghead in 18 – 22m of water (Figure 2.31). And the second, during October 2008, was carried out on the RV Alba ma Mara along the south coast of Arran in 20 – 24m of water (Figure 2.32). The sediments at these sites were classified as being of muddy sand (Nairn), fine – medium sand (Lossiemouth to Burghead) and coarse gravelly sand (South Arran). The particle size distribution of sediment samples from these sites is shown below in Figure 2.33.

Figure 2.31 The areas towed during the 2007 cruise.

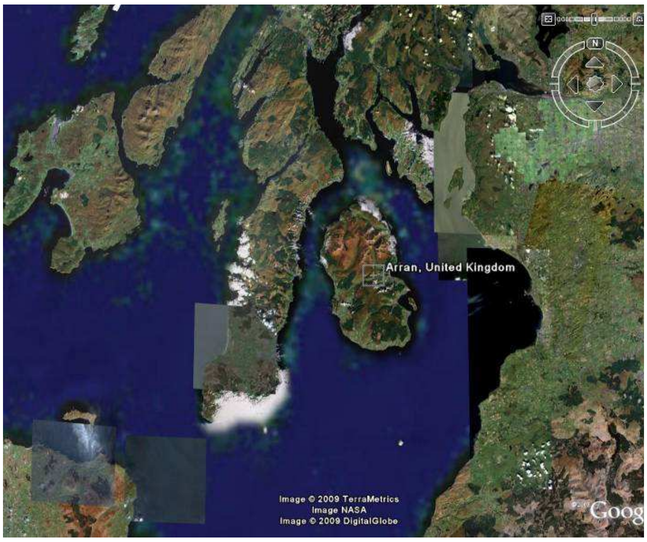


Figure 2.32 The area towed during the 2008 cruise.

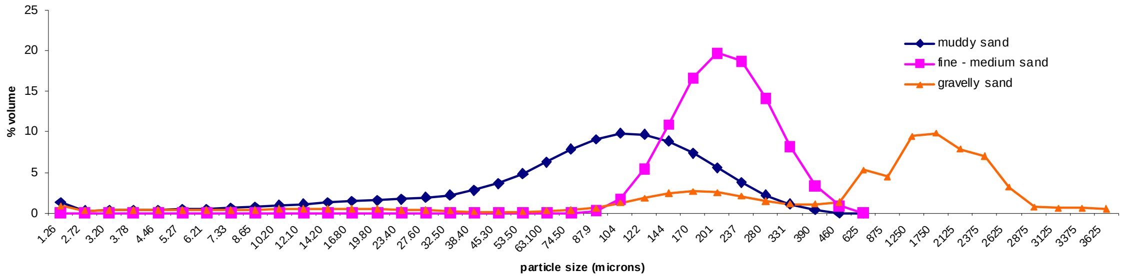


Figure 2.33 The particle size distributions of sediment samples taken from the three experimental sites

At each experimental site a 300 hp whitefish trawl with a rockhopper ground gear, 2.36 m^2 Morgère WS doors, 55 m double bridles and 75m warps was towed. The following operations took place and measurements were made at each site:

(i) infaunal core sampling for BACI experiment;

(ii) measuring the physical impact to the seabed outside the tow path and inside the impacted area using the laser-camera profiler;

(iii) measuring the large scale dimensions of the plume from the TUV, the particle size of suspended sediment using the LISST 100X, and taking water samples in the plume behind the trawl doors;
(iv) collecting high resolution engineering data on the trawl gear's performance using load cells, force sensors and accelerometers.

Infaunal core sampling for BACI experiment
For the BACI (before-after, control-impact) experiment three replicate trawls were conducted in each substrate and the following sampling protocol was repeated each time.

Prior to each tow a 100m baseline transect was established perpendicularly across the planned trawl path and marked with two buoys. Six sample cores of sediment with inhabiting infauna were collected by divers using SCUBA. The first core was taken 15m from the initial marker buoy and the rest at 8m intervals along the transect. These acted as baseline samples (pre-trawl) for the BACI comparison (Figure 2.34).

The trawl gear was then towed across the transect, and as close to the initial marker buoy as the skipper judged possible (Figure 2.34). This ensured that on each occasion at least half of the swept area of the trawl crossed the sampled part of the transect. The door spread, the wingend spread and the headline height of the gear were monitored during each tow using Scanmar sensors.

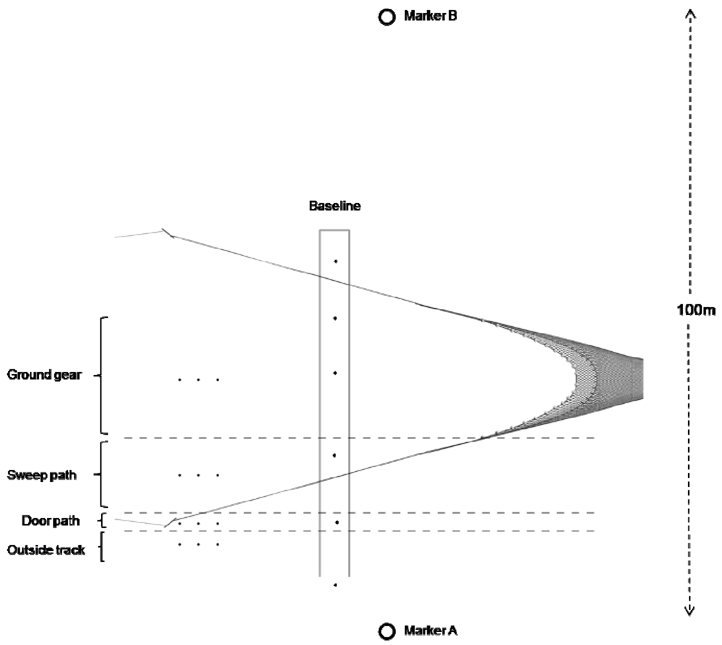


Figure 2.34. The infaunal sampling strategy

Approximately 15 minutes after the trawl crossed the transect, divers descended the initial marker buoy, swam along the transect and identified the distinctive door path. Using the Scanmar measurements it was possible to calculate the swept widths and the midpoints of the sweep and the ground gear paths. Nine core samples in total were then taken from the trawl path: three from the door path; three from the sweep path; and three from the ground gear path. A further three samples were taken outside of the trawl path, adjacent to the door track (Figure 2.34). Complete sampling from one replicate tow resulted in the collection of 18 sample cores - 6 pre-trawl (baseline) and 12 post-trawl (3 each for door path, sweep path, ground gear path and outside track) (Figure 2.34). Samples were sieved onboard over a 0.5mm mesh and the residue preserved in 4% buffered formalin in seawater.

In the laboratory, animals were sorted and identified to the lowest possible taxonomic level. In each of the cores collected, biomass and abundance per species were recorded, and total abundance per species further separated into three damage level categories: no damage, moderate damage, and mortal damage. This information on samples collected from the baseline was used to check for background levels of damage, including those sustained in the sampling process. Biomass and abundance of species in each core were standardised to the volume of a core at 20cm depth (16.34m^3).

Measuring the physical impact to the seabed using the laser-camera profiler.
Following the infaunal core sampling the laser-camera profiler was deployed to measure the physical impact of the sea bed in the aftermath of a towed gear. Divers identified the tracks of the trawl door, the sweeps and the groundgear and took images of each.

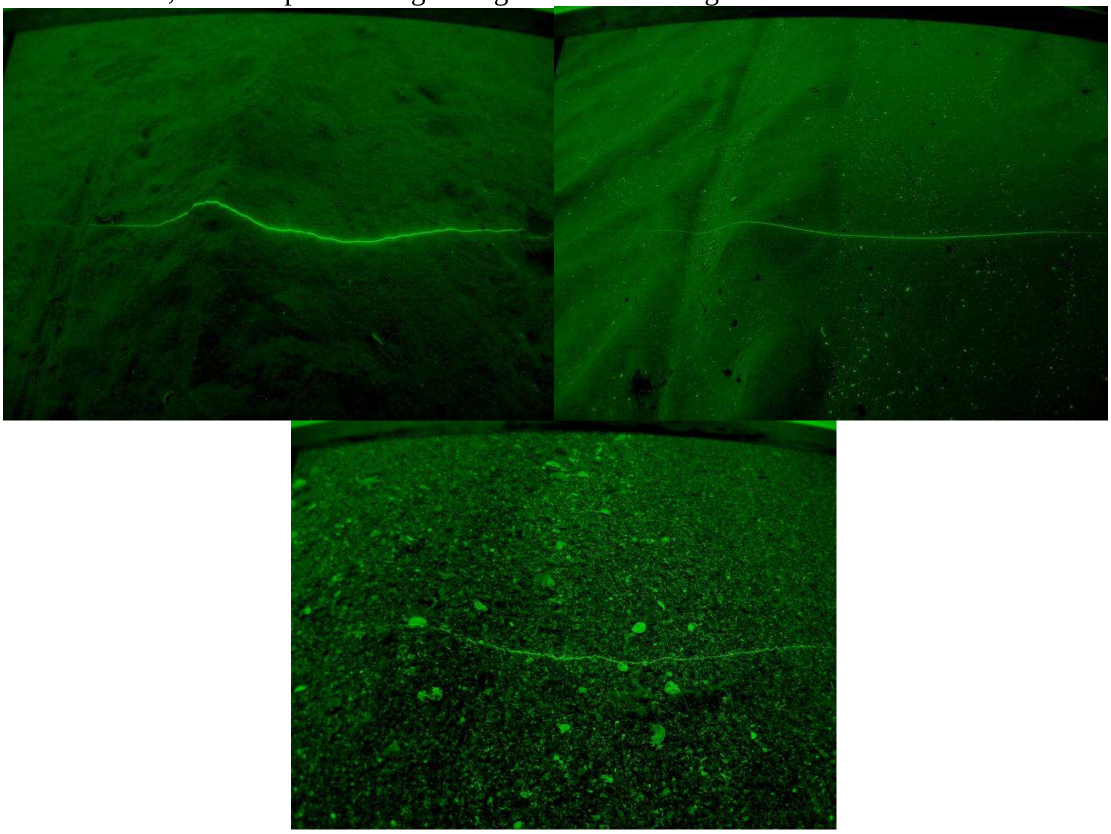


Figure 2.35. The physical impact of a trawl door on muddy sand, fine to medium sand and coarse gravelly sand

Measuring the plume dimensions, the particle size of suspended sediment and taking water samples in the plume behind the trawl doors

Four tows took place where the divers in the TUV estimated the large scale dimensions of the plume at distances of approximately 4, 10, 15, 30 and 50m from the trawl door (Figure 2.36). The results are presented in Figure 2.37 and demonstrate that the plume height increases quickly to about 2 m and then more gradually until it is about 4.5 m high 50 m from the door. While these values must be treated with caution as the plume is turbulent and variable and the estimates have been made by different divers they are indicative.

During three of these tows the particle size of the mobilised sediment was measured using the LISST 100X. As the TUV moved between these stations, the particle size distribution outside the plume was also measured. These results are shown in Figure 2.38. The thin lines are the measurements from the individual tows and the bold line is their average. The average concentration increases from 220 μl/l at approximately 5m behind the door to a maximum of 226 μl/l 10m behind and then deceases to a value of 164 μl/l at 50m. The background sediment concentrations taken between stations outside the sediment plume ranged between 2 and 7 μl/l.

Figure 2.36 The Morgere trawl door on fine – medium sandy sediment

Some of the results of these trials have been presented at conferences (O'Neill et al, 2008; O'Neill and Summerbell, 2009) and are included in Annexes 2.6 and 2.7.

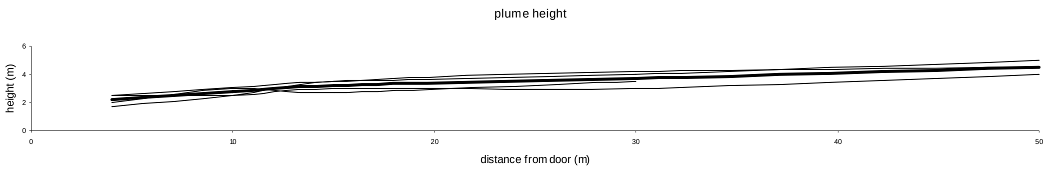


Figure 2.37 The plume height on fine – medium sand at different distances behind the trawl door.

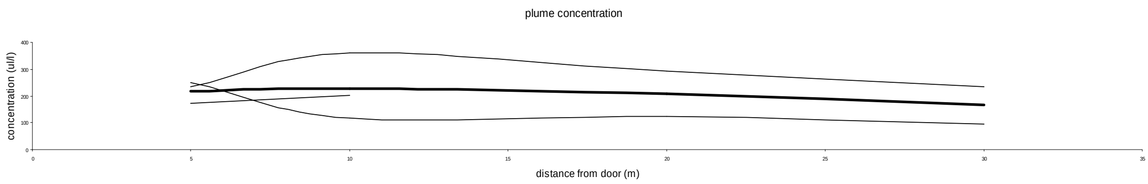


Figure 2.38 The plume concentration in μl/l of sediment, on fine – medium sand, at different distances behind the trawl door.

High resolution engineering data
High resolution engineering data were collected during the cruises using load cells, force sensors and accelerometers. These data will be used to verify the finite element models being developed by Aberdeen University Engineering Department.

5.3.4 Results of the BACI experiment

Background

Ecological effects of fishing gears on seabed communities have been extensively studied to investigate the different types of impact, and in severe cases these have been likened to those of forest clear cutting (Watling & Norse 1998). Bottom fished gears and dredges are known to impact communities in a number of ways (for reviews see e.g. Jennings and Kaiser, 1998; Kaiser 1998; Collie et al., 2000; Thrush and Dayton, 2002) and understanding the extent of these impacts is required in order to be able to properly manage current and future levels of effort within a more holistic ecosystem approach to fisheries management (Gulland, 1986).

Impacts to the benthos are generally considered to involve direct physical disturbance resulting in mortality to residing species (Kaiser & Spencer 1996, Gilkinson et al. 1998), physical alteration of habitat (Schwinghamer et al. 1998, Nilsson & Rosenberg 2003) alterations to the nutrient dynamics of the system (Pilskaln et al. 1998, Jennings et al. 2001, Dounas et al. 2007) and modification of the functional diversity of the community due to changes in abundance and composition of species present (Kaiser et al. 1998, Kaiser et al. 2002, Schratzberger & Jennings 2002, Tillin et al. 2006). However, while the direct effects of such an impact on benthic communities may appear obvious, their magnitude can be difficult to evaluate.

The impacts listed have obvious implications for the overall sustainability of benthic communities, and this has led to high levels of concern of the adverse effects that towed fishing gears cause. To counter this there is growing pressure to close considerable areas of the sea to bottom trawling, but this has clear socio-economic implications for fishing-dependent communities and may not be necessary in all cases. Another alternative is the development of fishing gears with a lower environmental impact, a proposal which has more support in the fishing industry (Paramor et al. 2004, 2005). Much of the work to date on modifying fishing gears has focused on methods for reducing bycatch of undersized target or non target species by modifying trawl nets, in particular altering mesh sizes (e.g. Kennelly & Gray 2000; Sardà et al. 2006). Limited attention has been paid to modifying the parts of the gears that make contact with the seafloor. However, for gear modification to be an effective solution for reducing benthic impacts, it is vital to understand the interaction of the different components of fishing gears with the sea floor.

Most studies of the effects of fishing gears on benthic communities have described changes in the composition of species in terms of changes in abundance and/or biomass between before/after or control/impact (BACI design) study areas (Kaiser & Spencer 1996, Jennings et al. 2002, Schratzberger & Jennings 2002, Tillin et al. 2006). However, no reference is made to either the effects of the different gear components or levels of damage incurred to infaunal species, and this questions what these changes in abundance and/or biomass represent. Are reductions in abundance and biomass in a BACI study a direct result of mortal damage to individuals, or are they caused by the movement of animals during an impact? Is it really a fair assumption that a decrease in numbers of individuals or biomass, actually equates to mortality? Or have the animals simply been temporarily displaced?

The work undertaken for WP2 Task 2.3 provided a unique opportunity to examine this effect. The aim of this work was to consider the individual gear components within an otter trawl, namely, the trawl doors, the sweeps/bridles and the ground gear, and to assess their effect on infaunal communities. The impact was first determined by changes in biodiversity indices recorded, and then investigated through examining the resultant observed damage. Data were collected using the experimental design described in 2.3.3 above, and the analysis and results are described below.

Expectations

1. The physical footprint of the gear should be considered in predicting the likely effects seen in sampled fauna behind the gear components

i. As shown by the work undertaken in the previous Tasks and sections of WP2, otter trawl doors can plough the sediment leaving a furrow in the path of the door, with the top layers of the sediment displaced (either in the plume or to the side of the door). This sort of physical footprint is most noticeable when otter trawl gear is towed in fine muddy sediments.
ii. When considering the effect of this on the infauna sampled post-trawling, this means that directly behind the door, the individuals will be sampled from a deeper layer of the substrate than for any of the other areas sampled (e.g. the baseline samples, behind the sweeps and groundgear) (see Figure 2.4);
iii. It is generally accepted that fewer individuals and species live at depth in the sediment and that those individuals that do live at depth tend to be bigger biomass individuals. Thus it should be expected that there will be lower diversity, lower abundances and possibly elevated biomass per unit area when compared to the rest of the trawled area.
iv. Based on this theory, we would expect higher numbers of individuals of species residing in the top layers, to be found in the areas subject to displacement either from the plume or to the side of the ploughed area. We would not necessarily expect higher species richness or diversity however, as there should just be more individuals of the same species that were already there. We might also expect that in those areas of displacement, biomass would be low relative to abundances, because the displaced sediment layer would be additional top layer, effectively meaning that the sample would be more representative of small light individuals.

2. Changes in actual numbers should not necessarily reflect actual mortality (impact)

i. Assessing the actual impact of the gear requires an assessment of damage as well as numbers. Simply assuming that changes in numbers equate to changes in effect (i.e. lower numbers post-trawling = higher mortality; similar or even higher numbers post-trawling = no mortality) should not be the accepted norm. However, individuals may also be damaged by the sampling procedure, and thus this background damage somehow needs to be discounted from the damage recorded to individuals in the path of the gear.
ii. Animals that are smashed into very small pieces by the gear interaction would not show up in the post-trawl samples.
iii. Many animals may be damaged by the gear interaction, but still show up in the post-trawl samples since the mesh size used to retain individuals for enumeration was 0.5mm.
iv. We would expect that having removed the ambient level of damage (i.e. that recorded from individuals in the baseline samples) it would then be possible to assess actual mortality levels post-trawling.
v. Due to the physical footprint effect on the position of samples taken (see ii-iv under expectation 1. above) it is likely that when considering whole gear effects on densities and diversity indices (i.e. all samples post-trawling pooled compared with all samples pre-trawling), there may be no overall difference, because displacement of individuals might balance out lower numbers recorded in the door path. If damage were taken into account, however, this may not be the case.

Data analysis

Differences in univariate and multivariate indices were examined at several different levels. Initially differences between substrate types (the two different surveys) were tested for, with all samples pooled from within a substrate type. Following this, effects of trawling were investigated for samples pooled across gear components (pre-trawl = all baseline samples, post-trawl = door path, sweep path and ground gear samples). This was further expanded by testing for specific gear components (e.g. otter door, ground gear), within each substrate, for differences between samples taken behind the individual gear components with the baseline samples.

The *Primer* statistical software package (Clarke and Gorley, 2006) was used for the calculation of the following univariate biodiversity indices from the standardised data per core: total abundance (mean number of individuals per core), total biomass (mean mass of individuals as grams per core), species richness, and the Shannon-wiener diversity index. Differences in biodiversity indices were tested using non-parametric Mann-Whitney tests, Kruskal Wallis tests or one-way ANOVA on $\log_{10}(n+1)$ transformed data. All analyses were undertaken using the software package Minitab V.15.

Multivariate community analyses were performed using the *Primer* package on all abundance data. A cluster analysis, using the Bray-Curtis similarity index was performed on square-root transformed data. The resultant similarity matrices were used to perform non-metric multidimensional scaling (MDS), identifying separate clusters of samples. Where any distinct clusters were found, these were tested for significant differences using the 'analysis of similarities' randomisation test (ANOSIM) (Clarke 1993). To establish which taxa contributed most to the similarity or dissimilarity between groupings of data, the 'similarity of percentages' routine was carried out (SIMPER). Here the contribution of each species to the Bray-Curtis measure was calculated after transformation, and the species ranked in order of their contribution to separating each group (Clarke, 1993).

The damage incurred to infaunal species during a trawl was investigated by analysing the abundance data in separate damage categories. Data were converted to a proportion of the total abundance in each of the three damage categories; no-, moderate-, and mortal damage. Total damage for each sample was also calculated as simply the sum of the moderate- and mortal damage categories. ANOVA tests for differences in damage levels between gear component positions and controls were performed on the arcsine transformed data using the Minitab V.15 statistical package. In each of the damage analyses, samples from the two substrate types were examined separately.

Substrate variation

The initial analysis of the indices of biodiversity confirmed that the differences in infaunal communities between the mud and sand substrates sampled were greater than any treatment effect (Figure 2.39). Mud communities were more diverse and productive in terms of numbers and biomass (Table 2.6). As such, the samples from the different substrates were, from here on, treated separately.

Table 2.6 Summary statistics for indices of biodiversity taken from each sediment type, presented with means and standard errors. Mann Whitney tests were used to test for differences between muddy and sandy substrate, with p values given for all comparisons where p<0.05 was used to identify significant differences.

	p	Muddy sediment (± SE)	Sandy sediment (± SE)
Total abundance (no.core)	0.001	55.11 ± 3.82	18.33 ± 0.85
Total biomass (grams. core)	0.001	2.29 ± 0.42	1.39 ± 0.58
Species richness (S)	0.001	25.92 ± 1.20	13.64 ± 0.59
Shannon-wiener diversity (H')	0.001	2.80 ± 0.08	2.36 ± 0.05

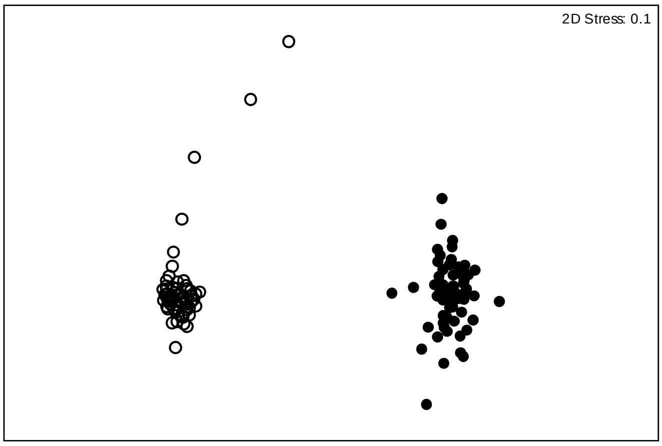


Figure 2.39. MDS ordination of the similarity in species composition between samples from sandy substrate (●) and muddy substrate (○), based on square-root transformed species abundance data (number per core).

Whole trawl impacts

Samples collected from the door path, sweep path and ground gear were pooled as one post-trawl treatment, and differences existing between this and the pre trawl (baseline) samples were investigated. A significant difference in total biomass was detected in the muddy substrate, with higher biomass recorded in pre-trawl samples when compared to post-trawl samples (Mann Whitney test: $W = 446.0$, $p = 0.034$). No other significant differences between the pre trawl and pooled post trawl samples were found in either substrate type (see Expectation 2.v).

Gear component impacts

The MDS ordination of the muddy site indicated that differences in species composition occurred in the experimental area (Figure 2.40a). Within the trawl path significant differences existed between the footprints of the gear components (ANOSIM on abundance, $R = 0.128$, $p = 0.4$) and pairwise tests indicated samples exposed to the door path were significantly different to those of the other four gear components, which did not differ from each other and grouped together. Furthermore, the high treatment variability that was seen in door path samples is indicative of a disturbed system (Clarke & Warwick 2001) (Figure 2.40a). The sandy site was not found to exhibit any differences in species composition between any of the treatments (Figure 2.40b).

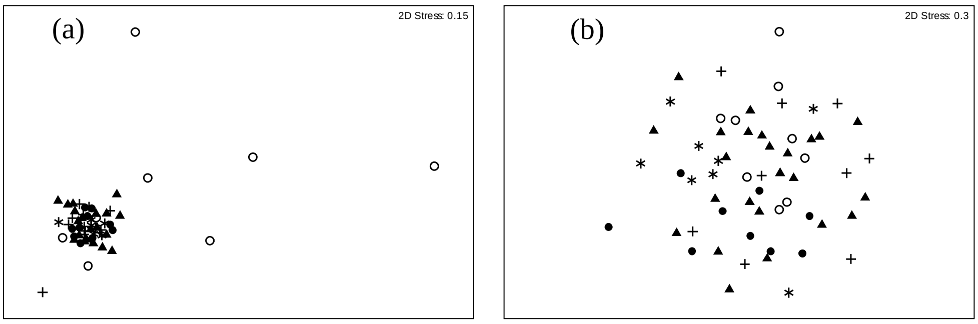


Figure 2.40. MDS ordination of the similarity in species composition between samples pooled from substrates that were grouped according to what part of the trawl path they were collected from: baseline

(▲), outside track (+), door path (○), sweep path (●) and ground gear path (*). Based on square-root transformed species abundance data from (a) mud and (b) sand.

Mud

Post hoc tests indicated that the trawl door path samples displayed the lowest total abundance, species richness, and Shannon-Weiner diversity values of all samples (ANOVA: Total abundance F = 4.14, p = 0.006; Species richness F = 4.71, p = 0.003; Shannon-Weiner index F = 5.80, p = 0.001) (Table 2.7). Samples taken from the door path had, on average, less than half the number of individuals and just over half the number of species recorded, when compared to any of the other samples. The highest values in these three indices were sampled in the sweep path and ground gear path. Values for species richness and Shannon's diversity were very similar from samples taken before the trawl and after the trawl, anywhere but in the door path. Biomass was greatest in the baseline samples and, unlike the other indices, was higher in the door path that in the sweep path and ground gear path, although it was noticeable that there was particularly high variation in biomass in the door path samples (Table 2.7) (see 2.3.4.2, Expectations 1. i-v).

Table 2.7 Summary statistics for biodiversity indices for samples collected in mud and sand in the path of parts of the trawl gear; 1 baseline, 2 outside track, 3 door path, 4 sweep path, 5 ground gear. Means are presented with ± standard error. Univariate tests were used to test for differences in indices between gear components, only p values for significant results are shown

			Gear type (±SE)				
		p	1	2	3	4	5
MUD	Total abundance	0.006	57.86 ± 4.28	56.86 ± 8.03	24.5 ± 10.2	66.21 ± 7.70	64.7 ± 10.7
	Total biomass		3.11 ± 0.56	2.34 ± 1.14	2.22 ± 2.06	1.72 ± 0.44	1.53 ± 0.31
	Species richness	0.003	26.87 ± 1.16	27.67 ± 2.35	15.63 ± 4.70	28.90 ± 2.00	28.75 ± 1.94
	Shannon-wiener	0.001	2.91 ± 0.05	2.89 ± 0.06	2.10 ± 0.37	2.95 ± 0.07	2.99 ± 0.06
SAND	Total abundance		19.80 ± 1.70	16.37 ± 1.32	15.27 ± 1.37	21.34 ± 1.88	17.46 ± 2.53
	Total biomass		1.07 ± 0.83	1.53 ± 1.35	2.78 ± 2.55	1.24 ± 0.58	0.58 ± 0.39
	Species richness	0.021	14.12 ± 1.02	12.00 ± 0.91	10.78 ± 0.83	14.22 ± 1.22	17.00 ± 2.02
	Shannon-wiener	0.025	2.37 ± 0.08	2.21 ± 0.12	2.17 ± 0.10	2.41 ± 0.11	2.66 ± 0.10

Sand

Door path samples in sand were also lowest in total abundance, species richness, and Shannon-Weiner diversity values (Table 2.7), although differences were not as pronounced as they were for the mud comparison (Figure 2.41). The highest values in species richness and the Shannon-Wiener index were once again in the sweep path and ground gear path, and although total abundance in the sweep path and ground gear path was higher than that found in the door path, the baseline results were higher still than those found in the ground gear path. Only two indices differed significantly; species richness and Shannon-Weiner diversity (ANOVA of species richness F = 10.23, p = 0.037; ANOVA of Shannon-Weiner diversity F

= 3.20 p = 0.025), and post hoc analysis revealed the significant difference occurred between the door path samples and the ground gear path samples in both indices.

Summary and potential explanations for patterns shown

If no effect of trawling occurred, the proportion of the total abundance present behind each of the gear treatments should be on average about the same and thus one fifth (0.2 or 20%). In muddy substrate, the baseline and outside track proportions of total abundance across the gears were near to this value, where door path samples had a reduced proportion and sweep path and ground gear path samples were slightly elevated. In sand, the baseline and ground gear proportions were approximately a fifth, where as the outside track and door path samples were reduced, and the sweep path samples showed an increase (Figure 2.41).

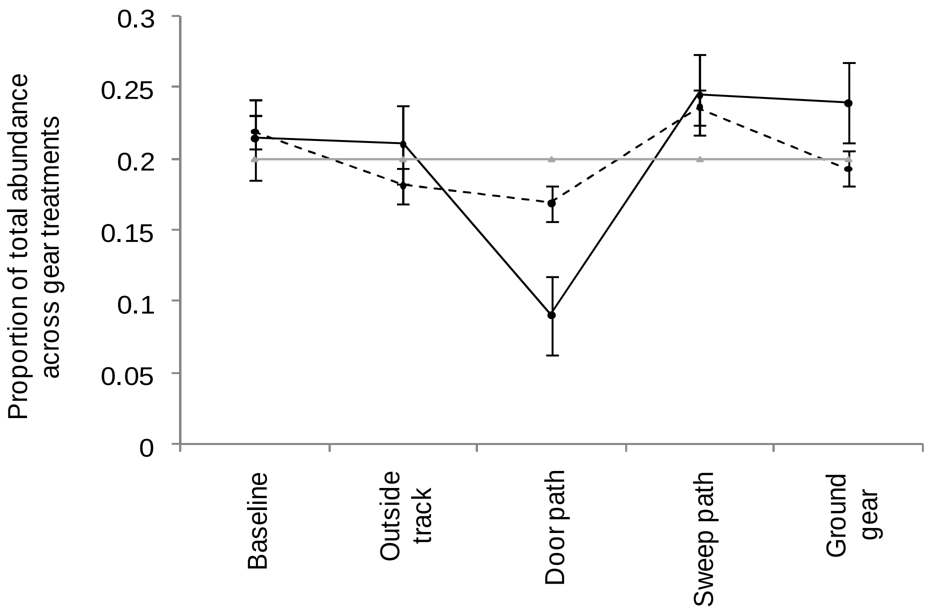


Figure 2.41. Proportion of total abundance across treatments for each individual treatment, in mud (solid line) and sand (dashed line). Expected values if no effect of trawling occurs are also presented (grey line).

Lower overall abundance (and corresponding higher biomass) of the door path samples, compared to the sweep path and ground gear path samples, occurred in both substrate types. SIMPER analyses of between group dissimilarities based on abundance data indicated that in mud, eight species accounted for 30% of the dissimilarity between the door path and the sweep path samples, and eight species accounted for 30% of the dissimilarity between door path and the ground gear path samples. The five taxa that contributed most to differences in abundance between the sweep and ground gear path samples (where they were highest) and the door path samples (where they were lowest) were the brittle stars *Amphiura filiformis* and *Ophiuroidea* spp juvenile, the polychaete *Pholoe baltica*, the amphipod *Ampelisca tenuicornis* and the bivalve *Mysella bidentata* (Table 2.8).

Table 2.8. Species contributing to the top 30% of dissimilarity between door path, sweep path and ground gear path samples, in mud and sand, as determined by SIMPER analyses based on square-root transformed abundance data. – equals absent.

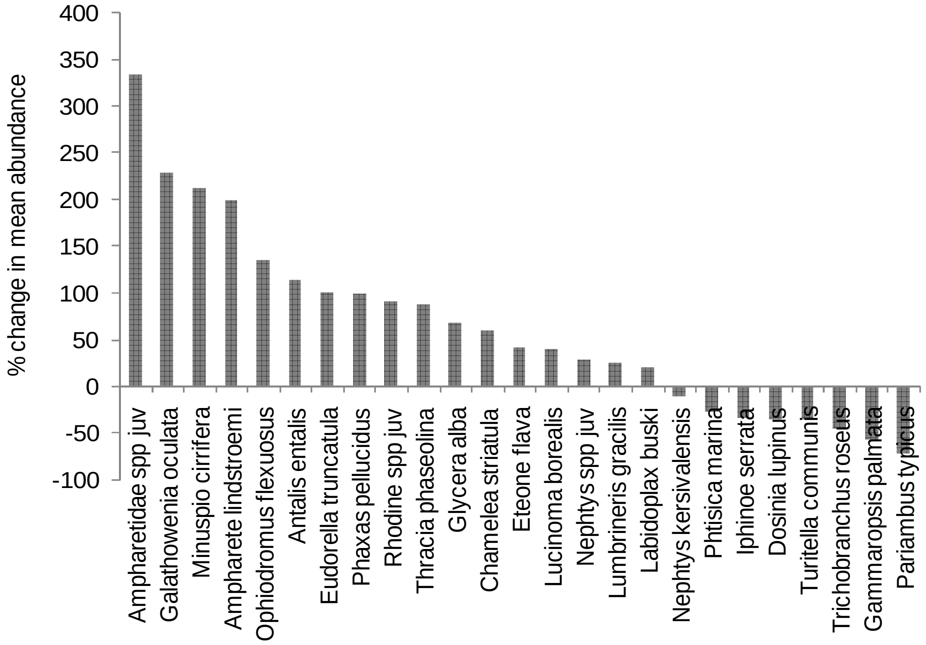
		Door path Av. abund. per $16.34m^3$	Sweep path Av. abund. per $16.34m^3$	Ground gear Av. abund. per $16.34m^3$
MUD	*Amphiura filiformis*	1.19	2.86	2.97
	Ophiuroidea spp juv	1.48	2.67	2.61
	Pholoe baltica	0.83	1.91	1.94
	Ampelisca tenuicornis	0.67	1.88	1.54
	Mysella bidentata	1.06	1.86	2.29
	Peresiella clymenoides	0.70	1.73	-
	Harpinia crenulata	0.22	1.21	1.03
	Euclymene oerstedii	0.17	1.15	-
	Levinsenia gracilis	-	0.27	1.25
	Abra nitia	-	0.59	1.18
SAND	*Bathyporeia spp*	1.48	1.77	1.20
	Perioculodes longimanus	0.52	1.32	0.68
	Megaluropus agilis	0.14	0.93	0.60
	Nemertea spp	0.59	1.01	-
	Spiophanes bombyx	1.27	0.69	-
	Cochlodesma praetenue	0.79	0.36	-
	Magelona filiformis	0.94	-	0.59
	Nephtys spp juv	0.85	-	0.78
	Aricidea minuta	0.70	-	0.59
	Phoronis spp	0.54	-	0.28
	Peresiella clymenoides	0.00	-	0.57

In sand, the between-group dissimilarities based on abundance data indicated that six species accounted for 30% of the dissimilarity between the door path and sweep path samples, and that eight species accounted for 30% of the dissimilarity between the door path and the ground gear path samples. The taxa that contributed to the differences in abundance between the door path and the sweep path were the amphipods *Bathyporeia* spp, *Perioculodes longimanus* and *Megaluropus agilis*, a *Nemertea* spp, the polychaete *Spiophanes bombyx* and the bivalve *Cochlodesma praetenue* (Table 2.8). The taxa that contributed to the differences in abundance between the door path and the ground gear were the amphipods *Perioculodes longimanus* and *Megaluropus agilis*, the polychaetes *Magelona filiformis*, *Aricidea minuta* and *Peresiella clymenoides*, a *Nephtys* spp juvenile, and *Phoronis* spp (Table 2.8).Unlike the samples from the mud substrate, differences in mean abundance were not always consistently higher in *both* the sweep and ground gear path, when compared to the door path in sand.

Not all species present in baseline samples were present in those collected from the door path. To further explore whether displacement had occurred in the plume produced by the trawl door, lists were generated of those species present in the baseline and absent in the door path. The change in abundance of these species between the baseline and both the sweep path and the ground gear was examined. It was considered that an increase from the baseline to either component would suggest displacement may have occurred.

For mud samples, of the taxa recorded in baseline samples but not behind the door, 68% had higher abundances in the sweeps than the baseline samples, and 74% had higher numbers in the ground gear path when compared to the baseline (Figures 2.42 a & b). Of these 23% had greater than a 100% increase in abundance in the sweeps when compared to the baseline, and 43% did in the groundgear path when compared to the baseline samples.

a)



b)

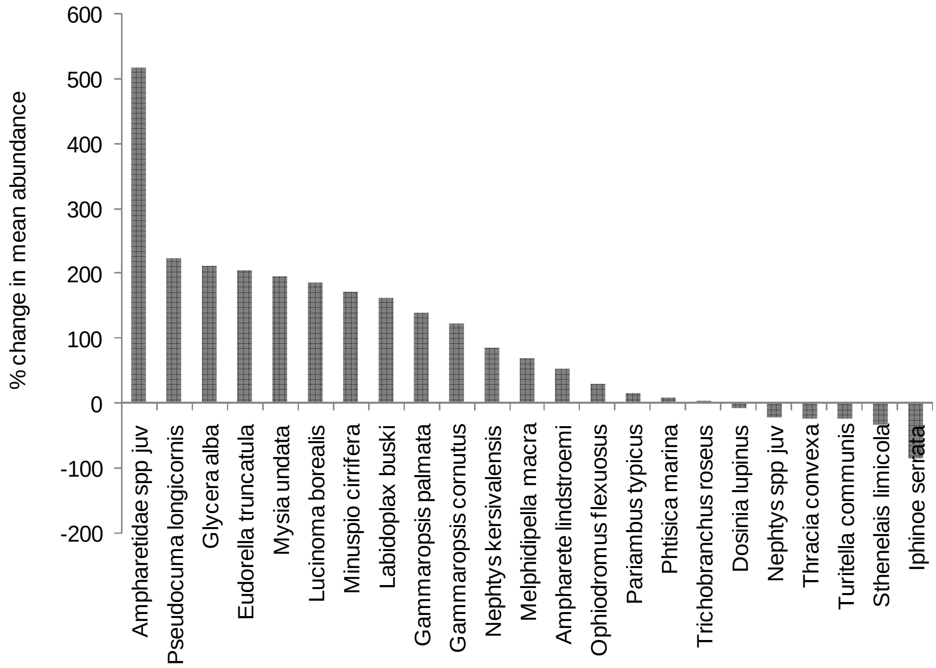
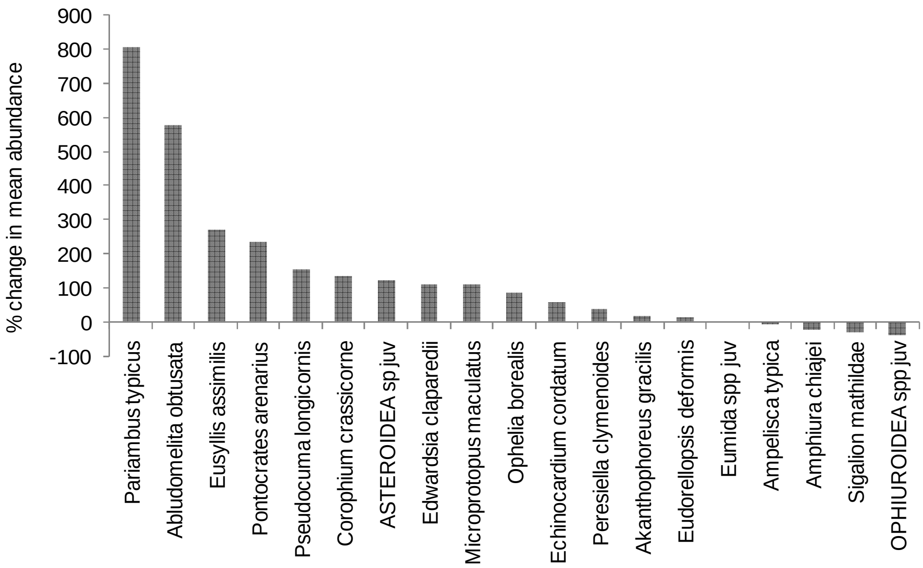


Figure 2.42. The percentage change in abundance in mud from (a) the baseline samples to the sweep path samples of species which had zero abundance in the door path, and (b) the baseline samples to the

ground gear samples of species which had zero abundance in the door path. Abundance was recorded as a proportion of the total abundance for that species, and the mean total for species found behind each gear treatment was calculated.

For sand samples, 74% of the taxa recorded in baseline samples but not behind the doors, had higher abundances in the sweeps than the baseline samples, and 71% did in the groundgear path when compared to the baseline (Figures 2.43 a & b). Of these 47% had greater than a 100% increase in abundance in the sweeps when compared to the baseline, and 41% did in the groundgear path when compared to the baseline samples.

a)



b)

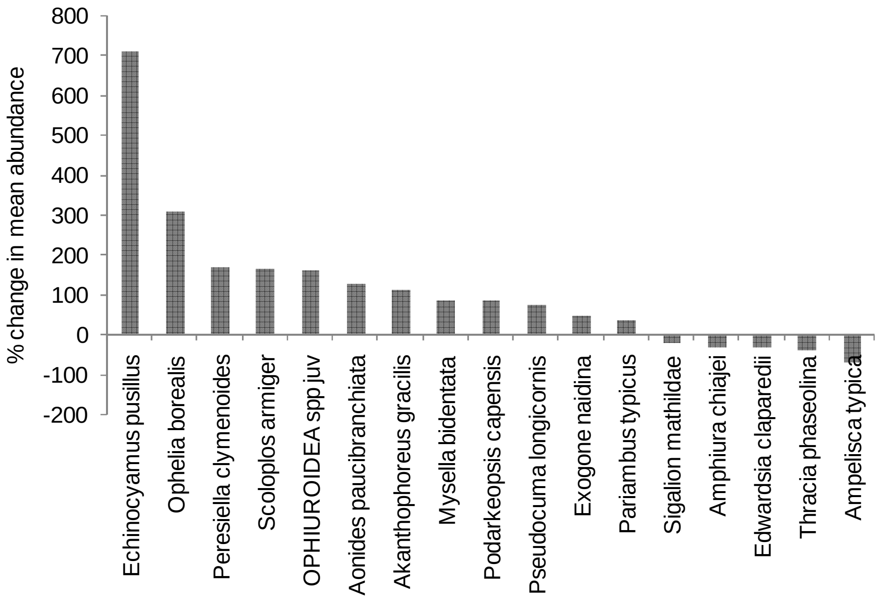


Figure 2.43. The percentage change in abundance in sand from (a) the baseline samples to the sweep path samples of species which had zero abundance in the door path, and (b) the baseline samples to the ground gear samples of species which had zero abundance in the door path. Abundance was recorded

as a proportion of the total abundance for that species, and the mean total for species found behind each gear treatment was calculated.

Damage to individuals sampled

In muddy assemblages, the number of mortally damaged individuals was greatest in the baseline samples (23.5% of all individuals sampled), whilst lowest levels were recorded in the sweep path samples (9% of individuals sampled). Mortal damage levels were significantly less in the sweep path than in the baseline, outside track and ground gear path samples (ANOVA, $F = 2.94$. $p = 0.029$) (Table 2.9). Conversely, in sand, the sweep path samples exhibited significantly higher numbers of mortally damaged individuals (21.7% of all individuals sampled) in comparison to all other treatments (ANOVA, $F = 4.65$, $p = 0.003$). The outside track samples demonstrated the lowest numbers of individuals with mortal damage; however this was not a statistically significant result (Table 2.9). The distribution of mortal damage across treatments in mud samples was broadly found to be the inverse of that recorded in sand (Figure 2.44).

Table 2.9. Mean proportion of total abundance of samples recorded with mortal and all damage at each gear treatment, in mud and sand. Presented with standard errors. ANOVA was used to test for differences occurring at each level of damage within mud and sand substrates

		p	Baseline (±SE)	Outside track (±SE)	Door path (±SE)	Sweep path (±SE)	Ground gear (±SE)
Mortal damage	Mud	0.029	0.235 ± 0.03	0.203 ± 0.03	0.149 ± 0.04	0.090 ± 0.03	0.201± 0.03
	Sand	0.003	0.087 ± 0.02	0.036 ± 0.02	0.118 ± 0.03	0.217 ± 0.05	0.058 ± 0.01
All damage	Mud		0.558 ± 0.02	0.515 ± 0.04	0.426 ± 0.09	0.477 ± 0.04	0.478 ± 0.02
	Sand		0.335 ± 0.03	0.227 ± 0.04	0.369± 0.03	0.418 ± 0.05	0.360 ± 0.04

When considering all damage to individuals (which includes partially damaged animals that may survive), for mud samples there were no significant differences between gear treatments; however, background damage levels were over 50%, with approximately 55% of all individuals in the baseline samples showing some damage. The lowest numbers of damaged individuals occurred in door path samples (42.6%). In sand, total numbers of damaged individuals were lower than those recorded for mud samples overall (Figure 2.44). Highest levels occurred in the sweep path samples, with 41.8% of individuals having some damage, and the least in the outside track samples (22.7%) (Table 2.9).

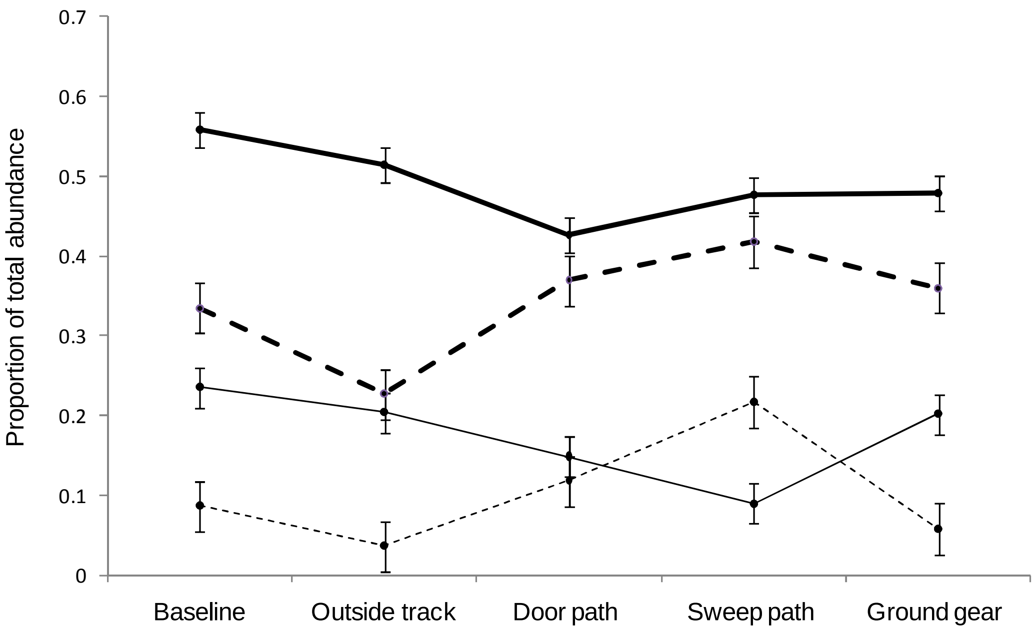


Figure 2.44. Proportion of total abundance of all invertebrates in each treatment that was mortally damaged in mud (thin solid line) and sand (thin dashed line), and all damage (including non-mortal) in mud (thick solid line) and sand (thick dashed line)

The background damage levels in mud were much higher than anticipated, therefore it was postulated that species recorded as damaged in baseline samples would be destroyed in the trawl and would not be present in the post-trawl samples (see Expectation 2.ii). This would therefore explain lower levels of damage in the gear component paths. At an individual level it was identified that the total abundance in the door path samples was significantly less than that in the baseline samples (Mann Whitney W = 5051.5, $p<0.001$). At a species level, of the 29 taxa recorded in the baseline samples with damage to more than 10% of individuals, 26 species had lower numbers of individuals in the door path samples than the baseline samples, and three species increased: the polychaete *Aricidea catherinae*, the sea potato *Echinocardium cordatum* and the sea cucumber *Leptosynapta inhaerens* (Figure 2.45). These are all species that live deeper than the top few centimetres in the sediment and thus would be less likely to be sampled in the baseline samples when compared to the door samples.

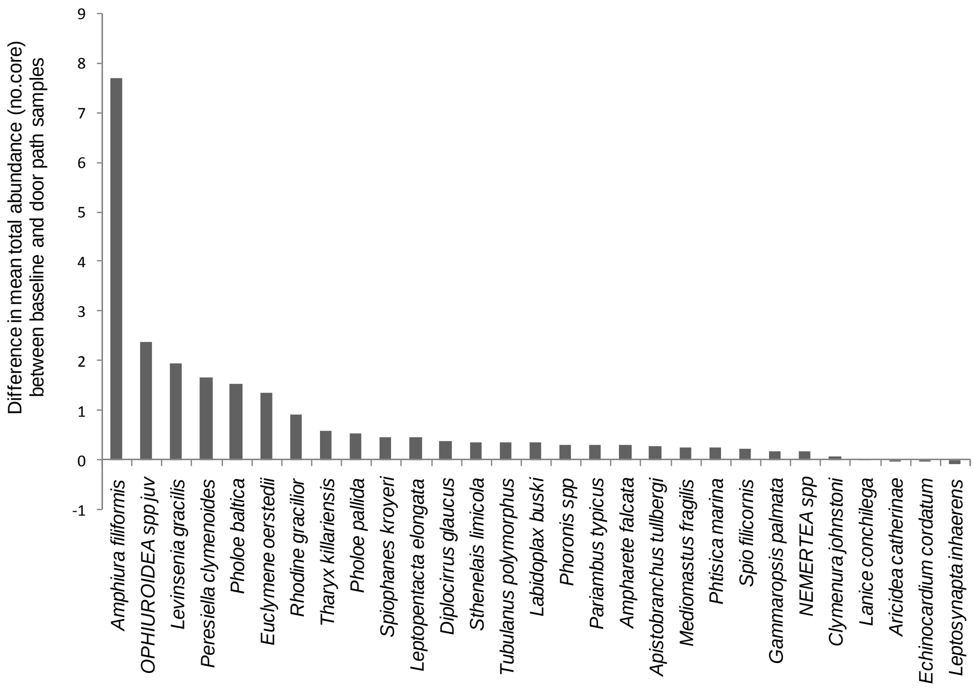


Figure 2.45. The difference in mean total abundance (number per core) between baseline and door path samples in the species noted to have damage to more than 10% of individuals in baseline samples

5.3.5 Overall summary in relation to expectations

Expectations:

1. **The physical footprint of the gear should be considered in predicting the likely effects seen in sampled fauna behind the gear components**

i. As shown by the work undertaken in the previous Tasks and sections of WP2, otter trawl doors can plough the sediment leaving a furrow in the path of the door, with the top layers of the sediment displaced (either in the plume or to the side of the door). This sort of physical footprint is most noticeable when otter trawl gear is towed in fine muddy sediments.

ii. When considering the effect of this on the infauna sampled post-trawling, this means that directly behind the door, the individuals will be sampled from a deeper layer of the substrate than for any of the other areas sampled (e.g. the baseline samples, behind the sweeps and groundgear) (see Figure 2.4);

iii. It is generally accepted that fewer individuals and species live at depth in the sediment and that those individuals that do live at depth tend to be bigger biomass individuals. Thus it should be expected that there will be lower diversity, lower abundances and possibly elevated biomass per unit area when compared to the rest of the trawled area.

Findings:

This was found in both muddy and sandy substrates, although effects were most pronounced in muddy sediments.

iv. Based on this theory, we would expect higher numbers of individuals of species residing in the top layers, to be found in the areas subject to displacement either from the plume or to the side of the ploughed area. We would not necessarily expect higher species richness or diversity however, as there should just be more individuals of the same species that were already there. We might also expect that in those areas of displacement, biomass would be low relative to abundances, because the displaced sediment layer would be additional top layer, effectively meaning that the sample would be more representative of small light individuals.

Findings:
This was found in both muddy and sandy substrates, although effects were most pronounced in muddy sediments. Higher numbers of individuals of certain species were found in the sweeps and groundgear paths for the muddy sediments, and the sweeps for the sandy sediment. The species found to be in high numbers relative to the door paths did tend to be near-surface dwelling light biomass species. This provides some evidence to support the theory suggested above.

2. Changes in actual numbers should not necessarily reflect actual mortality (impact)

i. Assessing the actual impact of the gear requires an assessment of damage as well as numbers. Simply assuming that changes in numbers equate to changes in effect (i.e. lower numbers post-trawling = higher mortality; similar or even higher numbers post-trawling = no mortality) should not be the accepted norm. However, individuals may also be damaged by the sampling procedure, and thus this background damage somehow needs to be discounted from the damage recorded to individuals in the path of the gear.

Findings:
Very high levels of background damage were recorded from the baseline samples taken in the muddy sediments (>20% for mortal damage and 50% for all types of damage). Conversely, in sand, the sweep path samples exhibited significantly higher numbers of mortally damaged individuals (21.7% of all individuals sampled) in comparison to all other treatments, and even discounting background damage levels (based on an average of the baseline and outside track samples) this would leave a mortal damage level of around 15% of individuals found in the sweeps behind the gear towed in sandy sediment, and 6% in the door path. The damage levels in the groundgear path were around background levels.

ii. Animals that are smashed into very small pieces by the gear interaction would not show up in the post-trawl samples.

iii. Many animals may be damaged by the gear interaction, but still show up in the post-trawl samples since the mesh size used to retain individuals for enumeration was 0.5mm.

iv. We would expect that having removed the ambient level of damage (i.e. that recorded from individuals in the baseline samples) it would then be possible to assess actual mortality levels post-trawling.

v. Due to the physical footprint effect on the position of samples taken (see ii-iv under expectation 1. above) it is likely that when considering whole gear effects on densities and diversity indices (i.e. all samples post-trawling pooled compared with all samples pre-trawling), there may be no overall difference, because displacement of individuals might balance out lower numbers recorded in the door path. If damage were taken into account, however, this may not be the case.

Findings:

Mud
For the muddy site background levels of damage were very high (>50% of individuals has some damage) suggesting that the fauna found in muddy substrates have fragile morphology. If this is the case, it is possible to think that lower levels of damage might be seen in the areas

sampled behind the trawl gear because the most fragile individuals would have been smashed by the gear interaction and would not show up at all. Lower proportions of individuals were damaged in a comparison of all post-trawl samples with all pre-trawl samples.

Taking into account the results from the damage analysis, the findings suggest that the impact in mud may actually be less than perceived by simply quantifying differences in numbers and biomass before and after trawling. There is circumstantial evidence (based on the analyses of changes in species numbers between the different areas) that some individuals were displaced into the path of the sweeps (and to a lesser extent the groundgear path). Damage data suggested there to be lower than background levels of damage to the individuals in the sweep path (which would include any displaced individuals).

We only took samples from part of the area where displacement of sediment behind the door would occur; the area where the plume would settle (in the sweep path, and to a lesser extent, the groundgear path). We did not take samples from the displaced sediment to the side of the furrow formed by the door. The differences in average abundances between the door path samples when compared with all others for mud, suggest that if the same proportion of the individuals that were displaced to the sweeps were displaced directly to the side of the furrow, there would still be a loss of about 10% of individuals in the door path when compared to background levels of abundance (Table 2.7). If we assume (based on the findings of the damage analysis) that those individuals displaced are not mortally damaged by the trawl passing through, this would mean that the impact to the infauna in mud would be reduced to a mortality level of approximately10% of individuals killed overall.

Sand

Taking into account the results from the damage analysis, the findings suggest that the impact in sand is actually greater than perceived by simply quantifying differences in numbers and biomass before and after trawling. Discounting background damage levels, 15% greater mortality could be assumed for individuals in the path of the sweeps, and 6% for those in the path of the doors (Table 2.9). Based on these percentages, this would reduce the number of individuals left in the door path to approximately 14, whilst the number in the sweep path would be around 18 (see Table 2.7). Thus sweep path numbers would be more equivalent to those recorded in the baseline samples, and a mortality level of approximately 8% would be assumed for the gear overall (based on the decrease below ambient levels in the door path).

5.3.6 Development from here

The findings from this study suggest that the outcomes from previous BACI studies of trawling should be considered with caution, since numbers are simply compared for the whole gear with no consideration of damage and an assumption of change being equivalent to mortality.

The conclusions from the study undertaken here are mainly based on suggested theories and a collation of supporting evidence for these. The suggested theories (expectations described above) are driven by the physical modeling work undertaken in this WP and on an understanding of the ecology and morphology of the animals affected. In order to truly validate the predictions made based on our expectations, modeling of the likely vulnerability of species to the trawl was developed and tested against the field data, and this is described below under Task 2.4.

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5.4 Predict the ecological disturbance of fishing (Task 2.4)

5.4.1 Introduction

The aim of Task 2.4 was to update the modelling approaches used to predict the ecological disturbance of fishing; specifically the mortality caused to benthos and demersal fish, and the habitat damage incurred. For disturbance associated with bottom trawling, the EU 5th framework project MAFCONS had started the process of developing predictive models for both benthos and fish (see Chapter 8 of the MAFCONS final report available at http://www.mafcons.org/finalreport.php). Both aspects have been taken further through Task 2.4 of DEGREE and the results for each are presented below (sections 5.4.2 and 5.4.3). Future development is described in Section 5.4.4.

5.4.2 Modelling mortality to benthic invertebrates

Background

The work published on the effects of trawling on the benthos has to date focussed largely on before/after, control/impact (or BACI) comparative studies. This research has proven important in terms of describing general trends, and has commonly identified the types of taxa that suffer high levels of mortality, and the habitat types in which impact is greatest (e.g. Sanchez et al. 2000, Schratzberger & Jennings 2002, Kaiser et al. 2006, Kenchington et al. 2006) (see Task 2.3 above). A limitation in this comparative work is the lack of prediction-based methodology. Hiddink *et al.* (2006) have developed a predictive model of changes in assemblage level properties, such as total biomass or production, given particular levels of fishing effort. Such an approach is useful for providing advice on broad-scale changes in important ecosystem functions, such as productivity and availability of food to the demersal system, but it does not allow predictions to be made about which species would be most vulnerable.

The MAFCONS disturbance model made predictions at the phyla level based on the results of the Kaiser et al. (2006) meta-analysis of BACI studies of experimental fishing (Greenstreet et al., 2006; http://www.mafcons.org/finalreport.php). Given the potential limitations of the results from conventional BACI studies (see 2.3.4.8 and 2.3.5) and the need to develop predictions so that they can be species-specific and gear-component specific, further development was required. In this task we explored the potential to develop a tool that would allow predictions to be made at the species level, and we added in the ability to consider the differential effects of the various components of fishing gear (e.g. trawl ground gear, trawl doors). Given that there are now readily available databanks containing information on the characteristics of species that may make them vulnerable to trawling (e.g. the BIOTIC database at *www.marlin.ac.uk/biotic*), it should be possible to make sensible predictions about the likely level of risk to species from particular fishing gears. Tyler-Walters et al. (2009) have undertaken such an exercise for common benthic assemblages found in temperate waters, using a qualitative approach. Here, we take this forward to a quantitative approach allowing for validation of the results against data collected in the controlled experimental trawling trials of Task 2.3. We also increased the level of precision making predictions for the individual components of the fishing gear, which is a necessary requirement if we are to provide advice on the potential benefits of gear modifications in minimising the broader ecosystem effects of fishing.

The predictive tool explored here is based on the fundamentals of vulnerability, which is essentially a risk model, defined as the product of the probability of exposure to an impact and the consequences of such an event (Zacharias & Gregr 2005). Associated with this definition are a number of characteristics of benthic invertebrates that relate to both the likelihood of encounter with trawling gears, and the expected deleterious consequences (such as mortality) that would be associated with trawling impact. These species characteristics cover a range of biological traits including life history, morphological and ecological aspects (Baird & Van den Brink 2007).

The descriptive work on trawling effects to the benthos has revealed that likelihood of a particular species being killed by physical contact with fishing gear, will depend on its position on/in the seafloor, its mobility and its morphology (most notably how fragile it is and how flexible it is) (see summaries in Collie et al., 2000; Kaiser et al., 2006). This can be broken down into two elements: (1) likelihood of encounter, which depends on the living position of the species relative to the contact area and penetration depth of the gear, and the mobility of the species, and; (2) probability of mortality given an encounter, where flexibility and fragility are the most important predictor traits. Fragility relates to how susceptible a species will be to breaking up on contact with the fishing gear, while flexibility relates to how malleable an individual is, also affecting its likelihood of being mortally damaged in the path of the gear.

The present study is unique because it devises a quantitative model based on these principles allowing predictions of post-trawl abundance to be made which incorporate the vulnerability of different species to trawling, using a traits-based approach. The predictions were validated with field data which was sampled specific to gear components between 15 and 60 minutes of a passing trawl, therefore allowing for a high level of control. This was an important development from previous work where general trends in the changes in abundance and/or biomass of individuals are not explained relative to impact from specific gear components and post-trawl measurements can be taken many hours or even days after the trawling event (see comment in Collie et al. 2000, Kaiser et al. 2006; and Task 2.3 above). The aim of this work was to improve the precision of predictions made on the vulnerability of a range of benthic species to trawling gears.

Materials and methods

Physical and biological data were available from the experimental field trials that were undertaken in two different sediment types; mud and sand, in the Moray Firth on the east coast of Scotland in October 2007(see details in Task 2.3). For the analysis presented here, only the faunal abundance data were used.

Physical footprint of the gear components

The physical footprint (area and depth of penetration into the sediment) of the separate gear components was calculated using data from the laser profiling measurements that were collected during the sea trials of Task 2.3 (O'Neill et al, 2009; see Annex 2.5). These measurements provided a cross sectional area of encounter for each gear component separately, and this was further split into the depth ranges 0-2cm, 2-5cm and 5-10cm below the surface. This gave the area of sediment encountered by the gear within each of those depth ranges.

Mortality model based on encounter probability

The mortality model tested initially assumed that all species that encounter a gear component are killed (or removed). To calculate the probability of encounter we took into account the living range of the species and the depth of penetration of a particular gear component. For each species the probability of mortality (or of removal) is defined to be the probability that they are encountered and this is calculated based on the probability that they are present in a given depth range multiplied by the proportion of that depth range impacted by the gear. Hence we have

$$P(\text{mortality}) = P(\text{encounter})$$

$$= \sum P(\text{in range Ai}) * (\text{proportion of Ai encountered by the gear})$$

where Ai is the cross-sectional surface area of living range i and the living ranges are defined as follows; (a) from the surface to 2cm below; (b) from 2 to 5cm below and (c) from 5 to 10cm below the surface.

Species measuring more than 100mm (core diameter) in length were removed from the species list. For as many as possible of the remaining species, data were gathered from scientific literature, online databases, and expert opinion on the living ranges inhabited both above and below the sediment surface. Where information on living range could not be found, inferences were made based on the species' living mode (i.e. surface dweller, burrower), feeding mode (i.e. sub-surface deposit feeder, passive suspension feeder), and size.

As an example, the burrow-dwelling bristle worm *Spio filicornis* is a surface deposit feeder, growing to lengths of 3-10cm (Tamaki 1987). Based on this information a living range from the sediment surface to 10cm depth was assigned, with greater weighting for deeper dwelling based on evidence from the literature that suggested it was not a continual feeder. This equated to it being assigned as being present in the surface depth range (at the surface to 2cm below the sediment surface) for a quarter of its time, the -2cm to -5cm depth range a quarter of its time and the -5cm to -10cm range for half of its time.

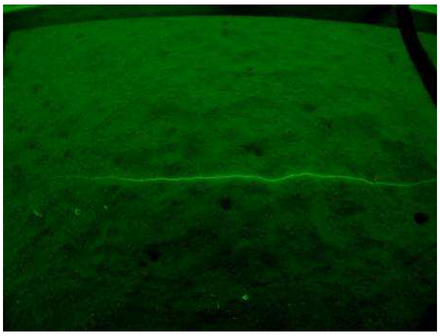
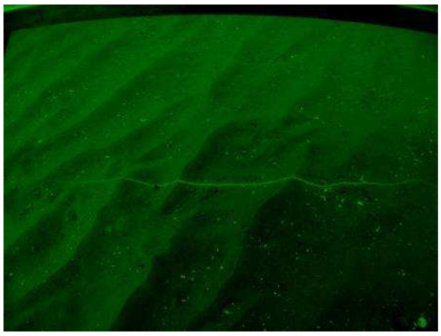
Testing the model predictions

There was sufficient living range information to predict the encounter mortality for 55 species in sand and 68 species in mud. Initially the average number of each species per core sample collected before (actual pre-trawl abundance) was simply compared with the average number sampled in each of the gear component tracks after trawling (actual gear-specific post-trawl abundance). Subsequently, the model predictions were tested separately for each gear component in each habitat by comparing the actual post-trawl abundance (mean of abundance in the path of the gear component post-trawling) with the *predicted* abundance post-trawling (actual pre-trawl abundance x 1- P(mortality)). See detail in Task 2.3for how field data were collected for pre and post trawling abundance in relation to the different components of the trawl gear.

Results

Physical footprint of the gear components

The proportion of a living range (Ai) encountered by the gear components differed depending on the component and the sediment type (Figure 2.46; Table 2.10). The sediment from the muddy habitat (mean particle diameter = 0.07 to 0.14mm) was very fine and the divers collecting infaunal samples noted it was easily resuspended in the water column through minor disturbances. The properties of this soft sediment resulted in the greater encounter area of the fishing gears of the two habitats sampled. The sediment from the sandy habitat (mean particle diameter = 0.198 to 0.231mm) was more compact and ‘rough’ in comparison to that of mud and the resultant areas of encounter by the gear components in sand was to a lesser degree (Figure 2.46, Table 2.10).

	Mud	Sand
Unimpacted		

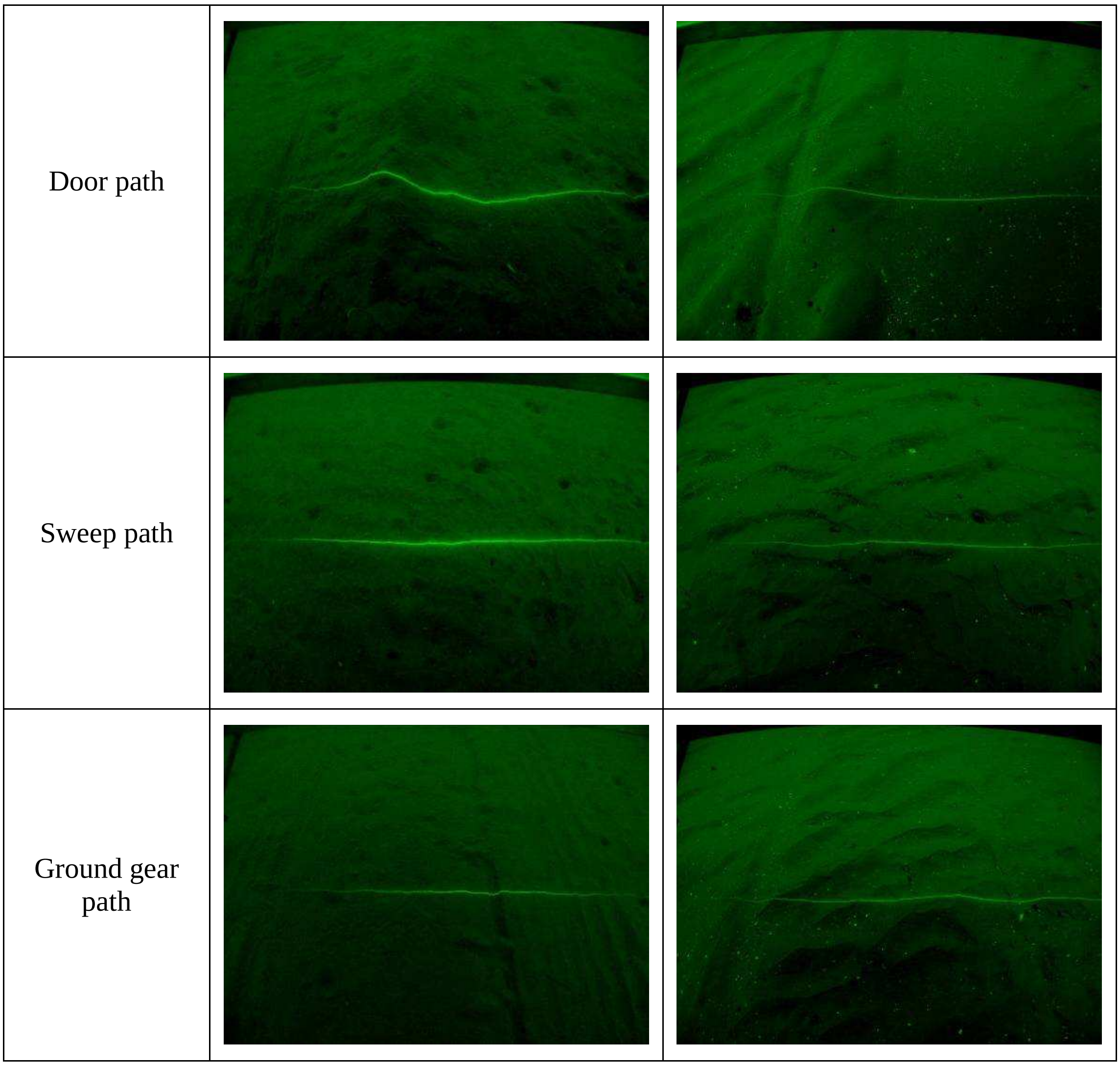


Figure 2.46. Images of unimpacted sediment, and impacted sediment by each gear component, in mud and sand. Laser profile is also displayed in each image

The trawl door exhibited the largest encounter area for all gear components (Table 2.10). The area was greatest in mud in the upper most depth range (0 to 2cm below the surface) where 91% of the sediment in the door path was encountered. The door penetrated to a depth of 10cm in mud, the proportion of sediment encountered decreasing with depth range. The door penetration in sand was not as great as in mud. From the surface to 2cm depth, 20% of the sediment in the path of the door was encountered. Penetration of the door in sand occurred to a depth of 5cm in the sediment encountering a greatly reduced area at each depth range.

Table 2.10. The proportion of sediment in each depth range encountered in the tow path of the doors, sweeps or ground gear, for experimental trawls undertaken in mud and sand habitats. No components penetrated deeper than 10cm in either habitat type.

Gear component	Depth range (cm)	Proportion of sediment encountered in mud	Proportion of sediment encountered in sand
Door path	0 to 2	0.91	0.20
	2 to 5	0.30	0.01
	5 to 10	0.05	0

Sweep path	0 to 2	0	0.19
	2 to 5	0	0
	5 to 10	0	0
Ground gear	0 to 2	0.20	0.12
	2 to 5	0.20	0
	5 to 10	0.20	0

The sweeps had the least overall encounter area of all gear components (Table 2.10). In mud, no penetration was observed. In the surface to 2cm depth category for sand, the sweeps encountered 20% of the pre-trawl un-impacted area. This value is, surprisingly, very similar to the encounter area of the trawl door at the corresponding depth in sand and is a result of the sweeps skimming the crests of the sand ripples.

The ground gear, much like the trawl door, had a greater encounter area in mud than in sand (Table 2.10). The component encountered 20% of the sediment in its path at each depth interval, down to 10cm. Due to the nature of the ground gear, only part of the component impacts the sediment, whilst the remaining structure runs along at the surface of the sediment (Figure 2.47) explaining why only a proportion of the sediment was encountered at each depth range. The ground gear had a more limited encounter area in sand, only penetrating the sediment in the upper depth range, encountering 12% of the path of the ground gear from the surface to 2cm depth.

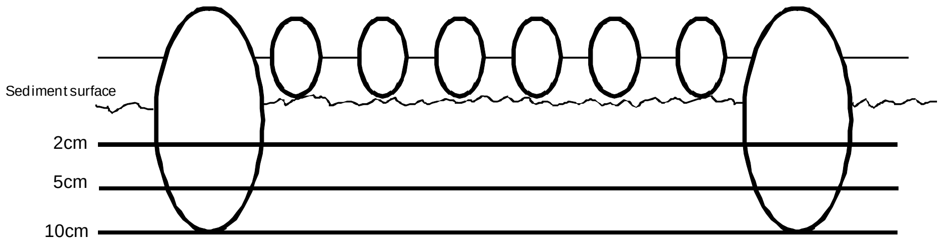


Figure 2.47. Schematic of a section of the ground gear, consisting of two large disks separated by several smaller discs. The proportion of area encountered was based on the assumption that the larger disks took up approximately 20% of the total area of the groundgear.

The living ranges of species from the sand and mud habitats covered species living entirely within the top 2cm of the sediment (and extending above it in many of these cases), to several that lived entirely as subsurface feeders with their living ranges never extending above 5cm below the surface. Most species in each habitat had living ranges that covered depths from the surface down to 10cm depth (Table 2.11). Less than 21% of the species explored in each habitat had living ranges that extended below this depth.

Table 2.11. The percentage of species living for at least some of their time in depth ranges from the surface to 30cm below the surface in mud and sand habitats based on the living range of each species

Depth range (cm)	Percentage of species in mud	Percentage of species in sand
0 to 2	97	96
2 to 5	69	53
5 to 10	49	44
10 to 20	21	18
20 to 30	4	2

Based on this information it was possible to predict what proportion of individuals of each species would be encountered by the different gear components in the different habitats across their entire depth range. Any individuals living below 10cm would not be encountered by any components of the gear tested for these habitats (see extent of penetration of the different gear components in Table 2.10).

Mud

In mud encounter rates were highly variable, but nearly 30% of all species were predicted to be subject to greater than 90% encounter rates in the path of the doors (Table 2.12). If we assume all individuals that are encountered are killed, this suggests mortality rates for species in the path of the doors could be as high as 90% of all individuals. Nearly 50% of species would have as high as a 60% encounter rate behind the doors and only 4% of species would have less than 20% of individuals killed. No more than 30% of individuals would be killed in the path of the groundgear, but 75% of species would suffer at least 20% mortality. Individuals located in the area swept by the sweeps would not be encountered at all (Table 2.12).

Table 2.12 The number of species with different likelihoods of encounter (percentage of individuals encountered) due to the individual gear components in each habitat type. In Mud the total number of species was 68 and in Sand it was 55.Thus in Mud 10% of species were predicted to have an encounter probability of between 20-30% of all individuals due to the Doors.

	MUD			SAND		
Encounter (% individuals)	Doors	Sweeps	Groundgear	Doors	Sweeps	Groundgear
0 -10	1	0	0	47	51	55
11 - 20	3	0	25	7	49	45
21 - 30	10	0	75	45	0	0
31 - 40	15	0	0	0	0	0
41 - 50	22	0	0	0	0	0
51 - 60	0	0	0	0	0	0
61 - 70	15	0	0	0	0	0
71 - 80	6	0	0	0	0	0
81 - 90	0	0	0	0	0	0
91 - 100	28	0	0	0	0	0

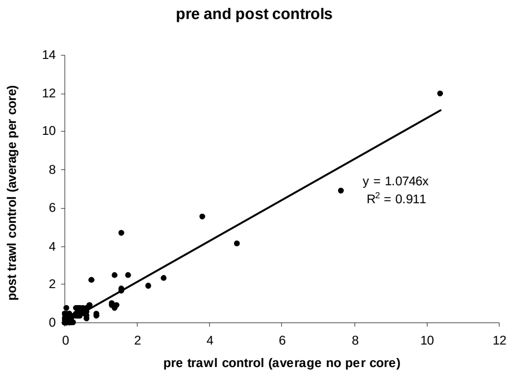
Sand

In sand, the model predicted that no species suffered more than a 30% encounter rate (Table 2.12). Encounters with the sweeps and groundgear would affect less than 20% of individuals for all species and less than 10% for over 50% of species. Forty-five percent of species in the path of the doors would have between 20-30% of individuals killed, but 47% of species would have an encounter rate of less than 10% (Table 2.12).

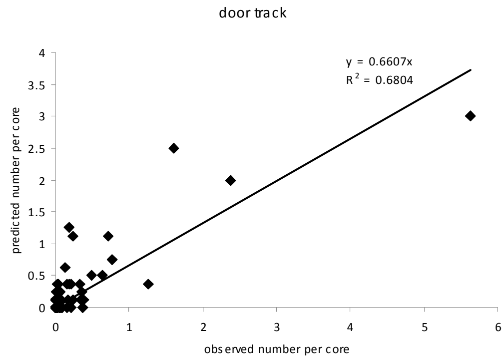
Testing predictions of the mortality model based on encounter probability

Mud

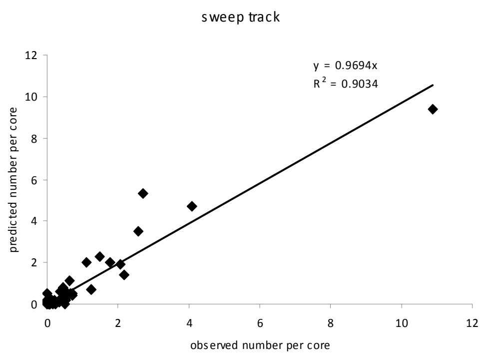
In mud, the linear regressions showed that there was a strong one to one correlation between the pre trawl abundance and the post trawl abundance sampled outside of the trawled area. There appeared to be about a 65% reduction in the number of species sampled in the door track and no (very little) reduction in the sweep or ground gear paths. A comparison of the predicted and the observed values find suggests that a simple model based solely on encounter probability (based on impacted sediment and living range information) is capable of accounting for a large proportion of the observed reduction in numbers (figure 2.48).



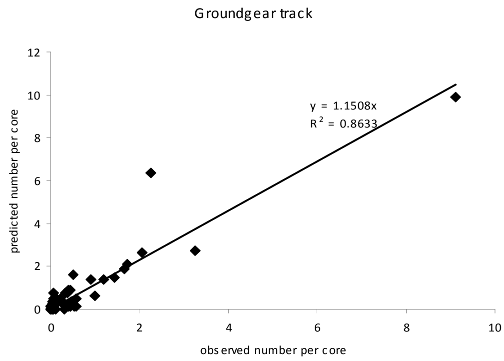
(a)



(b)



(c)



(d)

Figure 2.48 Relationships between the actual pre-trawl and post-trawl control samples of abundance for each species (a), and between the observed post-trawl samples and the predicted post-trawl abundances of the model in the path of the doors (b), sweeps (c) and groundgear (d). Linear lines of best fit are shown with the equation of the line and the R^2 values given.

Sand

In sand, a comparison of the slopes of the linear regression lines showed that there was a strong one to one correlation between the pre trawl controls and the post trawl controls sampled outside of the door path. There appeared to be about a 15% reduction in the number of species sampled in the door track and no reduction in the sweep path. There was a 22% reduction in the ground gear path but this was driven by just one species, which when removed suggested that there was no difference. A comparison of the model predictions again shows that the model can account for a large proportion of the observed reduction in numbers (figure 2.49).

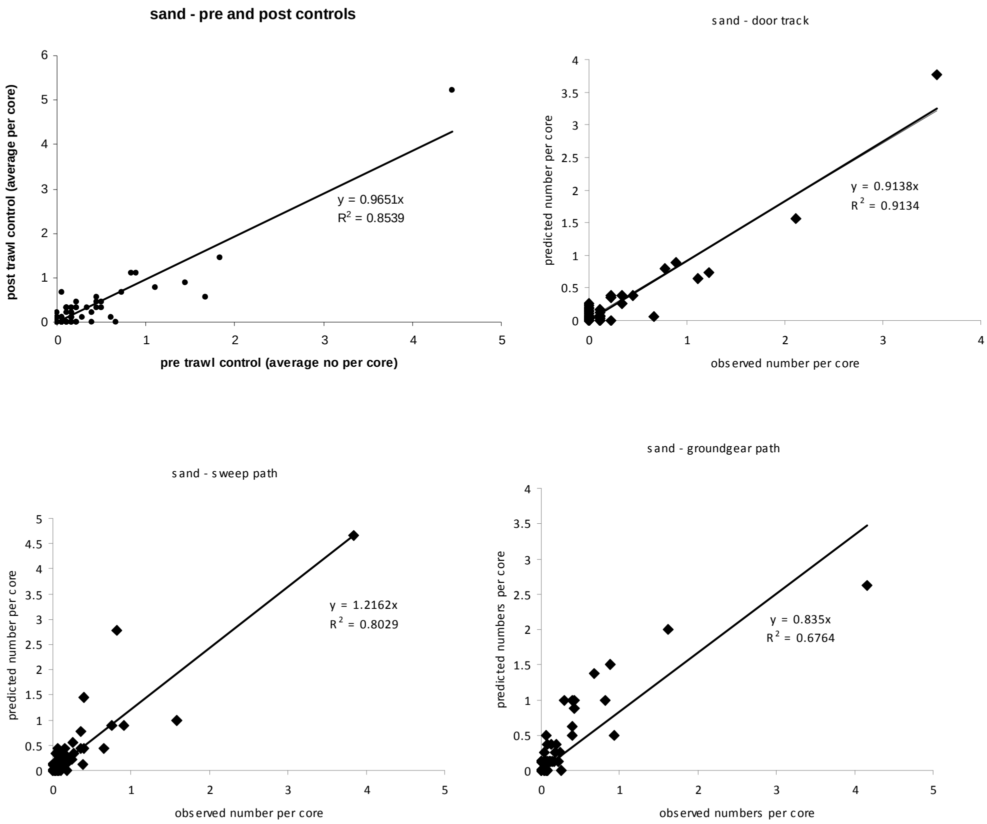


Figure 2.49 Relationships between the actual pre-trawl and post-trawl control samples of abundance in sand for each species (a), and between the observed post-trawl samples and the predicted post-trawl abundances of the model in the path of the doors (b), sweeps (c) and groundgear (d). Linear lines of best fit are shown with the equation of the line and the R^2 values given.

A problem with the analysis presented here is that it does not take into account the binomial nature of the data. Thus few species with relatively large numbers are having a disproportionate influence on the data (as can be seen in the ground gear – sand example). To address this we are in the process of applying hierarchical generalised linear mixed models. These models will then also be applied to the more sophisticated models incorporating life history and biological traits (see Section 2.4.2.4 below).

5.4.3 Further development

There is a need to further develop the analysis used to test the predictions of the mortality models as mentioned above. Having done so, we will assess the power of the predictions, and where necessary explore the need to further improve this by accounting for other characteristics of species such as their motility, size and fragility. All of these may in turn affect whether we would expect a species to show up in post-trawl assemblages behind the different components of the gear.

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5.4.5 Modelling mortality to fish

Background

Modifying fishing gears to reduce their impact to seafloor habitats and benthic invertebrate species (mortality on the seafloor) has been one of the main areas of investigation in this project, and the modelling approach described in Task 2.4.2 above is closing the gap on our ability to predict how much of a difference such modifications could make to overall impacts on benthic habitats and species.

Equally as important is the need to be able to predict the differences in catch mortality that may result from modifying gears. Fishing gear selectivity studies have long been undertaken in gear trials, but this has often been restricted to a limited number of commercial species. Two separate studies (Piet et al., 2000; Pope et al., 2000), both using variants of a “swept-area” approach, have suggested that rates of fishing mortality in different components of the marine ecosystem might be modelled from data that appropriately quantify spatial and temporal variation in the levels of fishing activity (Jennings and Cotter, 1999), along with abundance of the biota in question obtained from surveys and stock assessments (Kunitzer et al., 1992; Knijn et al., 1993). This work was developed initially in the 5th framework project MAFCONS (Piet et al., 2007) and was modified here to determine the direct mortality caused by fishing to members of the North Sea demersal fish assemblage. Our modifications involved, first, the use of “true” estimates of spatial variation in fish abundance that take account of catchability in the gears used in the groundfish surveys (Fraser et al., 2007). Second, we assumed gear-, species-, and size-dependent variable catch efficiencies in the two major fisheries, otter trawl and beam trawl, operating in the area. We then performed a sensitivity analysis to examine the extent to which our mortality estimates were affected by the various assumptions made. Finally, we validated the model by comparing model output with estimates of landings and discards of the main commercial demersal species derived from sampling programmes. Those analyses not only provided best estimates of fishing-induced mortality for the main fish species in the North Sea, but also insight as to which factors influenced those estimates most and which should therefore be considered for further research. This work has now been published (Piet et al., 2009) and details of the methodology, results and general implications can be found in a pdf of the paper in Annex 2.8. The major findings relevant to DEGREE and future work are summarised and discussed below.

Findings

The model generally performed well in predicting the quantities of each species landed by the beam trawl and by the otter trawl. There was perhaps a tendency for roundfish landings in the otter trawl to be slightly overestimated and flatfish landings in the beam trawl to be slightly underestimated by the model. Generally, though, landings of species caught in gears where they were not the principal targets of the fishery concerned, e.g. flatfish in otter trawls and roundfish in beam trawls, tended to be underestimated by the model. Although these differences might have been quite high in terms of relative proportion, i.e. predicted sole landings from otter trawls were only 40% of observed landings, in absolute terms (the difference in tonnes), the discrepancy was small. However, more serious problems emerged regarding some of the discard predictions provided by the model, particularly in respect of the otter trawl data, where the model suggested levels of cod, whiting, and plaice discards that were considerably smaller than the actual levels of discarding suggested by sample data. For all other species and gears, the model predicted discard levels reasonably accurately. This showed that depending on its configuration, the model could reproduce recorded landings and discards of these species reasonably well. This suggests that the model could be used to simulate rates of fishing mortality for non-target fish species, for which few data are currently available.

5.4.6 Further development and applications

Sensitivity analyses revealed that model outcomes were most strongly influenced by the estimates of gear catch efficiency and the extent to which the distributions of fishing effort and each species overlapped. Better data for these processes would enhance the contribution that this type of model could make in supporting work on the ecosystem level effects of gear modifications. In particular, as gear modifications are most likely to affect catch efficiency, the implications of the sensitivity analyses on varying gear efficiency could be adapted to be used to explore scenarios of effect level given different modifications to the gear.

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5.5 Predict the ecological disturbance of fishing (Task 2.5)

5.5.1 Introduction

The aim of Task 2.5 was to predict the differences in ecological disturbance of modified versus standard gears from WPs 3 and 4 using the modelling approaches developed and validated in Tasks 2.1-2.4.

5.5.2 Gears modified in WP

In WP3 the aim was to design gear that would reduce the impact of the otter doors and the groundgear on a standard otter trawl. Unfortunately, it was not possible for the partners involved in Tasks 3.5 - 3.8 to collect the full complement of physical and biological data required to validate any predictions generated using the models developed in Tasks 2.2-2.4 of WP2. Much of the time required for work in WP3 was related to development, testing and flume tank trials of the newly designed gear components and due to weather constraints, it was only possible to run limited sea trials. At the same time, the dynamic model required to simulate the standard and modified otter trawl is not yet complete (see Task 2.2.3.3) and so it was not possible to make full gear predictions about the physical impact of the gear components anyway. The biological models for predicting mortality to invertebrates on the seafloor will need some further refinement too (Task 2.4.2.4), in particular to account for vulnerability on encounter given that this will be important for many of the epifaunal species likely to be encountered in areas where some of the otter trawl fleets operate.

5.5.3 Application of physical and biological models

Once the dynamic model and the biological mortality model are completed the partners of Workpackage 2 will test a range of scenarios to assess the impact of commercial whitefish fisheries on a range of sediment types and for a range of gear designs. This will allow an investigation of the extent to which commercial fisheries affects the benthic ecology. We will be able to distinguish between heavy/light gears, habitats, sediment types and determine the worth of gear design modifications.

For instance, the groundgear used in Task 2.4 may have an encounter rate of less than 20% with infauna in sandy sediments, and less than 30% in muddy sediments. Thus, modifying a demersal trawl with this type of groundgear may only have benefits in terms of reducing benthic mortality and damage to habitats in areas where there is a lot of emergent epifauna and/or complex biogenic habitats. (In these sorts of habitats, mortality and habitat damage will occur unless the gears are towed above the seafloor; in many such areas the gear would need to be >30cm above the seafloor to avoid many of the epifaunal animals and habitat features which would then likely significantly decrease the performance of the gear in catching the target species). The ecological benefits of modifying this type of light groundgear are likely to be minimal for fleets operating in areas of fairly homogenous sands dominated by infauna. On the other hand, the groundgears used by the medium to large commercial whitefish boats in the north east Atlantic are heavier and more closely packed. The infaunal encounter rates are likely to be much higher for these groundgears and accordingly there may be real ecological benefit to modifying their design.

5.5.4 Gears modified in WP4

In WP4 modifications included those to the groundgear and netting of beam trawls, and also work on a modified oyster dredge. Details of the differences in ecological disturbance of modified versus standard gears are summarised below and comment on how the modelling work developed in WP2 could be used in relation to any further development is also given.

5.5.5 Beam trawl modifications (T90 cod ends and benthos release panels)

For the work done by partners on modifications to the cod end and netting of the beam trawl (ILVO and Cefas), it was assumed that the biggest difference would be in catch mortality (numbers retained in the catch) as the rate at which animals are caught (catch efficiency) should not change, but the numbers that are retained in the net will (i.e. less discards). As the alterations to the gear affect the retention of animals in the net, but not the physical footprint of the gear on the seafloor, any differences in mortality on the seafloor would be assumed to be due to differences in assemblage types/habitats between the areas fished. There would be no difference in seafloor mortality/habitat change resulting from the gear modification.

Results are summarised under WP4 of this report and detailed under Annexes 4.1.3 and 4.1.2. Overall, although there were some mixed results in terms of catchability of target species, the modified gears generally reduce discards of commercial and non-commercial fish and invertebrates and retain good catches of commercial sized target species. It is planned that once the dynamic model and the biological model described in Task 2.2 and 2.4 have been updated, comparisons will be made to see how the reduction in mortality in the catch of benthic invertebrates compares to the level of mortality caused on the seafloor. This work will be undertaken based on collaboration between ILVO and ULIV with FRS and UNIABD and outcomes will acknowledge the contribution of work undertaken through DEGREE.

5.5.6 Beam trawl modifications (groundgear)

Under DEGREE work has been furthered on the electric pulse beam trawl (Annex 4.2.1) and on a light Mediterranean beam trawl (Annex 4.1.8), both designed to reduce contact and thus impact with benthic habitats and species. Neither have produced inputs for modelling the differences in impact to benthic habitats and species at this stage, but in both cases preliminary results suggest an improvement from the modified gears. In both cases the level of “improvement” could be quantified if measurements of the gears could be used to predict the physical footprints of modified and existing gears, and this then used to predict mortality rates for the benthic assemblages in areas where these fleets operate. As yet, it is unknown whether there is access to information on distributions and densities of benthos in the areas where the Mediterranean gears operate, but it will be possible to undertake a comparison for the pulse gear in the southern North Sea, should this work progress. This would then enable a comparison of the benefits associated with a reduction in impact to the benthos and habitats with any detrimental effects on other components of the ecosystem (e.g. levels of mortality of bony fish in the path of the pulse trawl) or in terms of economic and commercial viability.

5.5.7 The low impact oyster dredge

The low impact oyster dredge was designed to reduce impacts to the benthic habitat and species encountered on the seafloor, whilst retaining a commercially viable catch of the target species of oyster (Annex 4.1.7). It is clear from the physical measurements produced in the comparison of the low impact oyster dredge with the standard dredge that the encounter rates would be quite different for the two different gears (Fig.11, Annex 4.1.7). The standard dredge has deeper penetration in the track of the dredge (although this is limited to <1cm) and the modified low impact box dredge actually elevates the sediment behind the knife (presumably because the net is no longer squashing the sediment behind the knife). The physical profiles suggest that animals will only be encountered if they live in the top 2cm of the sediment or on the surface in either case.

Preliminary results from the catch comparisons suggest that the low impact oyster dredge catches similar amounts of commercially sized individuals, and is more selective in terms of having lower catches of small undersized oysters (Table 2, Annex 4.1.7). At the same time, the drag of the low impact modified gear is greater as it is heavier (Table 1, Figure 13) and this may affect commercial viability in terms of fuel costs. Once the biological model described in Task 2.4.2 has been perfected, it will be possible to calculate the actual difference in impact to the benthos. DTU Aqua have provided WP2 partners (Partner 13) with information on assemblage types in the areas where the oyster dredges are used, and these can be used to predict likely encounter and ultimately mortality rates for both the modified and standard gears. There is no data from the study area to validate these predictions but the model will be validated with data from other study areas first (as described in Task 2.4.2). Having completed this it will be possible to compare the difference in impact rates for the two gears and to assess the significance of this in light of any differences in commercial catch retention and economic viability.

6 WP3 – approach and results

6.1.1 Summary

The aim of this work package is to develop and evaluate modifications to trawl doors and groundgears that reduce the physical reaction forces acting on the seabed. Traditional otter trawl gear has several components i.e. the groundgear or footrope, the bridle or sweeps, the doors and/or the clump weight(s) (in the case of multi-rigs) that contact or approach the seabed to a lesser or greater degree. Variations in the composition and design of these components influence their effects on benthic ecosystems. There has, however, been few studies specifically relating to benthic impact of otter trawls and such studies have been sporadic in nature, concentrating only on one or other component and have not directly identified the mechanisms by which gear interacts with the substrate and organisms. Many have had minimal industry input, resulting in gear modifications that are unacceptable either through reduced catches or the gear developed being too complex. From various literature reviews, it is also apparent that the methodologies used to measure impact have been highly variable and somewhat subjective in nature. It is intended to redress these issues within this work package.

Table 5 summarises the work completed in this period, which covers the period of months 19-38 of this project. For this final period, initially the partners split into two groups with one group continuing to look at trawl doors and the other testing alternative groundgear designs.

All partners then attended a project workshop held in the flume tank in Hirtshals, in preparation for the final cruise on the Norwegian research vessel “GO Sars”.

Partners 05 (IFREMER), Partner 07 (BIM) and Partner 12 (CNR-ISMAR) have worked on trawl doors. Partner 05 and 12 have developed new novel door designs, while Partner 07 has concentrated on identifying what features of existing door designs enable them to work lightly on the seabed in a stable and acceptable way.

Partner 05 has tested a prototype trawl door with a novel arm system, firstly through flume tank experimentation and then through sea trials on board the research vessel “Gwen Drez”. No measurement of the actual force or pressure on the seabed were taken and thus these trials were very much used as a proof of concept to verify the results from the earlier flume tank testing and also to observe the performance and handling of the prototype. The overall conclusion from this trial was that the prototype was stable and efficient but that it would be difficult or impossible to use these doors commercially, especially on small fishing vessels due to their shape. Potential handling problems with the doors were observed in that the arms had to stay outside the trawl gallows and could not be stored as per standard doors. Also concerns were expressed regarding the strength of the arms themselves. On the basis of these trials and from the previous flume tank analysis, it was therefore concluded that there was no need to design a door with such an elaborate arm system as simple “standard” doors with a high “height / width” ratio already exist. Taking this into consideration it was thus decided by Partner 05 to look at an intermediate option between a “standard optimised door” and a door with an arm system. This led to the development of a prototype door with a monolithic shape. This was tested at sea on the “Gwen Drez” and it was concluded that with further modification these “jumper” doors have potential but need further testing under commercial conditions to assess performance in terms of spreading and stability as well as catch rates given the lower impact and reduction in herding due to reduced sand clouds.

Partner 07 has completed small-scale trials on 10m and 14m commercial vessels to verify the results from earlier flume tank tests with different door designs completed in PAR1. The results showed that while it is easy to re-rig any door design to operate lighter on the bottom, when the warps are shortened or the vessel tows faster, operating with doors in this condition requires a more stabilised and balanced door rig. Door designs need to focus on the weight required for fishing and not just structural considerations as overweight doors are difficult to fish optimally. These findings were demonstrated to the other project partners during a flume tank workshop held in Hirtshals in March 2008.

Partner 12 has also developed a prototype door design particularly to suit Mediterranean bottom trawl fisheries. The new door design was tested in the flume tank during PAR 1 in conjunction with Partner 07. This has been followed by three separate research cruises on the research vessel “G. Dallaporta”. Results related to performance of trawl doors such as the drag, lift and pressure coefficients and the angle of attack were measured extensively with the new door design, tested against a standard door used in the Mediterranean. As a main result of this work, estimated values of attack, heel and pitch angle and the corresponding horizontal door spread, drag, lift and efficiency-coefficient in sea trials condition for different warp attachment position to the doors have been calculated. Some conclusions of the door’s impact on the seabed studying the reaction force have also been made. In the flume tank test the reaction was measured and it was found that for a given angle of attack, it was smaller for the prototype *Clarck-Y* door than the standard *AR* door. For sea trials data, a prediction of reaction force has been calculated considering equivalent hydrodynamics for the flume tank experiment. In sea trials the estimation of reaction force was strongly dependent on towing speed, in particular the reaction force decreased when towing speed increased. In particular, the prototype *Clarck-Y* presented positive values of reaction force (i.e. the door lifted off the bottom) when towing speed was around 3.8 knots.

Partner 06 (IMR) and Partner 09 (DIFRES, SINTEF & MFMA) have worked collectively on developing low impact groundgear designs as a replacement for standard rockhopper footropes commonly used. The development of this alternative design has been based on the novel self-spreading groundgear concept originally developed by IMR and SINTEF. The basic idea behind the development has been to reduce the contact areas with the bottom of the various gear components, and to introduce a rolling function of the components in contact with the bottom. Following on from the work completed in PAR 1, which involved a series of small-scale trials on a 15m vessel and full-scale testing on the IMR research vessel "*G.O. Sars*", two sets of trials with full scale groundgears were completed on commercial vessels. The first of these trials concentrated on the rigging of the plate gear on a commercial trawl. This was followed by a catch comparison trial comparing the plate gear with a standard rockhopper trawl. This trial was conducted using the twin trawl method and showed the plate gear to be very sensitive to small changes in rigging. It was found that the angle of attack of the plates relative to the tow direction varied after several hauls, resulting in variations in catches. To address these issues, different rigging arrangements for the plate gear as well as modified bridle arrangements were tested during the flume tank workshop in Hirtshals

The final research cruise on the research vessel "GO Sars" and coordinated by Partner 06 was completed in December 2008. This cruise had the main objective of comparing the physical and biological impact of the bottom trawl modifications developed during the DEGREE project to a standard bottom trawl used in the Barents Sea cod fisheries. The "new" trawl was fitted with the last modification of the plate gear developed during the project as well as trawl doors rigged for minimal bottom contact. The commercial trawl used for comparison was rigged with a conventional rockhopper ground gear and the doors were rigged to fish normally with heavy bottom contact.

To find the optimal rigging of the doors and plate gear a series of engineering trials were completed at the start of the cruise with both the plate and rockhopper trawls. This was then followed by a series of hauls to measure the physical and biological impact on the bottom habitat of the two trawls. Only two valid impact hauls were, completed with each trawl, both on very soft sediments due to time constraints. However, all parameters measured indicated that the plate gear trawl had a lower impact on the bottom substrate and benthic organisms than the conventional rockhopper trawl. The physical impact on the bottom was visually inspected and measured using ROVs. In addition the turbidity of the water volume above the trawl tracks at different time steps after trawling was measured. A higher turbidity above the rockhopper trawl path indicated that the rockhopper gear raised more sediments than the plate gear trawl. This was probably both due to the heavier doors and the heavier gear on the conventional trawl. The larger impact of the rockhopper trawl was also confirmed by the ROV observations where the rockhopper trawl was documented to have a larger impact on the bottom sediments both horizontally and vertically than the plate gear. The difference in door rigging added to the difference in sediment disturbance.

Less data was obtained on biological impact. The rate of disturbance of bottom dwelling species raised by the ground gears was assessed using two collecting bags mounted inside the mouth of the trawl and at different distances behind the groundgear. Although the number of hauls was low, the results indicated that the rockhopper dug up more living material than the plate gear. This tendency was confirmed by the ROV investigations. The bottom type, where the experiments were conducted, had a low biodiversity. Tube dwelling polychaetes dominated the fauna. It was not possible from the ROV recordings to classify benthic organisms on the sea bed according to level of damage inflicted by the trawl components. Earlier investigations on soft bottom have not clearly demonstrated long term effects of trawling on benthic organisms (Ball *et al.* 2000; Hansson *et al.* 2000; Drabsch *et al.* 2001), but it is obvious that living organisms can only be damaged by a trawl if hit by one of its components during towing. Acknowledging that the area impacted by the trawl components as well as the depth of their digging into the sediments is what decides the severity of the impact on bottom living species (see e.g. He and Delouche 2004; Rose *et al*. 2000), it must be concluded that the new gear developed during the DEGREE project has the potential to reduce the impact of bottom trawling if taken into use by the fishing fleet.

The overall conclusions from Workpackage 3 are that given the differences in the design of trawls, trawl doors, sweep arrangements and actual fishing operations and the characteristics of the target species there is no universal solution to reduce bottom impact of towed gears but in many cases simple rigging changes to the trawl doors or groundgears can limit impacts. It is also concluded that the cruise on the “GO Sars” has confirmed that it is difficult to assess the physical and biological impacts of all components of towed gears accurately. Biological impacts are particularly hard to measure. The modelling carried out in Workpackage 2 is thus felt to be vital for further studies carried out to assess bottom impact. On the basis of the information disseminated to the industry and feedback received, it is also concluded that acceptance by fishermen of gear modifications to reduce bottom impact will be dependent on the modified gears maintaining catch rates at economically viable levels. Furthermore even though there is a greater awareness amongst fishermen of the need to reduce bottom impact, the main driver for using lighter or less impacting gears is the need to reduce fuel costs.

Table 5 Summary of completed trials by task and by partner

Task	Partner(s)	Trials	Results
3.2	05	Flume Tank Tests – Trawl Doors	Testing of modified doors with arms
3.3	07	Small-scale Engineering Trials on Commercial Vessel – Trawl Doors	Testing and Verification of Alternative Rigging Strategies (3 trials)
3.3	06 & 09	Sea Trials on Research vessel - Groundgears	Testing of Prototype Groundgear Designs & Initial measurement of Physical Impact (1 trial)
3.4 & 3.5	05,12	Sea Trials on Research vessel – Trawl Doors	Testing and Quantification of Prototype Door Designs (5 trials)
3.4 & 3.5	06 & 09	Catch comparison trials on commercial vessel - Groundgear	Catch comparison analysis with standard rockhopper and prototype groundgears (1 trial)
3.6	05,0 6, 07, 09 &12	Flume Tank Tests – Trawl Doors and Groundgears	Demonstration of prototype door designs and groundgears
3.7	05, 06, 07, 09 & 12	Final Research cruise	Integration of gear modifications and measurement of physical and biological impacts (1 trial)

6.2 Review of current rigging of doors and groundgears

Partner 07

Partner 07 has updated the gear inventory produced in PAR 1. See Annex 3.1.1.

Partner 09

Partner 09 has carried out an extended analysis of the groundgear data collected as part of the inventory. The main purpose of this inventory was to give state of the art information of trawl gear and trawl doors in use for the partners involved in the project and to serve as a platform for the following developmental work with the low impact groundgears and trawl doors. However, having compiled a detailed and comprehensive international inventory, it was speculated that the paired vessel and gear observations could serve additional purposes. Specifically it was decided to allocate time to analyses targeting the quantification the relationship between trawl size and vessel engine power. Such quantification was considered of interest in defining fishing effort. Fishing effort is seen as a proxy for impact and this exercise was seen as a way for developing a replacement for kilowatt days as a standard descriptor of effort in trawl fisheries. This analysis showed that there was a linear fit relationship between trawl circumference and horsepower. However, departures from this linearity due to e.g. the introduction of high performance netting or the presence of some functional limitation of trawl size at higher engine powers was not ruled out. The definitions and parameterization of a mechanistic model for the relationship between engine power and trawl size depending on target species was considered the next step in this analysis. A detailed description of the findings from this analysis is reported in Annex 3.1.2.

6.3 Flume tank testing and DynamiT trawl simulation software

This task was largely completed during the first period of the project and is reported in PAR1 with Partners 05, 07 and 12 all completing flume tank tests during the first period of the project.

Partner 05

Partner 05 has carried out further flume tank testing with a prototype door in the Lorient flume tank, in March 2008 following earlier testing and flow visualisation of this door design. A full report of these trials is given in Annex 3.2.1.

Partner 5 has completed numerical simulation trials in order to assess mechanical impact of doors on the seabed. The method is detailed in Annex 3.2.2 It take advantage of commercial trawl simulation software and door hydrodynamic coefficients measured in flume tank. Large range of door behaviour, trawl design and deployment parameters can be taken into account.

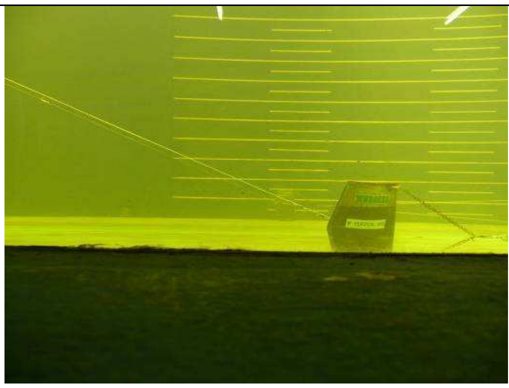
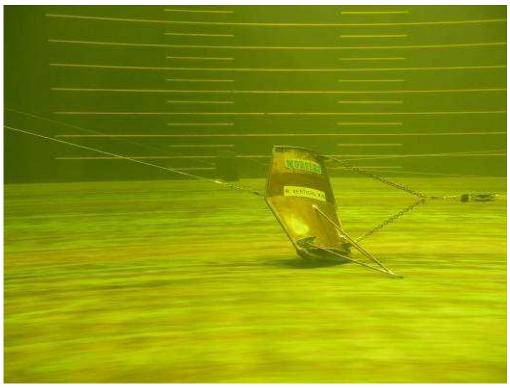
The prototype door model was a Morgère WV high aspect door with a modified arm system. The key idea behind this prototype design is to move the position of the contact point with the seabed (which becomes the new effective shoe) away outside from the door’s centre of gravity. On the middle picture of Figure 6, it can be seen that the position of the end of three arms under and beside the door shoe. The contact point with the seabed is a new small shoe.

Figure 6 : Scaled model of the door with its arm. Side view, front view and flume tank view.

When the shoe arrives on the seabed, the vertical force component applied by the seabed on the door shoe produces a momentum force. This momentum makes the door roll inwards and thus the lift hydrodynamic force is partly directed upward. The vertical force component of the lift force then relieves the door weight applied on the seabed.

This prototype was tested against standard Morgere WV doors, which are designed for semi pelagic fishing with a high ratio of height to width. The trawl model used for the tests was a standard bottom trawl with 41.5m headrope at the scale of 1/20. The towing speed was 3-4 knots full scale.

Figure 7 and Figure 8 below provide a comparison of the door behaviour with or without the arm system for different warp angles (measured just before the door) and for different towing speeds.

Case	Normal door	Door with arm
3.0 knots 23°		
3.0 knots 18°		

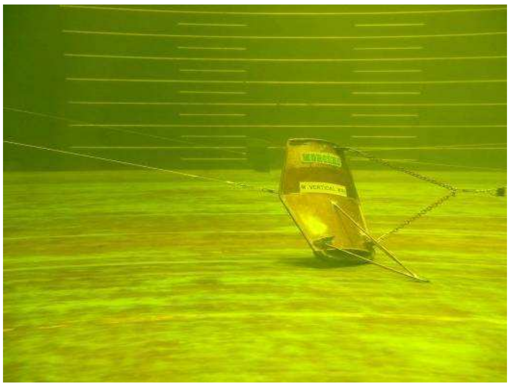
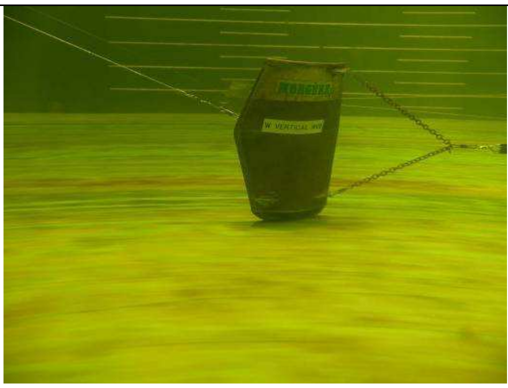
3.0 knots 11°		
3.0 knots 6°		

Figure 7 Different views in Lorient flume tank comparing the effect on the roll angle of the added arms for different warp angles at 3 knots.

Case	Normal door	Door with arm
4.0 knots 23°		
4.0 knots 18°		

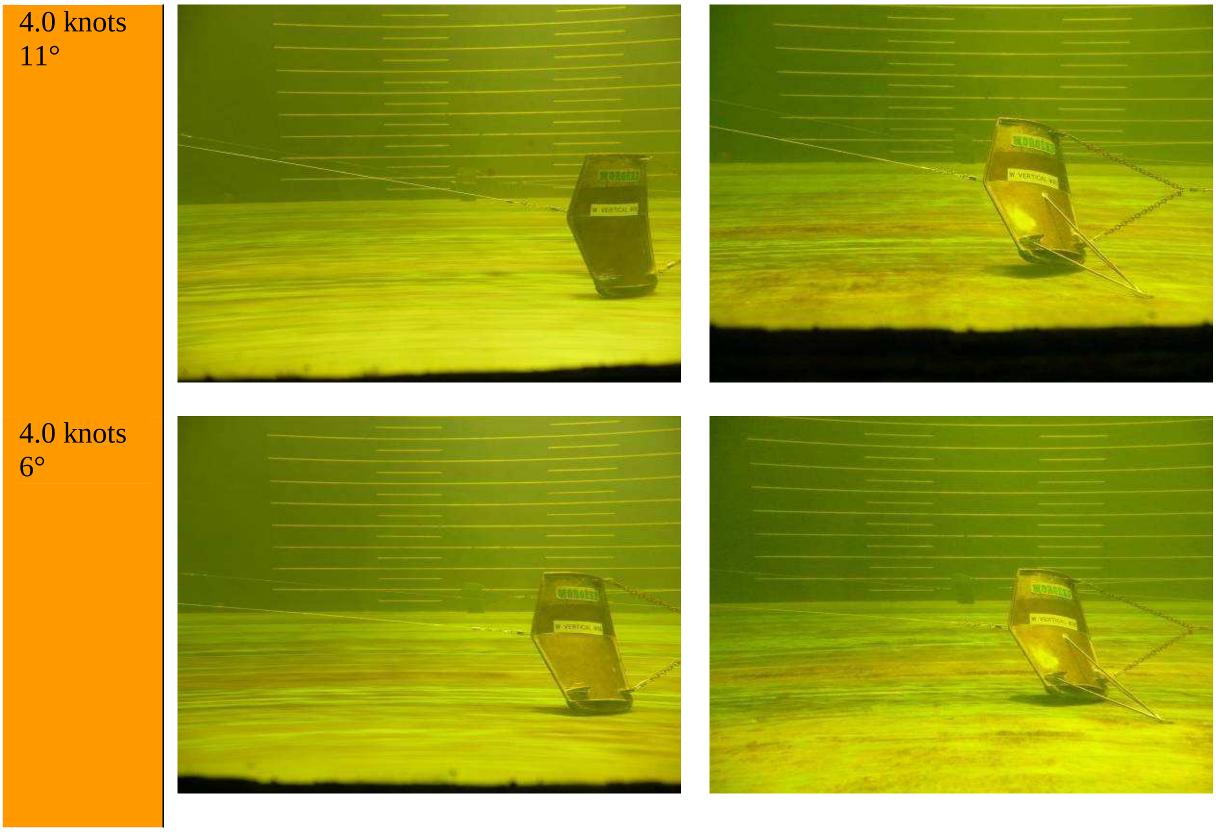


Figure 8 Different views in Lorient flume tank comparing the effect on the roll angle of the added arms for different warp angles at 3 knots.

Generally, it was concluded from these tests that for each configuration of towing speed & warp angle, the prototype door with the arm system had a larger roll angle than the standard door. This means that impact on the seabed would be reduced at sea. This was particularly the case for low warp angles and low towing speeds.

In "normal" fishing configuration (i.e. warp angle about 23 degrees and 4 knots) the arm system is useless, as the behaviour of the door is the same for both configuration and the door sits vertically. The normal force on the seabed is also the same although the pressure force is different as the shoe surface of door and arm are not the same. The flume tank tests also suggested that re-suspension would not be the same for the two configurations as the door with arm system lifts off the bottom and would therefore produce almost no re-suspension at full-scale. In fact, the arm starts to act when the vertical force on the seabed becomes significant, as it applies a momentum proportional to the lever arm. For the following configurations:

- warp length to big for considered depth,
- or warp angle too low at the door,
- or towing speed too low

the arm system is useful as it rolls the door inward and the hydrodynamic force relieves the door weight and reduces the force applied on the seabed.

Further testing of this concept was complete by Partner 05 in December 2008. These tests attempted to develop ways to use the high sensitivity of the towing bracket (door arm) height to control the door roll better, as the earlier testing had demonstrated that the position of the bracket had a big influence on the door stability and hence bottom impact. If the door bracket was a few centimetres too high the door was shown to roll inwards, a few centimetres too low and the door rolled outwards. This was due to the moment exerted by the couple of forces constituted by the hydrodynamic force and the warp force.

In the prototype tested during these flume tank trials as shown in Figure 9 the towing bracket position was directly modified by having a “leg” lying under the door shoe. The two parts were linked with an adjustable chain and this leg was designed to act as a “seabed sensor”. When the leg was in contact with the floor of the flume tank (i.e. the seabed), the bracket pulled up and the door rolled inwards. The hydrodynamic force was then partly directed upward and the intensity of the contact on the flume tank floor decreased. By doing the opposite, the system could be adjusted to make the door sink faster when shooting the trawl. The results obtained from this trial were, however, only considered preliminary and there were stability problem as the roll angle of the door directly modified the position/angle of the “seabed sensor. It was concluded that further testing of this concept was required at sea on larger scale models given the limitations with flume tank testing in simulating bottom contact.

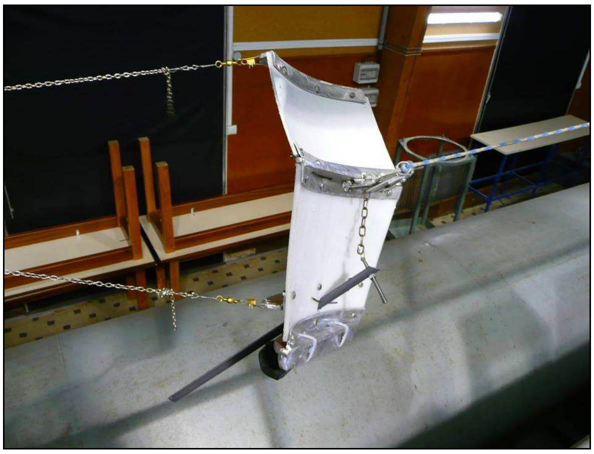


Figure 9 Scale model of door where the articulated bracket is controlled by a “seabed sensor”

6.4 Small Scale Engineering Trials

Partner 07

Following flume tank testing carried out under Task 3.2 and reported under PAR 1, Partner 07 carried out a series of small-scale engineering trials. The first of these was carried out in July 2007 and the preliminary findings were reported under PAR 1.The objective of these trials were to examine practical rigging problems found during flume tank tests carried out under Task 3.2 by Partner 07, as well as assessing how the application of basic gear technology and training could be used to help fishermen work existing doors better, with lower bottom impact. A full report of the three trials completed is given in Annex 3.3.1.

As these trials were not designed to measure the physical and biological impacts of trawl doors, minimal instrumentation was used so that the technical staff carrying out the trials only had the same information and symptoms of how the doors were working as was available to fishermen operating them. This was important in developing guidelines for fishermen as to how to rig doors optimally. The only electronic instruments brought aboard each trials vessel was a pair of Star-Oddi DST pitch and roll sensors (self recording) which were used for the first time during these trials to assess their usefulness as practical sea trials devices. The sensor is about the size of a small finger and housed in a heavy duty protective case welded to the door as shown below.

The roll and pitch sensor was set to start before the first tow of the day and recorded the roll (heel) and pitch angle every 10 seconds. The instruments were inserted into their housings on the doors then a calibration routine carried out to mark zero degrees of heel (door top plate upright) and zero degrees of pitch (door shoe horizontal). The door was then heeled in and out and pitched nose up and down to ensure the right sign was applied to each sensor i.e. pitch nose up and down is the same for each door but heel in is the opposite rotation for the port and starboard sensors. Pitch nose up is +ve and heel out is +ve in these experiments as seen in the tabulated results.

The small size of the sensor can be seen in Figure 10 below attached to a 1.5m vee door.

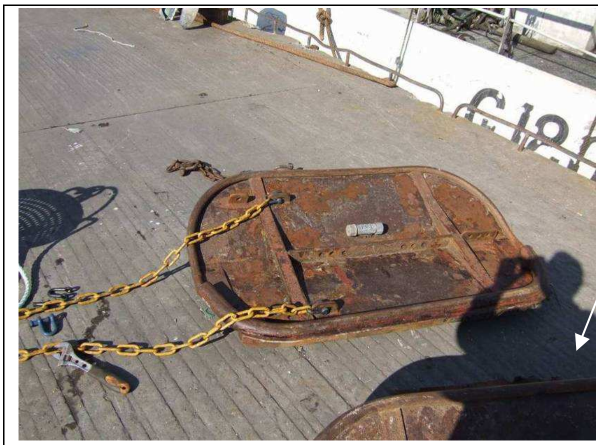


Figure 10 Roll and pitch sensor welded to back of vee door

GPS was used to measure speed over the ground as no method was available to measure speed through the water. To help counter this lack of water speed, measurement runs were conducted with and against the tide to obtain average results.

The warp divergence method was used to assess door spread. The warp divergence method involves measuring warp spread one fathom (or a fixed distance) down from a centre towing point then multiplying this distance by the warp length out to give a calculated spread as shown in Figure 11 below. A small nominal allowance (5% chosen in this case because of short warp lengths) can then added to this calculated spread to allow for warp curvature and hence give an estimated door spread.

Figure 11 Measuring door spread using warp divergence

Each skipper of the trials vessels was asked to rig a central towing point to make it easier to measure. Although it is possible to use this method towing from the trawl gallows, accuracy is generally poor.

Depth of water was measured using the vessel’s echo sounder. The reading taken was adjusted by the keel offset, gallows height etc. to give a fair assessment of warp length to depth ratio.

Sea Trials 1: gear and procedure

The first sea trial as reported in PAR 1 was carried out on the "Crystal Dawn" (WD201) based at Greencastle (Figure 12). This vessel targets mixed demersal fish (especially flat fish) and *Nephrops*. The vessel is 9.5m long and 127bhp fitted with a Kort nozzle.

Figure 12 "Crystal Dawn" WD 201

The trawl was a standard general purpose trawl with 12 fathom fishing line and rigged with 30 fathom of single sweep and 7 fathom bridles.

The vessel had two sets of vee doors, one pair nominally 1.5m long (Figure 13) and the other pair 1.36m (Figure 14). Both sets had hinged towing arms. The 1.5m doors weighed 144kg each and the 1.36m weighed 98kg each.

Figure 13 1.5m vee doors

Figure 14 1.36m vee doors

Two tow areas were identified by the skipper at typical depths of 8-10 fathoms and 15-17 fathoms. Due to the relatively shallow water the skipper has to shoot 60 fathoms of warp giving high warp/depth ratios of between 6 and 4 in order to get adequate door spread.

Extra brackets and lugs were welded onto each of the sets of vee doors to allow for any combination of bracket or chain warp attachment, and single twin or triple backstrop arrangement. However, in practice these were not needed as the 1.5m doors were fundamentally too heavy for the warp/depth ratio so other solutions were sought. The twin backstrop fitting on the 1.36m set were used.

The holes on the tow arm were numbered 1-3 from inside to outside (3 furthest out from door face), and the single backstrop holes numbered 1-3 from forward to aft. For both door sets the twin backstrop arrangement only had one setting.

In order to examine the full range of performance of the doors each set was towed at varying speeds, both faster and slower than the normal towing speed used by the skipper (2.2 to 2.3 knots, and occasionally faster with the tide).

A run comprised up to six towing speed settings with the tide (first leg) then six speed settings on a reciprocal course against the tide (second leg). This was done to average out any effects of tide on the door performance.

<u>Results - Trial 1</u>

The first trials examined the performance of the 1.5m vee doors in the shallow and deeper tows. On these tows the skipper used the same warp out of 60 fathoms in 8-10 fathoms and 15-17 fathoms giving warp/depth ratios of approximately 6 on the shallow tow and 4 on the deeper tow.

At the skipper’s normal towing speed (2.2 knots) the bridle angle was only about 9° in the shallow tow and 10° in the deeper tow (not validated with reciprocal tow). As speed increased the bridle angle increased as the door stood more upright but it was found that the skipper would have to tow above his required towing speed to allow the gear to open properly.

In the deeper tow the 1.36m door gave a bridle angle of 8.5° and in the shallow tow 8.5°. When the angle of attack was increased to maximum they still achieved 8.5°.

The results showed that for the smaller door, weight is not so detrimental. However, the bridle angles are still increasing and the door is gradually standing more upright indicating that a lighter door could still be used (i.e. it is falling in at lower speeds).

The final two runs showed the effect of adding small extensions to the top of the 1.5m vee doors. In the deeper tow the bridle angles are 12-13°. This was due mostly to the door being more upright and a little due to the extra door area when compared with the unmodified door. This simulates the towing point being lowered on the door which would be another way to correct this excessive heeling in experienced.

The conclusions from these trials were that the 1.5m doors were probably the correct weight for a vessel of this power when towing with a warp/depth ratio of about 3 but were too heavy in shallow water showing a tendency to heel in excessively and fall over. The problem which this creates is that in shallower water the gear does not open properly with warp/depth ratio of 3 as there would only be 30 fathoms of warp out in 10 fathoms depth. The smaller doors worked better in the shallow water but had a tendency to fall in at lower speeds. What trial 1 showed is that excess weight badly affects door performance, and leads to compromised gear performance, excess drag and increased bottom contact.

Sea Trials 2: gear and procedure

These trials were again carried out on the "Crystal Dawn" (WD201) based at Greencastle. As the 1.5m vee doors used during sea trials 1 were deemed too heavy for the shallow water tows, a new set of 1.5m vee doors was commissioned from Blair of Dunbar (Figure 15). These new doors were specified to be nominally the same size as the old 1.5m set but have thinner plate to make them lighter. Instead of a tow arm a series of lugs was added so that any combination of tow chain length and height could be used. Each lug had 5 holes as shown in the photograph, one on mid door height with 2 above and 2 below. Two ballast plates for each door were specified in case weight needed to be increased.

Figure 15 1.5m light vee door

These doors weighed 82kg each without ballast plates compared with 144kg for the old 1.5m set, a reduction of ~45%.

Results - Trials 2

The first comparison made was between the 1.5m light vee door and the 1.5m heavy door used in trial 1 towed in about 12 fathom depth. The 1.5m light vee gave a bridle angle of 10.5° at 2.2 knots compared with 9.0° for the 1.5m heavy vee door. Also the bridle angle of the heavier door dropped much more rapidly below 2.2 knots. The reason for this can be seen in the door heel graphs which show the heavy door falling in rapidly as speed reduces. One problem this creates is that the heavy door may momentarily fall down completely and then fail to stand up again without towing faster.

Further tests showed that the 1.5m light door spread the gear in even shallower water giving 11.0° bridle angle in 8 fathom depth.

The tow chain was subsequently raised at the forward end as the doors had previously been running slightly pitched up. However, the adjustment did not work as it caused more heel in which in turn lead to more pitch nose up. This showed that as the door is lighter, heel and pitch are linked.

Another method was tried to reduce pitch by adjusting the towing chain attachment to give the same angle of attack but be towed from further aft. Tow chains allow a much greater range of adjustment than hinged brackets as the link into which the warp is shackled can be changed and the length of the chain can be shortened. However, adjusting more than one item can lead to confusion. This adjustment produced no noticeable change in pitch compared with earlier runs.

Subsequently the chain towing bracket was adjusted to the top position both fore and aft, effectively raising the towing point. This reduced the outward heel so the top plate was always heeling in compared with other runs at mid height. Having vertical adjustment of the warp bracket allows fine tuning of the door heel. Following this floats were attached to each door. While this did not produce much significant additional gear spread (13.0° bridle angle with floats and 12.5° without), it changed the heel characteristics of the doors especially at lower speeds. Without floats the maximum heel was -58°, and with the floats only -14°. This demonstrates what happens with doors which are lighter and have a lower centre of gravity.

Overall the conclusion from this trial was that in the case of trial 1, the doors are so heavy for the warp:depth ratio that the reaction force on the seabed is very high. The excessive weight and hence high reaction force creates a large moment which tips the door inwards. No amount of subtle re-rigging can counter this large moment. It is necessary to lower the towing point drastically, reduce door weight, lower the centre of gravity or add flotation to the top of the door as proved by the tests with the lighter doors in this trial

Further it was proven that for doors which do not have excessive reaction forces, there are two main force/moment adjustments which can be made to rebalance a door which has excessive inward heel.

- Either lower the towing point. This effectively means the top part of the door is providing a larger moment than the bottom part, and so the net effect pushes the door more upright.

or

- Move the lines of action of the warp and bridle relative to the centre of gravity of the door. If the lines are moved towards the face of the door away from the centre of gravity this will apply an additional moment to heel the door out. If the lines are moved towards the back of the door away from the centre of gravity this will apply an additional moment to heel the door in.

Sea Trials 3: gear and procedure

The third sea trial was carried out on the “Kay BB” (W203) based at Castletownbere (Figure 16). This vessel targets mixed demersal fish and *Nephrops*. The vessel is 14.9m registered length and has a 127bhp engine. It does not have a nozzle. The trawl was a standard general purpose trawl with 20 fathom fishing line and rigged with 46 fathom of single sweep and one fathom bridles.

Figure 16 "Kay BB" W203

The vessel normally uses a set of 1.5m vee doors with hinged towing arms (Figure 17). These doors are very similar to the original ones used in trial 1 at Greencastle, except the tow arm had four attachment holes instead of three. The skipper normally used hole 3 out from the door face. Twin backstrops were rigged instead of the vessels normal single to give better stability at lower towing speeds. The vee doors weigh 157kg each.

Figure 17 1.5m vee doors

The skipper had just purchased a set of Bison No. 3 doors (Figure 18) and these were compared directly with the vee doors.

Figure 18 Bison No. 3 doors

The Bison doors have ballast weights which could be added to the bottom of the door to increase weight and lower the centre of gravity. The Bison doors weigh 127kg with 5 ballast weights and 140kg with 7 ballast weights. The warp and bridle brackets have restraining chains which are attached to the door by shackles onto a vertical pin. The shackle height can be adjusted on the pin to raise or lower the warp and bridle attachment points. Because of the potential for bad weather at the time of year of the trials a number of tows were selected to give a lee depending on the weather direction.

Results - Trials 3

This trial was intended to help the skipper set up his new Bison doors to fish light on the bottom, applying the principles tested in trials 1 and 2. Due to the texture of the grounds fished little polish was obtained on the doors to assess the performance in one run compared with the next. For this reason the runs with increasing speed were abandoned in favour of towing at constant speed at the skipper's normal towing speed.

This trial contrasted the two extremes of door technical performance. Vee doors have a low spreading force per unit area whereas the Bison doors have a relatively high spreading force per unit area. This means that the Bison door area is much smaller than the vee for the same spreading force and gear opening. This allows the basic structure of the door to be lighter as there is less plate area for the same plate thickness.

If necessary, weight can be added to the Bison doors to make them the same weight as the larger area vee doors. The advantage that this has is twofold, firstly the Bison doors are initially lighter which means that they can be used with greater warp/depth ratios as used in shallow water tows, and secondly, when the ballast weights are added to the bottom of the door the centre of gravity is lower. Lower centre of gravity means the doors will stand up more quickly at lower towing speeds and hence spread the gear more at these lower speeds with minimal bottom contact.

With the vee doors it was found that the bridle angle was only 10° with 75 fathom of warp out in 26 fathom depth, but 13° with 100 fathoms out in 35 fathom depth. To get adequate spread in shallower water required more warp out but was detrimental to the vee door performance as they heel in too much and fish heavy on the bottom.

This same experiment was conducted with the Bison doors except the depth was kept constant. With 100 fathoms of warp shot in 35 fathoms depth a 11.5° bridle angle was found. With 125 fathoms of warp shot in the same depth (constant speed tow) the bridle angle increased to 14º. This was accompanied by more inward heel because of greater door reaction loads but this could have been reduced by taking out some of the ballast weights.

Further tests with the Bison doors, compared with the vee doors illustrated the difference in performance and stability of these two door types. Door angles of attack were estimated for the Bison door as between 37-39°, compared to 27°- 31° with the vee doors. At these angles both the Bison and vee doors were working at the maximum point on the spreading force curve but the vee doors were quite unstable and had a tendency to fall down. Conversely the Bison door seemed to fish efficiently with light bottom contact.

The main conclusion from this trial was that if doors are well balanced with the centre of gravity in a position where it neither tips the door, heeling it in or out excessively, it can be fished lightly on the bottom in a controlled manner. It also showed the benefit of door designs in which the weight can be easily changed to match depth and environmental conditions.

Partners 06 & 09

Partners 06 & 09 carried out a set of small scale engineering trials in September 2007 with the new ground gear concept based on vertical rubber plates lifted above the sea bottom by rolling bobbins was developed during the first part of the DEGREE project as reported in PAR 1. The groundgear concept had first been tested onboard the research vessel G.O.Sars in April 2007 (Valdemarsen, 2007). This test showed that the bobbins near the center of the gear were rolling along in the towing direction as the trawl was towed forward, while the rolling of the bobbins on the wings was hampered. Based on the assumption that the impact of bobbins rolling over the bottom impacts the bottom sediments and benthic life less than bobbins dragged sideways, a set of experiments with modified bobbins were conducted onboard the small research vessel RV “Fangst” (15m/49 feet) in September 2007. A full cruise report is provided in Annex 3.3.2.

The groundgear that was tested in the experiments was mounted on a small whitefish trawl with a fishing line of 17 m. The groundgear used is shown in Figure 19 below. In theory the bobbins were designed to lift the plates a few cm above the bottom in order to reduce the bottom impact relative to the standard rockhopper groundgear. The plates were mounted in a slightly lifting position in the middle section, and were vertically mounted on the wings. The four bobbins placed on the wings, two on each side, were mounted in a special frame between the plates so that the axis of these bobbins was 90^{o} on the towing direction in order to facilitate the rolling movement of the bobbins. The construction of the rolling bobbins is shown in Figure 20. Both steel bobbins with 9” diameter and plastic bobbins with 11” diameter were tested during the field trials.

Figure 19 The ground gear used for the experiment

Figure 20 9” steel bobbins monted in a circular steel frame with a shaft as diameter

The experiments with the rolling bobbins were all performed on fishing grounds close to the small town Kiberg in the outer Varanger Fjord, northern Norway. The fishing depth was 60 m, and the towing speed about 2.5 knots. Two self recording UW cameras were placed on the trawl to observe the behavior of the bobbins and ground gear setup. When the cameras were mounted on the headline, as was tested initially, the pictures turned out to be blurred. Therefore they had to be placed on the wings closer to the bobbins. Consequently it was not an easy task to adjust the cameras to focus exactly on the critical points of the ground gear. Some trial and error was used to obtain shots of acceptable quality.

In some experiments the bobbins frames were attached to the chain of the ground gear in front of and behind the bulb in such a way that the shaft of the bulb was perpendicular on the towing direction, while in other experiments the lock in front of and behind the bulb was loosened in order to let it rotate freely. To make the bobbins roll with the shaft horizontally, a clamp above the bulb was attached to the upper chain of the plate gear.

The results from the experiments that were performed are summarised in Table 6. A total of 11 trawl hauls were done with the different variants of rolling bobbins. A general observation was that the bobbins rack with shaft worked as assumed. The bobbins bulbs were rolling in the towing direction when these were locked in front of and behind the steel frame where the shaft was attached. Without an attachment point like this, the bobbins were accidentally observed to rotate, so that the rolling direction was skewed compared to the towing direction. The UW recordings showed that both the 9” and the 11” bobbins rolled as supposed, but that the 11” bulb made of plastic had a tendency to lift off from the bottom more often than the 9” steel bobbins, probably because of less weight. In addition to UW shots, the abrasion of the different parts of the surface of the steel bobbins was a good indicator on how the bulbs had been oriented during towing.

Table 6 Experimental setup with rolling bobbins and camera posistion during the experiments. (att. = attached)

		Positioning of different bobbins and observation status							
Haul no	Date	STB mid		STB front		BB mid		BB front	
		Bobbins	Obs.	Bobbins	Obs.	Bobbins	Obs.	Bobbins	Obs.
11	3.9	9”, att.				9”, loose	yes		
12	3.9	9”, att.				9”, loose	yes		
13	3.9	9”, att.				9”, loose	yes		
14	3.9	9”, att.		11”, att.	yes	11”, att.	yes	9”, loose	
15	3.9	9”, att.		11”, att.		11”, att.	yes	9”, loose	
16	4.9	9”, att.		11”, att.	yes	9”, att.	yes	11”, att.	
17	4.9	9”, att.		11”, att.	yes	9”, att.	yes	11”, att.	
18	4.9	9”, att.		11”, att.	yes	9”, att.	yes	11”, att.	
19	5.9	9”, att.		11”, att.	yes	11”, att.	yes	9”, att.	
20	5.9	9”, att.		11”, att.	yes	11”, att.	yes	9”, att.	
21	5.9	9”, att.		11”, att.	yes	11”, att.	yes	9”, att.	

The experiments showed that the principle with a shaft as diameter in a steel frame is a possible way to make the bobbins bulbs roll in the towing direction. A clamp over the bulb, as tested in the experiments, seemed to be useful for holding the bobbins upright. It was planned to assess the rigging further during the flume tank workshop planned under Task 3.6.

6.5 Initial evaluation trials and analysis of physical impact and biological impacts of doors and ground gears.

Partner 12

Partner 12 has completed testing and quantification of Italian otterboard designs and rigging modifications. A standard door type and a prototype door have been tested in flume tank tests and at sea on board a research vessel. The initial work was reported in PAR1. Comparative sea trials have aimed to assess the performance of an existing and a new door designs (traditional Grilli high efficiency *“AR”* door: 180x100cm, 270-360kg; and experimental Grilli *“Clark-Y”* door: 180x100cm, 250-325kg) and also measure the effect of modified rigging on both door types. Figure 21 shows the two door designs.

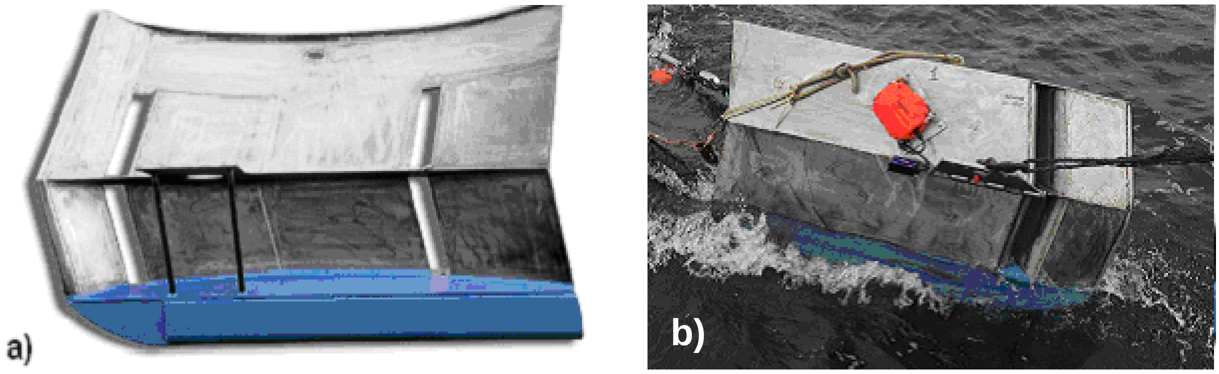


Figure 21: **a) traditional Grilli high efficiency *"AR"* door (180x100cm, 270-360kg); and b) experimental Grilli *"Clark-Y"* door (180x100cm, 250-325kg)**

Both the full-scale *AR* and *Clarck-Y* otterboards were tested in the Adriatic Sea, using the Italian Research Vessel "*G. Dallaporta*". All rigging components of the gear were identical with those commonly adopted in commercial practice in Mediterranean demersal trawl fisheries.

Testing of the doors was conducted in the course of three sea cruises on two different fishing grounds with depth ranges of 25-30 m and 60-70 m. The first and the third cruises (termed ST3.8[1] and ST3.8[3] respectively) took place from 31/05/07 to 05/06/07 (reported in PAR 1) and from 03/03/08 to 13/03/08 respectively at about 27 m of depth with a towing speed of 3.8 knots. The second cruise (termed ST3.2[2]) was conducted from 16/10/07 to 18/10/07 at a depth of about 66 m with a towing speed of 3.2 knots.

The trials illustrated the performance and impact on the seabed of the existing door and the new door design (*Clarck-Y* door) for demersal fisheries, discussing the differences between engineering sea trials and flume tank tests and also the differences between both trawl doors. For the purposes of the DEGREE project only the first of these is described. A full description of these trials is contained in Annex 3.4.1.

Overall, 12 valid hauls of the first cruise, 9 of the second and 8 of the third were analysed. In order to determine the effects of the current (Fiorentini et al., 2004), at least two tows on reciprocal courses were made for each gear arrangement tested. The otterboard to be used first was chosen randomly at the beginning of each trip, then the two otterboards were alternated on the same trawl. Adverse weather conditions prevented the same number of hauls from being performed with both otterboards. After the first two cruises it was realized that the prototype *Clarck-Y* door had poor spreading and shooting behaviour and hence were felt unstable. Therefore, in the third cruise the attachment of the chain backstrop brackets was moved 23 cm forward attempting to give a larger spreading force.

For all the hauls completed, a SCANBAS SGM-15 system (SCANMAR, Norway) was used to measure the gear performance: door spread, horizontal net opening, heel and pitch angle of the doors. Moreover, two MICREL (France) underwater force sensors were inserted just in front and in the backside of the port-door to measure the drag ahead and behind the otterboard. All the instruments were linked by RS232/485 serial ports to a personal computer, which automatically controlled data acquisition and provided real time data collection through an appropriately developed *Microsoft Visual Basic 6.0* program.

In order to compare full and scaled otterboards, the forces were balanced and then the spreading, drag and down-force of the full-scale otterboards were obtained. These forces in the case of scaled door are known as a function of angle of attack and heel angle with zero pitch angle, however angle of attack of the full-scale door was unknown, and a model was developed to calculate the angle of attack form the sea trials (see Sala et al., 2009). For the calculation of forces and coefficients of drag, lift and down-force as well as the angle of attack in sea trials refer to Sala et al. (2009).

Results

6.5.1 Full-scale engineering tests of otterboards

The performance of each otterboard was ascertained over a range of angles of attack. These angles, calculated on the basis of the model developed by Sala et al. (2009), were achieved by adjusting the warp attachment position to the otterboard (HF) and in the cruise ST3.8[3] by also modifying the attachment of the chain backstrop brackets which was moved 23 cm forward. The testing procedure adopted gave accurate and consistent results defining the performance of trawl doors in sea trial conditions. Coefficients of drag, lift and down-force (CD, CL and $C_Z^{'}$ respectively) for each cruise are shown in Figure 17 as a function of angle of angle of attack. The confidence region is due to the sea cruise variability. Results for the cambered vee *AR* door showed higher values of both drag and lift coefficient than the experimental *Clarck-Y* door (Figure 22 and Figure 23). The behaviour of the drag coefficient in both doors presented some differences: with the *AR* door it rose steeply with angle of attack while in the *Clarck-Y* it increased steadily. The lift coefficient tendency is different in both doors: it reached a maximum for the *AR* door but it increased with the angle of attack for the *Clarck-Y* door. Apparently, for a given angle of attack, the *Clarck-Y* showed an evident higher efficiency (Figure 24), however, displayed corresponding poor shooting behaviour and lower door spread performance. Sometimes the otterboard tended to be unstable (heterogeneous measurements of door spread and tensions). For this reason the drag of the *Clarck-Y* was very low compared to the *AR* door and had a higher efficiency. Fine adjustment of the attachment of the chain backstrop brackets, and consequently of the angle of attack, carried out just before the third cruise proved to be necessary as the instability disappeared and the door spread improved, conversely in such conditions, the *Clarck-Y* provided evidence of lower performance than the *AR* door.

In Figure 22, it can be seen as the down-force coefficient $C_Z^{'}$ is towing speed dependent and, for a any given speed, it is similar for both door designs. The absolute value of $C_Z^{'}$ ranges between 0.31-0.50 at the towing speed of 3.8 knots, and it reaches higher absolute values (0.60-0.93) at 3.2 knots. For each warp attachment position (HF), estimated values of angle of attack, heel and pitch-angle and corresponding drag, lift and efficiency-coefficient for both the doors have been summarized in Figure 24. In both doors, the angle of attack, heel and pitch increased as warp towing point (HF) was moved aft. Moreover, the differences in angles of attack between consecutives towing points are not constant and, in fact, these differences are smaller as towing point moves aft (or as hole number increases). Comparing both doors, it was noticed that the *Clarck-Y* worked with bigger heel and pitch-angle than the *AR* door. In terms of performance of the full-scale door spread, important for door manufacturers and fishermen, the estimated values of door spread calculated showed that the horizontal door spread of the full-scale traditional *AR* door was higher than that of the experimental *Clarck-Y* door by up to 26%.

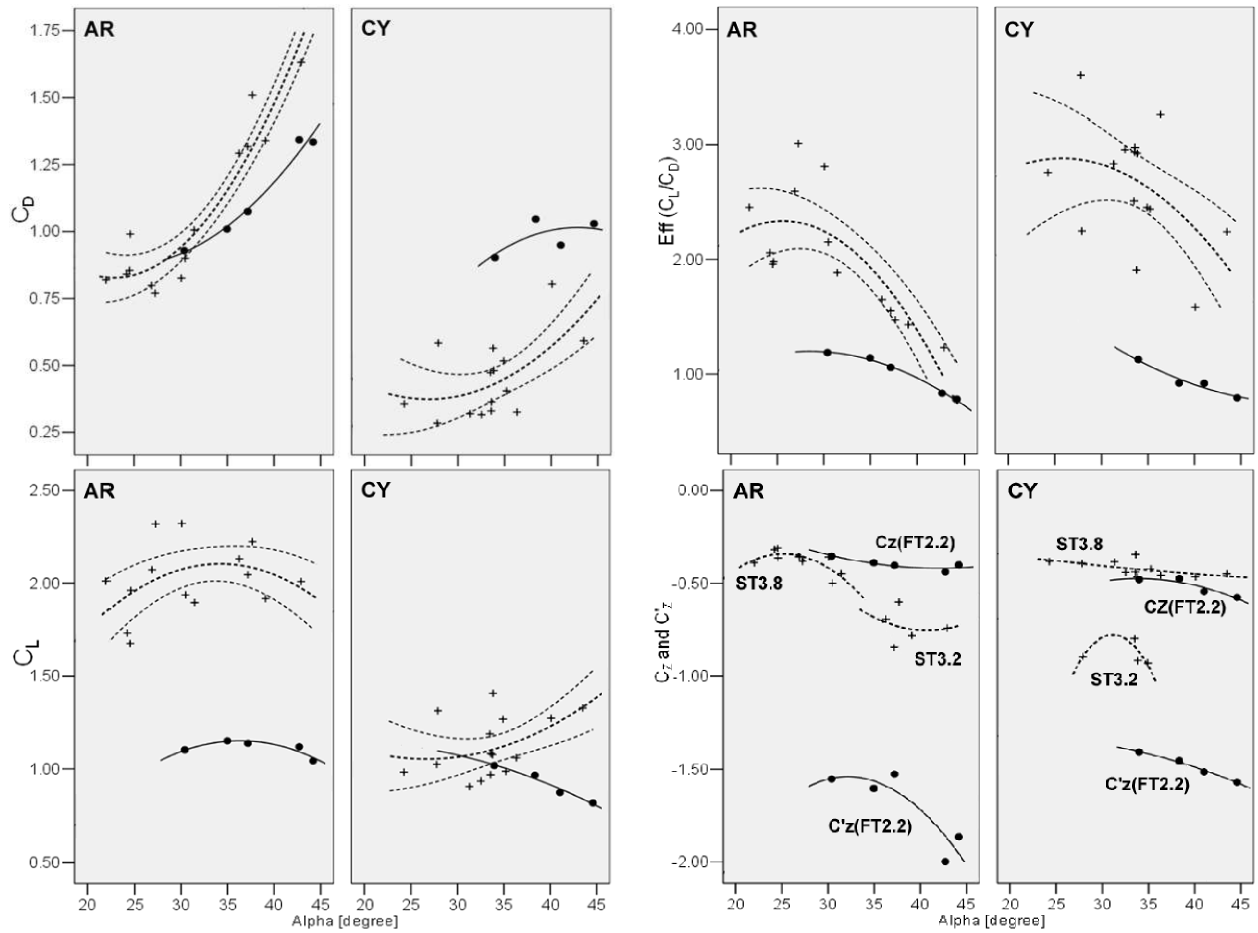


Figure 22 Drag-force coefficient, (C_D); lift-force coefficient, C_L; efficiency coefficient, Eff(C_L/C_D); hydrodynamic down-force coefficient, C_Z and down-force coefficient, C'_Z, with attack angle, Alpha: comparison between the experimental flume-tank (circle points and continuous lines) and full-scale (cross points and dotted lines) obtained on the Cambered vee *AR* (AR) and *Clarck-Y* (CY) otterboards. In the last graph on the right, the hydrodynamic down-force coefficient, C_Z(FT2.2), obtained in the flume-tank experiment at 2.2 kn has been reported together the C'_Z data, C'_Z(FT2.2). The C'_Z data attained during the sea trials at towing speed of 3.2 (ST3.2) and 3.8 kn (ST3.8) have been also underlined.

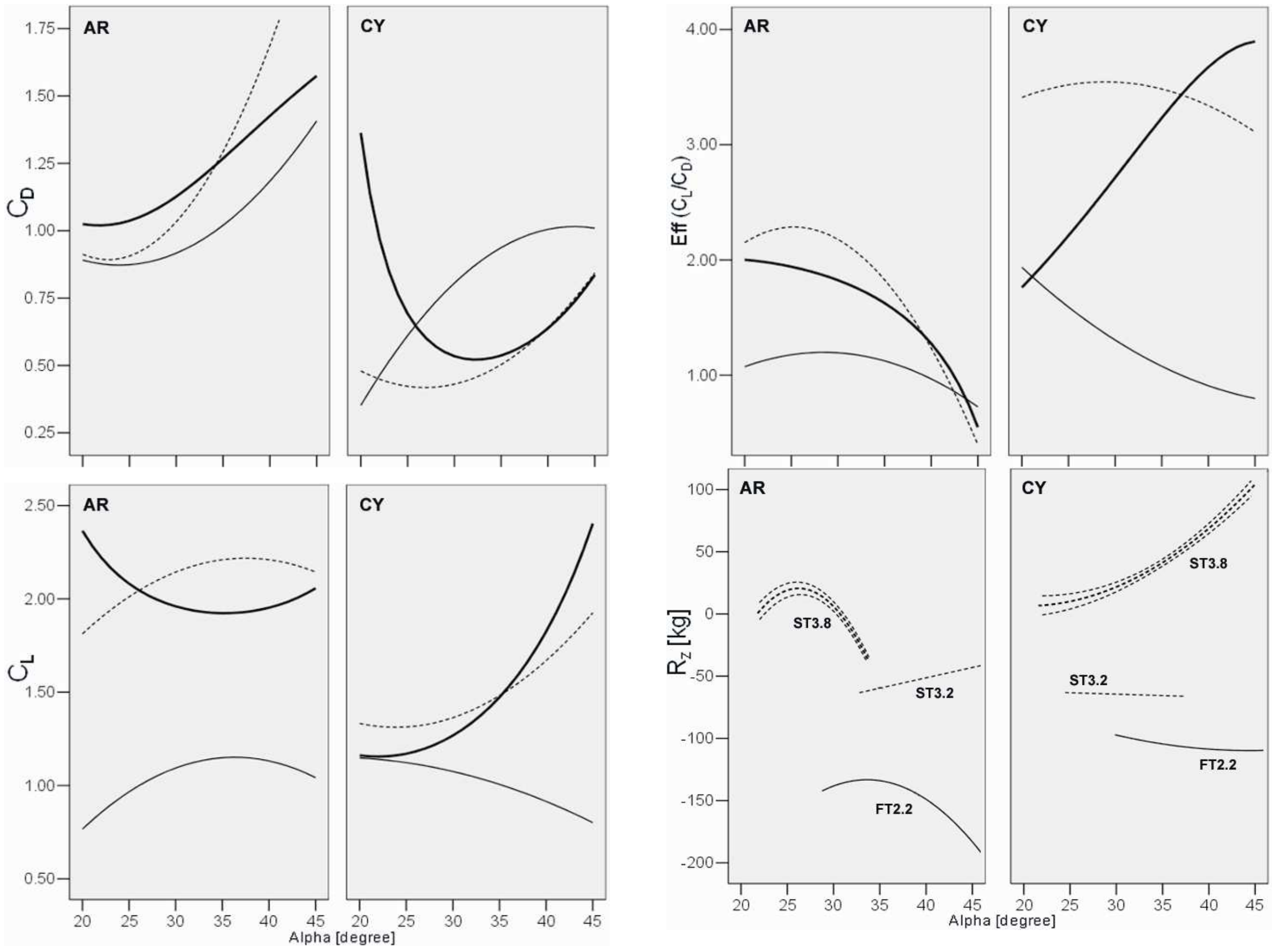


Figure 23 Statistical models at 0° of heel for the drag-force coefficient (C_D), lift-force coefficient (C_L), efficiency coefficient (Eff(C_L/C_D)) and reaction force (R_Z[kg]) with attack angle (Alpha): comparison between the flume-tank (continuous line) and full-scale (dotted line) obtained on the Cambered vee *AR* (AR) and *Clarck-Y* (CY) otterboards. The bold line represents the ratio between the full-scale and the flume-tank test. For R_Z[kg], the data of the flume-tank experiment carried out at 2.2 kn (FT2.2) and full-scale attained at towing speed of 3.2 (ST3.2) and 3.8 kn (ST3.8) have been underlined.

Figure 24 Estimated values of traditional- (AR) and experimental (CY) doors for the flume-tank, FT(0); sea cruises at 0° of heel, ST(H0) and when heel is free to vary, ST(H). Heel angle of otterboard (φ); warp attachment position to the otterboard (HF); attack angle of otterboard (α); pitch angle of otterboard (θ); drag force coefficient (C_D); spreading force coefficient (C_L); efficiency of otterboard (Eff).

Door			φ [deg.]	HF	α [deg.]	θ [deg.]	C_D [-]	C_L [-]	Eff [-]
AR									
	C_{LMAX}	FT(0)	0.0	-	36.3	-	1.05	1.15	1.09
		ST(H0)	0.0	2	29.3	8.6	1.12	2.30	2.05
		ST(H)	4.7	3	34.2	11.2	1.05	2.10	2.00
	C_L=Eff	FT(0)	0.0	-	34.1	-	1.00	1.14	1.14
		ST(H0)	0.0	2	26.7	8.6	1.00	2.24	2.24
		ST(H)	4.2	3	32.8	10.9	1.00	2.10	2.10
	Eff_{MAX}	FT(0)	0.0	-	28.5	-	0.89	1.06	1.20
		ST(H0)	0.0	1	21.5	8.6	0.74	1.76	2.38
		ST(H)	2.5	2	25.6	10.0	0.85	1.98	2.34
CY									
	C_{LMAX}	FT(0)	0.0	-	-	-	-	-	-
		ST(H0)	0.0	3	39.7	11.0	0.45	1.55	3.44
		ST(H)	-	-	-	-	-	-	-
	C_L=Eff	FT(0)	0.0	-	39.3	-	1.00	0.93	0.93
		ST(H0)	0.0	-	-	-	-	-	-
		ST(H)	16.5	6 *	47.4	19.2	1.00	1.48	1.48
	Eff_{MAX}	FT(0)	0.0	-	-	-	-	-	-
		ST(H0)	0.0	2	31.5	11.0	0.40	1.41	3.56
		ST(H)	7.2	2	25.8	12.8	0.37	1.05	2.88

C_{LMAX}: maximum spreading force coefficient; C_L=Eff: optimum condition at a given attack angle when C_L=Eff and with different attack angles decrease one of the two; Eff_{MAX}: maximum efficiency of the otterboard.

Note: (*) the warp attachment position to the otterboard, HF=6, does not exist. The statistical model estimated, for that attack angle (α), a backward attachment position to get larger attack angle.

Results related to performance of otterboards such as the drag, lift and pressure coefficients and the attack angle have been measured. An accepted indicator of the impact of the otterboard on the seabed such as the reaction force has also been calculated. In flume tank tests both doors not only presented a similar behaviour with angle of attack but also similar magnitude of drag, lift and efficiency coefficients. When comparing both doors in sea trials, however, there are important differences, for instance, the *AR* door works with a higher drag and lift force as well as a larger spread but lower efficiency (C_L / C_D) than *Clarck-Y* door.

As a main result of this work, estimated values of attack, heel and pitch-angle and the corresponding horizontal door spread, drag, lift and efficiency-coefficient in sea trials condition for each warp attachment position to the doors have been calculated. This is useful information both for door manufacturers and fishermen: the maximum lift and the optimum behaviour estimated for the *AR* otterboard were for the third attachment warp position. For *Clarck-Y* door, the estimated optimum condition might have been reached at a fictitious aft warp attachment position (i.e. moving 55 mm further backward from the existing last one).

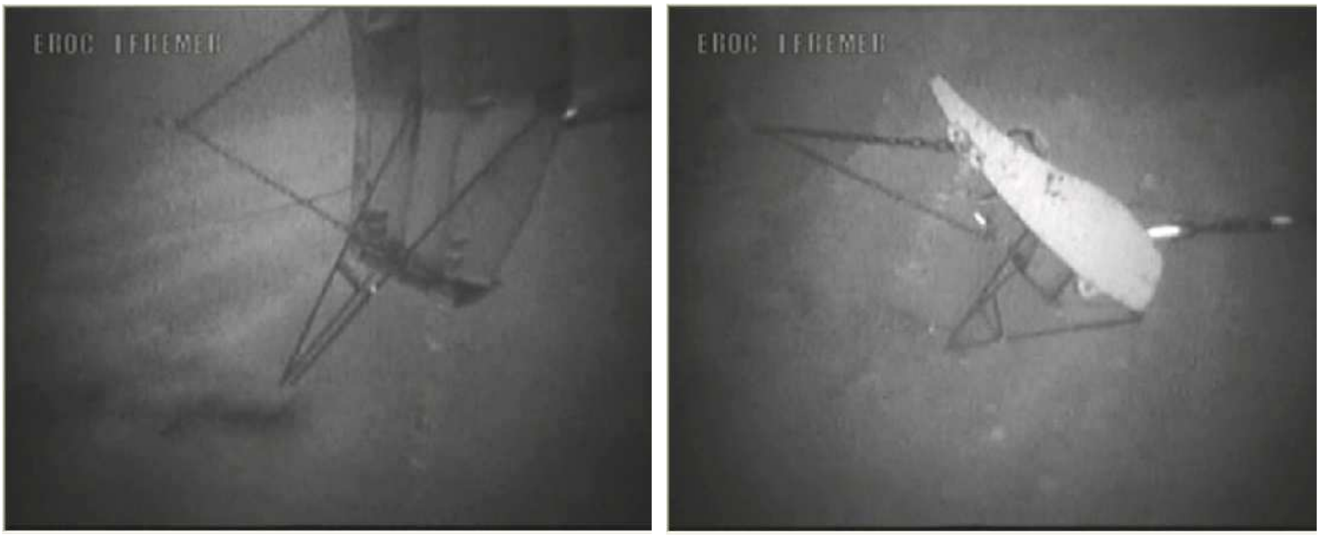
Finally, some conclusions of the door's impact on the seabed studying the reaction force can be made. In the flume tank test the reaction was measured and it was found that for a given angle of attack, it was smaller for the prototype *Clarck-Y* door than the *AR* door. For sea trials data, a prediction of reaction force has been calculated considering equivalent hydrodynamics for the flume tank experiment. In sea trials the estimation of reaction force was strongly dependent on towing speed, in particular the reaction force decreased when towing speed increased. In particular, *Clarck-Y* presented positive values of reaction force (i.e. the door lifted off the bottom) when towing speed is around 3.8 knots, which indicated poor warp and backstrop rigging.

Partner 05

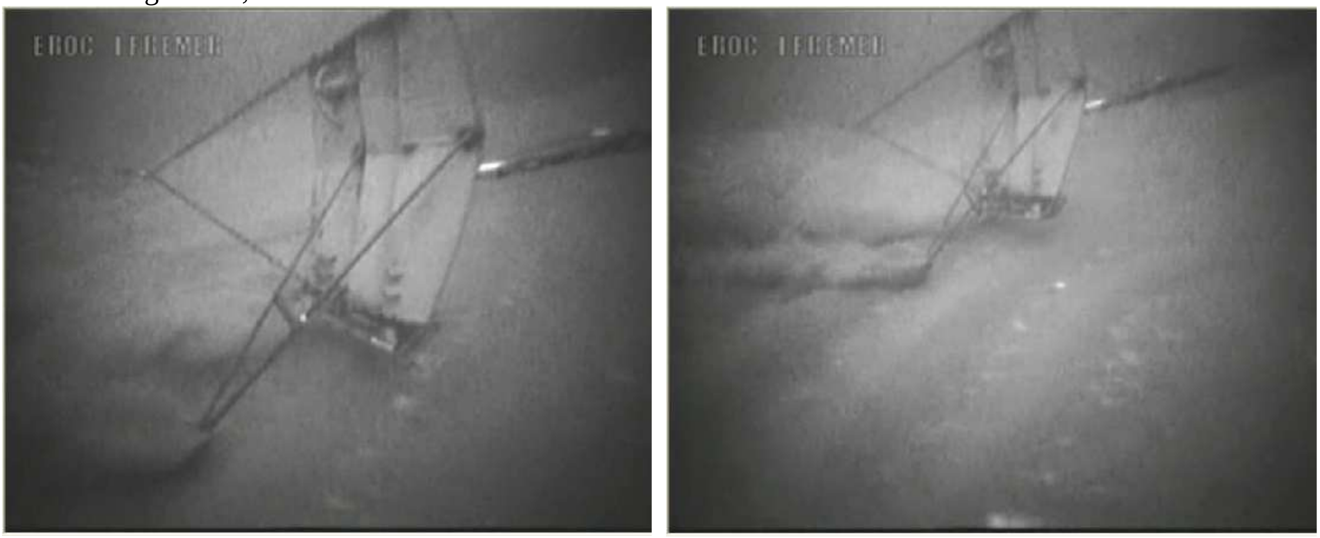
Partner 05 tested a door prototype, constructed by Morgère on the basis of new SPH doors resulting from hydrodynamics optimisations previously reported under Task 3.2 of PAR 1. The prototype doors (surface 2 m², weight about 330 kg) were equipped with different arm systems made of steel round bars (Figure 25). Three configurations were tested. See Annex 3.2.1 for full details of these trials.

Figure 25 New SPH door resulting from optimisation study, with arms. Shoe is equipped with force sensors

The door was tested on different soft sand and/or muddy sediment types as shown in Figure 26 below. The stability of doors & arms were observed using the ROV EROC (towed submersible vehicle equipped with video). The results were encouraging although some reduction in door spread with the prototype door was noted.



In this configuration, the door shoe is far from the seabed. Front view and view form above



In this configuration, the door shoe is almost in contact with the seabed (sand clouds)

Figure 26 Different views of the prototype door with arm system tried at sea

No trials where undertaken on hard bottoms and due to the novel design of the prototype it was not possible to measure the force or pressure on the seabed. Thus these trials were very much used as a proof of concept to verify the results from the earlier flume tank testing and also to observe the performance and handling of the prototype.

The overall conclusion from this trial was that the prototypes were stable and efficient but that it would be difficult or impossible to use these doors commercially, especially on small fishing vessels due to their shape. Potential handling problems with the doors were observed in that the arms had to stay outside the trawl gallows and could not be stored as per standard doors. Also concerns were expressed regarding the strength of the arms themselves.

On the basis of these trials and from the previous flume tank analysis, it was therefore concluded that there was no need to design a door with such an elaborate arm system as simple “standard” doors (e.g. Morgere WV door), with a high “height / width” ratio already exist. The pronounced V shape of such doors ensure bigger distances of L and D as shown in Figure 27 than standard bottom trawl doors with very low “height / width” ratio and so corresponding low distances L even if they have a pronounced V shape. The higher the door is, with high centre of gravity (small distance between O and G), the better the door is from the point of view of impact. However, stability problem must be considered when putting the centre of gravity at higher levels.

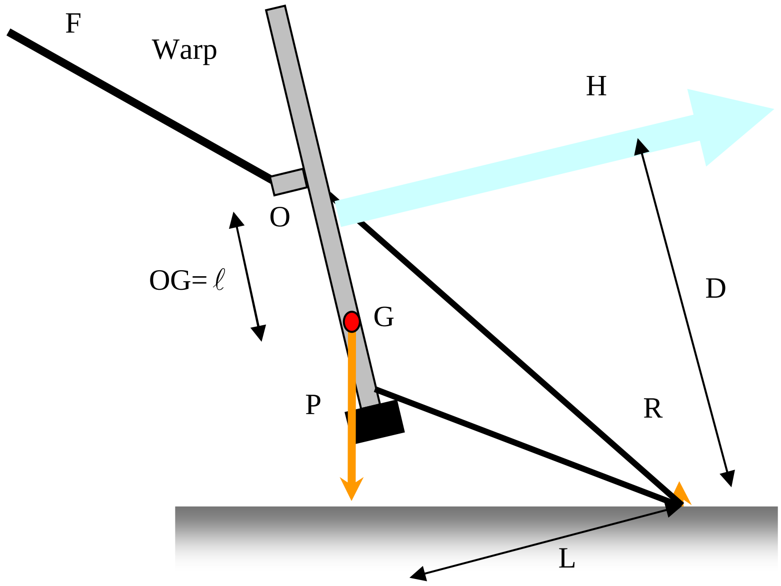


Figure 27 : Forces, distances and angles considered to describe the door balance.

Following these key concepts for a "low impact door" design, high ratio height to width ratios will lead to better hydrodynamic performances, lower impact on the seabed and lower energy use but potentially will be much less stable, particularly at lower towing speeds. It also must be noted that such doors would develop only limited, small sand clouds leading to potential avoidance by certain species that are sensitive to herding.

Taking all of these factors into consideration it was thus decided by Partner 05 to look at an intermediate option between a "standard optimised doors" as described above and a door with an arm system. This led to the development of a design a door with monolithic shape but with high distance L and D created by making the door with a very pronounced vee shape.

The main advantages of such a design were identified as:

- A smooth and progressive shape in the lower door part to avoid hard bottoms;
- An end-profile to give water flow recirculation lowered by the progressive (possibly elliptic) shape giving better hydrodynamic performance;
- A high shape ratio for better hydrodynamic performance.

and:

- Almost no re-suspension;
- Contact on the seabed reduced by approximately magnitude of 10;
- Reaction force on the seabed reduced by approximately a magnitude of 5 to 10;
- Possibility to orient the shoe in the towing direction, so as to avoid deposit abutment; and
- Possibility to add damper system between the lower part of the door and the upper profile to make the action on hard bottom smoother.

A prototype of the monolithic door has been designed and was trialled aboard the research vessel “Gwen Drez” during an eight day cruise in May 2008. Underwater video was taken using EROC (Figure 28) and all work was carried out on soft sediment (sand/mud).

Figure 28 : views of the new Jumper door (and EROC submersible on the right view)

Again given the unique shape of the prototype door, measurement of physical impact was not possible, so the trials concentrated on proof of concept and handling and performance.

The adjustment of the rigging (towing bracket and backstrops) was found to be critical. It took some time to find a suitable configuration as the centre of gravity centre of this door is rather high compared to standard doors and poor adjustment led to instability. On adjustment, however, from the extensive video footage obtained, bottom impact was observed to be almost negligible when warp:depth ratio was correctly set. When compared to the standard doors set in order to have very low impact, the new “Jumper” doors were found to be less sensitive to towing speed variation (or under currents) and depth variation as they self adjusted in order to maintain low impact. In normal configuration the vertical component of the warp is rather large and the door weight is relieved by this force, so the force on the seabed is not that large. This was verified from the underwater footage which showed the shoes just lightly touching the seabed (Figure 29).

Figure 29 : EROC video of Jumper doors on sandy bottom. In this configuration, impact is almost negligible.

It was concluded from these trials that with further modification the “jumper” doors have potential but need further testing under commercial conditions to assess performance in terms of spreading and stability as well as catch rates given the lower impact and reduction in herding through smaller sand clouds.

Partners 06 & 09

Partners 06 & 09 carried out a cruise to test the catch efficiency of the new plate ground gear developed and compare it against a conventional rockhopper gear commonly used by the Barents Sea demersal trawl fleet. The full cruise report from these trials is given in Appendix 3.4.2. The comparative fishing trials were conducted onboard the commercial stern trawler Granit F-23-VD (Loa 56, BT 1345) on fishing grounds close to Bear Island and Hopen in October 2007. In all 42 hauls were carried out with 22 hauls giving valid data. The other hauls were excluded from the analysis due to gear rigging problems. The first nine hauls were taken on grounds at Bear Island. On these fishing grounds two of the target species, cod and haddock, were caught in suitable amounts, but only a few saithe were caught. It was therefore decided to change grounds to Hopen after haul 10. However, on these fields only cod gave reasonable catches. After haul 28 the fishing grounds were again changed, this time to grounds west of Bear Island. Saithe were not found, but a good mix of cod and haddock were caught.

The fishing trials were carried out as a twin trawl catch comparison experiment. To minimise bias and to avoid differences in location influencing the catch data, the rockhopper and the plate gear trawls were alternated between the port and starboard sides. Trawling speed was kept at around 4 knots and towing time varied between 3 to 5 hours. The catch (or a subsample of the catch when the catches were large) was split into species, and length measured and counted. Catch differences were analyzed using a one way Anova on log transformed data.

The trawl nets were modified Selstad 444 trawls, which is standard trawl design used in the Barents Sea. One trawl was rigged with a rockhopper ground gear as normally used by this fleet segment with the other rigged with the plate gear developed. It consisted of vertical rubber plates, which in the first 12 hauls were divided into eight sections by seven 16” bobbins, three on each wing and one on the mid-gear. This rigging is called Rigging 1. As there seemed to be diminishing catch rates through these hauls, it was decided to change the rigging of the experimental ground gear. Two hauls were then done with nine 16” bobbins instead of 7 (Rigging 2), but this was soon changed to two 16” bobbins on the wings (one on each) and 14” on mid-gear, the other bobbins replaced by plates (Rigging 3). This rigging was maintained for the rest of the cruise (9 hauls). The hauls taken with Rigging 2 are excluded from the analyses because of the low number of replicates. At the end of the cruise period a few hauls were performed where the two outer bobbins on the wings were specially designed to always roll in the direction of the trawl path (Rigging 4). These hauls were carried out primarily to test the functionality of this setup, and the data is not included in the catch analysis.

Results

A summary of the catches of cod and haddock with Rigging 1 and Rigging 3 are given in Table 7 and Table 8 below. The catches from the two hauls with Rigging 2 are included in the total catches but not reported separately as the data is limited. The number of rockhopper hauls is larger than plate gear hauls because two hauls with Rigging 1 and one haul with Rigging 3 were taken with rockhopper gear on both trawls.

Table 7 Average catches of cod per haul taken during the experiments. ns means no significant difference between plate gear and rockhopper trawls (One-way Anova on log transformed data).

	Total			Rigging 1			Rigging 3		
	N	Mean	Std	N	Mean	Std	N	Mean	Std
Plate gear	21	1952	2892	12	2660	3699	7	745	279
Rockhopper	25	1959	3309	14	2851	4241	9	585	252
Difference		ns			ns			ns	

Table 8 Average catches of haddock per haul taken during the experiments. ns means no significant difference between plate gear and rockhopper trawls (One-way Anova on log transformed data).

	Total			Rigging 1			Rigging 3		
	N	Mean	Std	N	Mean	Std	N	Mean	Std
Plate gear	21	3193	5017	12	2740	5337	7	4879	4957
Rockhopper	25	2366	4197	14	2253	4765	9	3067	3739
Difference		ns			ns			ns	

The variation in the amount of catch was considerable, as usually found in catch data, and statistical analyses were therefore carried out on the log transformed data. No significant differences were found between the two ground gear types tested. There was a tendency that the plate gear caught more haddock than the rockhopper gear, but the difference was not statistically significant. Figure 30 and Figure 31 shows the difference in catch weight between the two types of ground gears presented haul by haul. Valid hauls are given in chronologic order. Bars above the horizontal axis show that catch rates are higher in plate gear than rockhopper trawl. Bars below show catch rates higher in rockhopper trawl. From these charts it can be seen that there was no real trend in relative catches over time.

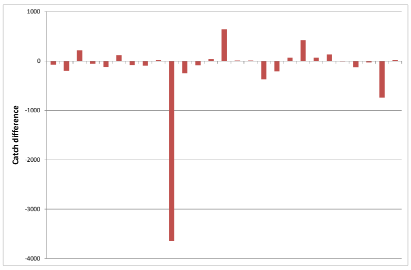


Figure 30 Catch differences of cod between the rockhopper and the plate gear

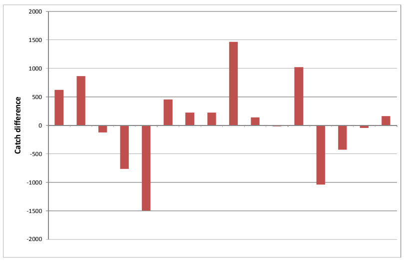


Figure 31 Catch differences of haddock between the rockhopper and the plate gear.

Figure 32 shows the length frequencies of the catches of cod and haddock taken by the different trawl gears. This indicates there is a tendency for the plate gear trawl to catch caught larger cod than the rockhopper gear, although the difference is marginal and not statistically significant.

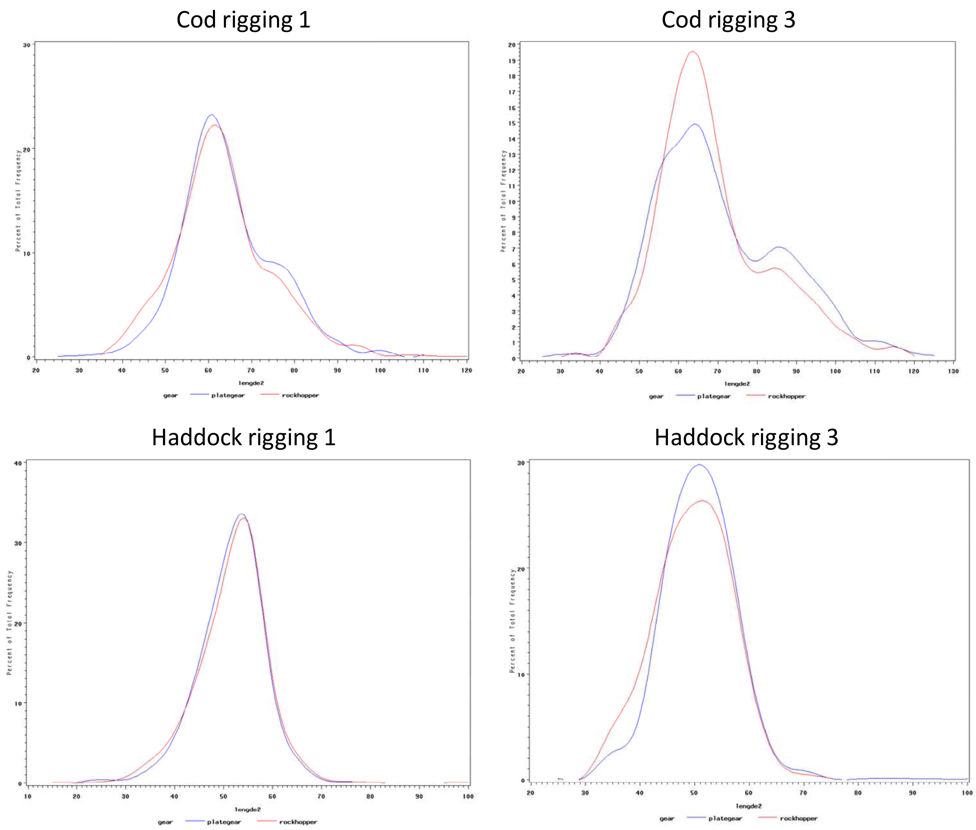


Figure 32 Length distributions of cod and haddock in the catch experiments

Red curve is rockhopper gear and blue is plate gear

These experiments did not show any catch increases or decreases with the new plate ground gear. There was no apparent difference in cod catches between the new and the old ground gear and although there was a tendency for the new gear to catch more haddock, this difference was not statistically significant.

During the experiment it was observed that the stability of the plate gear was not optimal. Angle sensors placed on the gear showed that although the plates were rigged to keep certain angles relative to the bottom, these angles were difficult to maintain during prolonged towing. It seemed that this instability lowered the catch rates. This prompted further testing of the plate gear in the flume tank to develop ways to stabilize the plate gear rigging. These tests were carried out as part of Task 3.6 reported below.

6.6 Flume Tank Workshop

Partners 05, 06, 07, 09 and 12

A flume tank workshop was held in Hirtshals in March 2008 with participation from all partners involved in WP3, as well as participants from WP2. The workshop had a number of objectives as follows:

1. To demonstrate the concepts tested during the sea trials completed by Partner 07. This is detailed in Annex 3.6.1.
2. To demonstrate the prototype door developed by Partner 05. This is reported in Annex 3.2.1.
3. To demonstrate the prototype groundgear and bridle/sweep arrangements developed by Partners 06 and 09. This is reported in Annex 3.3.2.

On the basis of this workshop a further planning meeting for the final research cruise on the "GO Sars" was held immediately after the workshop. At this meeting the methodology, instrumentation, personnel and provisional timetable for this cruise were discussed at length. This is summarised in the minutes for the 3rd project meeting (Annex 1.1.1).

A further workshop was held by Partners 06 and 09 in Hirtshals in September 2009 with Russian and Norwegian fishermen and fishermen's organizations. Flume tank demonstrations, video footage and oral presentation were given about the Degree trawl and also the operation of trawl doors to fish with low impact. The details of this workshop are given in Annex 3.6.2).

6.7 Final research cruise integrating the gear modifications in to one trawl, including measurements of physical and biological doors and ground gears.

A final research cruise comparing the physical and biological impact of the bottom trawl modifications developed during the DEGREE project to a standard bottom trawl used in the Barents Sea cod fisheries was completed in November/December 2008. This cruise was co-ordinated by Partner 06 with participation from Partners 05, 07 and 09 as well as participants from WP2. The methodology employed and the results are summarised below and a full cruise report is given in Annex 3.6.1.

Main objectives

The main objective of the cruise was to compare physical and biological bottom impact and relative catch rates from a bottom trawl rigging developed during the DEGREE project (the "plate gear trawl") with a standard bottom trawl used for cod fisheries in the Barents Sea (the "rockhopper trawl").

- The "plate gear trawl" or "new trawl" was rigged with a modified plate gear consisting of seven specially designed bobbins and plates between them, and with trawl doors rigged to barely touch the bottom

- The "rockhopper trawl" or "old trawl" consisted of a conventional rockhopper gear with doors rigged to go steady on the bottom.

Materials and methods

The experiments were carried out on board the research vessel RV "G.O. Sars", owned by Partner 06. The vessel (LOA 77.5) is well suited for trawling, having a 18 m wide trawl deck with four trawl winches and room for two sets of trawl doors. It is also suited as a platform for running ROVs, being equipped with DP (Dynamic positioning system) and HIPAP (hydro acoustic positioning system). Several grab systems exist on board for taking bottom grab samples, for measuring seawater condition (STD) and others. In addition to normal echo sounders and sonar, it is equipped for detailed multi-beam mapping of the sea bed topography using an Olex system.

The area of operation was in the Varanger Fjord, northern Norway (Figure 33). This area with shallow waters is well protected from most winds directions (except for easterly) and has almost no undercurrent, which ensures good working conditions for carrying out engineering trials with rather low variability in physical measurements. This also makes the area well suited for studies of bottom impact, i.e. running ROV. Trawling in this area is prohibited, which enabled the trials to be carried out in an area with pristine sea bottom without visible tracks from previous trawling activity.

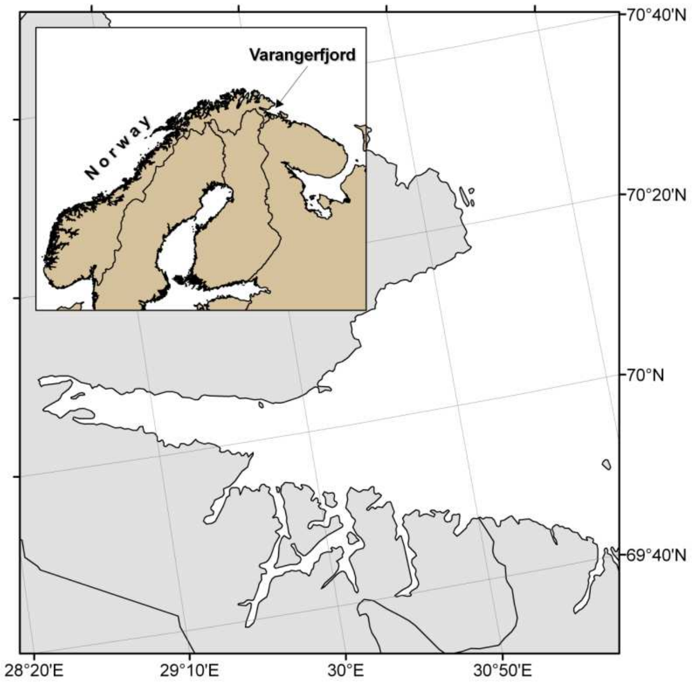


Figure 33 The experiments were conducted in the inner part of the Varanger fiord in northern Norway not far from the Russian border.

<u>Trawl Design</u>

Three days prior to the start of the cruise, a team of five gear experts participating gathered in Tromsø to build the trawl gears and to rig the trawls for the planned experiments. The same trawl was used in all experiments. The trawl type was a modified "Selstad 444". The headline and fishing line length were 45.6 m and 25.4 m respectively. The vertical opening was about 4.4 m. The net material was 155 mm PET and 145 mm PET in the codend. The sweep arrangement for both trawls was identical. The total length of sweeps was 105 m and was divided into three main parts split by discs/bobbins. Full details of the trawl, trawl doors, sweep arrangement and groundgears are given in Annex 3.7.2.

<u>Trawl Doors</u>

The same Type 12 120" Thyborøn doors were also used for both trawls although different rigging arrangements were used for the rockhopper and the plate gear trawl. When trawling with the rockhopper gear the doors were rigged as standard for bottom trawling in the Barents Sea, with good bottom contact in order to make the trawl spread well, and to create mud clouds to herd fish. With the plate gear trawl the doors were rigged with minimal bottom contact. The sweep length and attachment point of the doors for the two trawl riggings to achieve these arrangements were verified from a set of engineering trials.

<u>Rockhopper Groundgear</u>

The rockhopper groundgear was built up of rubber disks mounted on chain. The discs were ~450mm (18") in the mid sections and ~420mm (16") at the wing ends. The distance between the discs was 21 cm (8") in the middle and 42 cm (16") at the wingends. Between the discs, rubber packers of 21cm (8") were inserted. Rockhopper groundgear is traditionally rigged to touch the bottom along its length. In addition the discs do not roll, but are connected directly to the fishing line of the trawl. This causes friction between the bottom and the ground gear along the whole cross sectional area of the groundgear.

<u>Plate Gear</u>

The modified plate gear was constructed with rubber plates 500 mm x 540 mm. Seven specially designed steel bobbins were inserted between the plates to lift them of the bottom. Three 406mm (16") bobbins placed in the midsection of the groundgear were mounted directly on a 19 mm chain between the plates. Four bobbins, two on each side, were mounted in a special frame between the plates. In theory the bobbins were designed to lift the plates 70 mm above the bottom. The plates were mounted in a slightly raised position in the bosom of the groundgear and vertically at the wingends. One problem with the original plate gear was its sensitivity to the angle of attack of the plates relative to the tow direction. With the original plate gear, a single incorrect connection of the gear to the fishing line in the setup reduced fishing efficiency. For this cruise, the groundgear was re-rigged by connecting the plate gear to a wire attached to the fishing line. This setup made the gear self-adjusting and therefore not so sensitive to changes in angle of attack. This had been verified prior to the trials in the flume tank.

Modified danleno and sweep lifter

Experiments to reduce the bottom impact from the danleno (the danleno is the bobbins on the aft end of the sweeps) and the sweeps in front of the groundgear were also undertaken on the cruise. The new design consisted of two bobbins mounted on an axle fastened 90° from the sweep direction. The rolling directions of these bobbins were design to better orientate them to the towing direction than the conventional way of rigging the danleno directly onto the sweeps. On the basis of the engineering tows, it was found though that the new design did not act as expected, and this design was therefore not used subsequently during the impact tows.

Documentation of trawl performance

The performance of the trawl was visually inspected using the towed underwater vehicle FOCUS fitted with a lowlight SIT camera and scanning sonar. This was used to evaluate the bottom contact of doors and ground gears as well as the trawl configuration. The trawl was equipped with different sensors in order to assess working parameters and behaviour.

- Geometry sensors were used to measure headline height, door to door distance, door depth, tilt and pitch angles of doors and sensors to measure the angle of the plates on the gear;
- Sounders also measure the seabed depth;
- Warp length and warp tension were measured;
- The speed over the ground was measured by an electromagnetic speed sensor placed on the headrope. This speed was used as reference speed for all the experiments as it enables the integration of possible undercurrents, which can highly affect the trawl gear behaviour; and
- A tension meter was mounted between the doors and the sweeps behind each trawl door to measure the tension of the sweep. However, one did not work properly. Therefore tension was only measured at one side at the time. In addition warp tension was measuredfrom sensors mounted on the winches.

Data from the different sensors were logged and stored in a database onboard the vessel.

Engineering trials

A series of tows were performed prior to the experiments of bottom impact to fine tune the plate gear and danleno arrangement and to establish the correct settings for the doors for both the rockhopper and plate gear trawls. For these trials the following methodology was used:

- A door depth sensor was used to assess its height over the seabed
- A headrope height sensor (vertical opening of the trawl) was used to assess the plate gear contact on the seabed using the image provided by this sensor: the seabed, the ground gear and the head rope were represented on the screen which enables to determine the moment at which the ground gear lifts off the bottom. For instance, for some measurements, the vertical trawl opening was bigger than the

standard opening (around 4.4 m for the trawl considered). However, the plate gear could still be on the seabed, which ensures a good fishing efficiency for the plate gear.

The experimental protocol:

- Speeds over the ground were changed in order to observe the door lifting off the bottom. The minimum speed was 2.5 knots to avoid the groundgear digging into the mud. The maximum speed was around 3.3 knots, where the doors were clearly observed off the bottom for a reasonable warp length.
- The speed increase steps were chosen so as to observe the moment when the doors lifted off the bottom (series of measurements were done just before and after they lifted off the bottom). Thus, the speed step was reduced around this critical speed (around 0.1 knot).
- For the plate gear trawl the warp lengths were chosen such that they maintained the plate gear on the bottom and enable the doors to lift off the bottom. This warp length parameter is particularly important.
- For the rockhopper trawl, a warp:depth ratio of 2 was set, then towing speed was increased until the trawl lifted from bottom. Thereafter towing speed was matched so that the doors were stable on the bottom. Finally the warp:depth ratio was decreased until the doors lifted from bottom.
- Once a configuration was settled (speed and warp length), a 5 minute stabilisation period was observed.
- Thereafter the trawl geometry data were logged for 15 minutes and the average values recorded.

Investigating impact of trawls

Codend catches

Fish catches were only collected and measured during the bottom impact tows and for the engineering trials the trawls were towed with an open codend. During the bottom impact hauls, all catch from the codend was identified to species level, counted and length measured.

Mapping of bottom impact

The purpose of the work was to assess the physical and biological impact of the two trawl riggings and to compare the relative impact of the two gears i.e:

1. The trawl with the plate gear as specified previously and with lightly rigged doors as determined during the engineering trials

2. The same trawl but with the rockhopper gear and normal (“heavy”) rigged doors, also as specified during the engineering trials

Multibeam mapping of seabed prior to trawling

Before starting trawling, a detailed bottom map of the inner Varanger fiord was made using the multibeam mapping system (Olex) (See Figure 34). A relatively flat and homogenous area, large enough for the planned impact trawl hauls was chosen. Engineering hauls were run during night time, but outside the borders of the impact haul area.

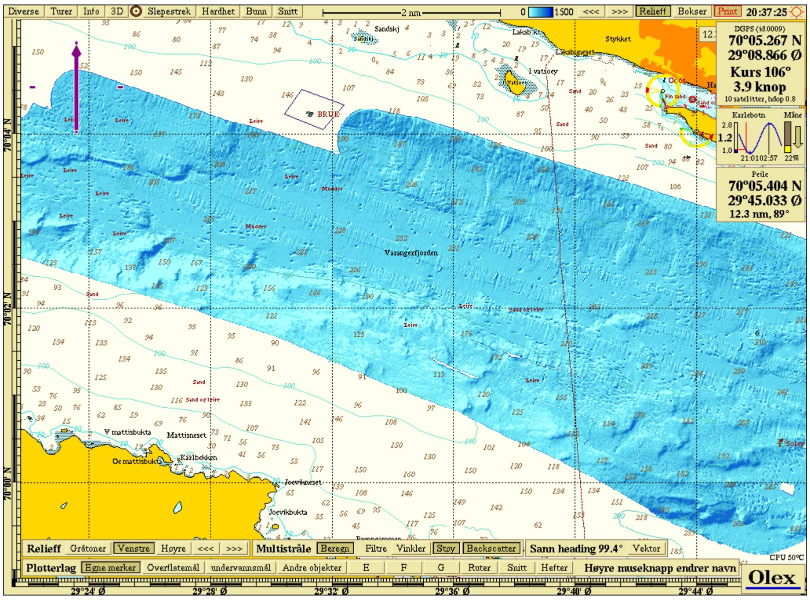


Figure 34 Multibeam map of the investigation area made before the trawl experiments begun

The ROV used for seabed mapping was a SUB-fighter 15K, made by SPERRE Ltd (See Figure 35). It was equipped with seven 2000W thrusters enabling a speed over ground of about 3.5 knots. One HD camera for high quality recordings as well as three other cameras used for orientation and surveying were placed on the ROV. It was also equipped with a scanning sonar for navigation, a depth sensor, compass, 4 x 250W halogen lights and HMI gas lights 2 x 400W.

The ROV was fitted with a HIPAP positioning system which enabled communication between the ROV and the DP (Dynamic Positioning) system of the vessel. During ROV surveys the vessel was set in “follow target” modus, so that the movements of the ROV controlled the movements of the vessel. Navigation data from the vessel and ROV was stored using NaviPac format.

The HD video material was stored using Final Cut Pro, while data from one of the other cameras was stored on conventional DVD format. Visual observations were logged in a logging program developed at IMR, Norway where events seen on the screen during surveying were recorded and classified and stored together with navigation data from the vessel.

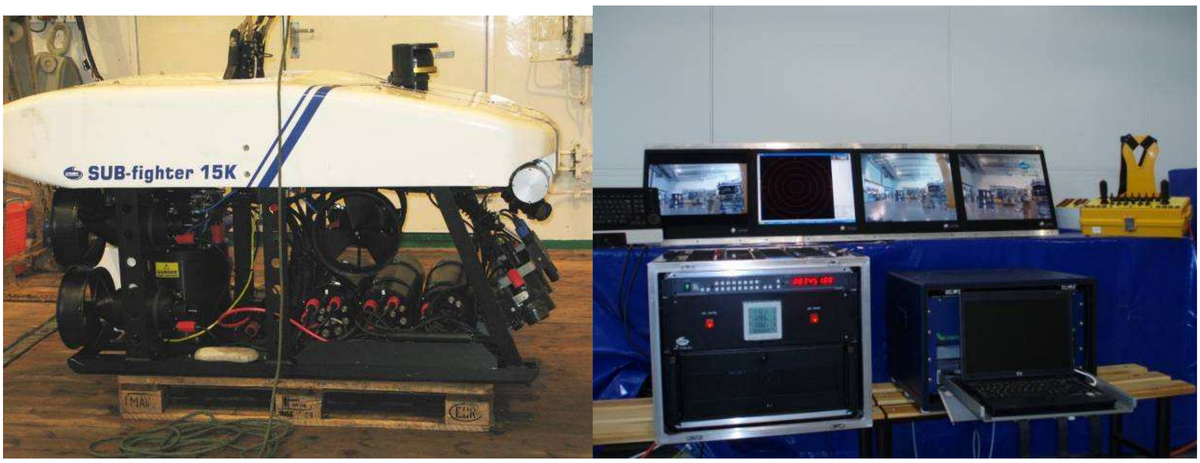


Figure 35 The ROV Subfighter 15K (left) used for bottom habitat mapping. The right picture shows the surface control equipment and observation screens.

<u>Impact trawl hauls and ROV survey</u>

Before trawling, the investigation area was surveyed with ROV in order to map possible existing trawl tracks or other footprints in the bottom substrate from previous activities. No traces from fishing gears or other human activity were observed, but the bottom was more or less covered with footprints from king crab (*Paralithodes camtschatica*).

The original plan was to compare the two trawls on two different bottom types, one soft and one harder bottom, if time permitted. It was, however, decided to concentrate on doing a proper investigation on the soft sediment only due to time restrictions.

Two hauls with each trawl, each haul lasting for 30 minutes, were carried out at a bottom depth of about 230 m. A fifth haul was completed but during which too much warp was shot for the plate gear trawl. As a consequence the trawl doors were fished hard on the bottom and the haul was discarded from the analysis. Table 9 shows an overview of the bottom impact hauls completed.

Table 9 Overview of bottom impact hauls

Station nr.	Trawl type	Date	Time (UTC) start	Position start	Position stop
354	Plate gear, light doors	27.11.2008	08:55	7002.55N 2937.20E	7002.06N 2941.76E
355	Plate gear, heavy doors*	28.11.2008	02:19	7002.39N 2836.19E	7002.98N 2932.02E
362	Rockhopper gear, heavy doors	29.11.2008	06:00	7002.24N 2937.23E	7001.65N 2941.87E
363	Rockhopper gear, heavy doors	29.11.2008	22:41	7002.89N 2933.67E	7002.28N 2938.17E
364	Plate gear, light doors	30.11.2008	12:26	7002.57N 2936.82E	7003.19N 2932.36E

*By mistake the tow was done with too long warps (identical to rockhopper trawl)

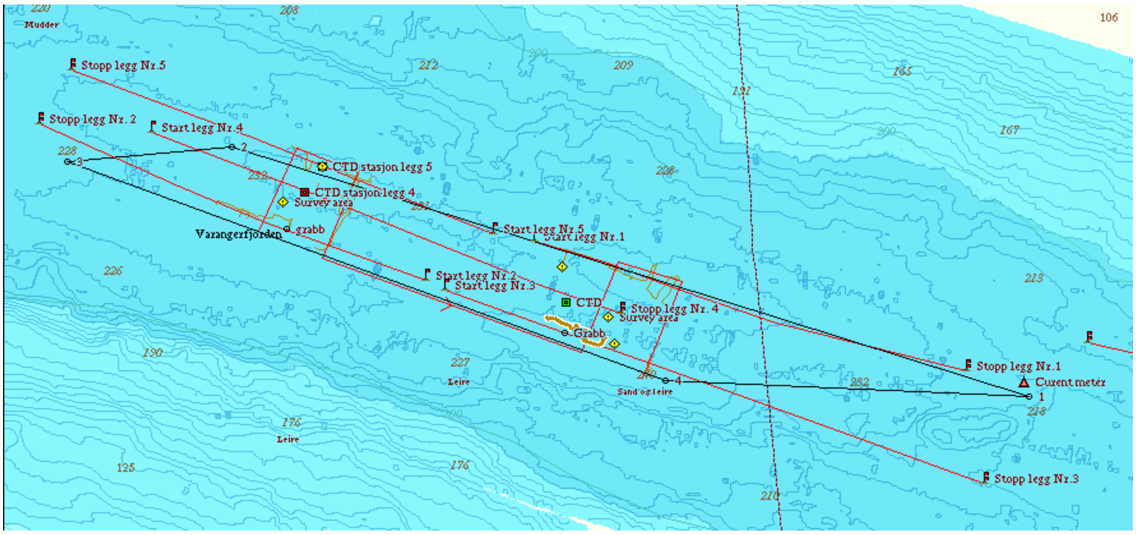


Figure 36 Location of trawl hauls (red lines), pre trawling ROV survey (red lines crossing the area at four locations, after trawling ROV surveys (orange lines), CTD stations (yellow tags), and current meter location (red triangle) in the investigation area. (Note that "legg Nr 1" equals haul 354, "legg Nr 2" equals haul 355, "legg Nr 3" equals haul 362", legg Nr 4" equals haul 363, and "legg Nr 5" equals haul 364).

Figure 36 shows the localization of the trawl hauls as well as placement of CTD, grab samples and current meter localization. Figure 37 shows an idealized ROV survey track after trawling. First the trawl path was crossed twice with the ROV in order to trace, if possible, the tracks of the different trawl components. It turned out that this could be done fairly easy, except for the trawl doors on the plate gear trawl that did not touch the seabed. When the tracks from the different trawl components were identified, the direction of the ROV was turned 90^{o}, and each individual track was followed for 15 minutes. A CTD sample and a grab sample were also taken close to each trawl track.

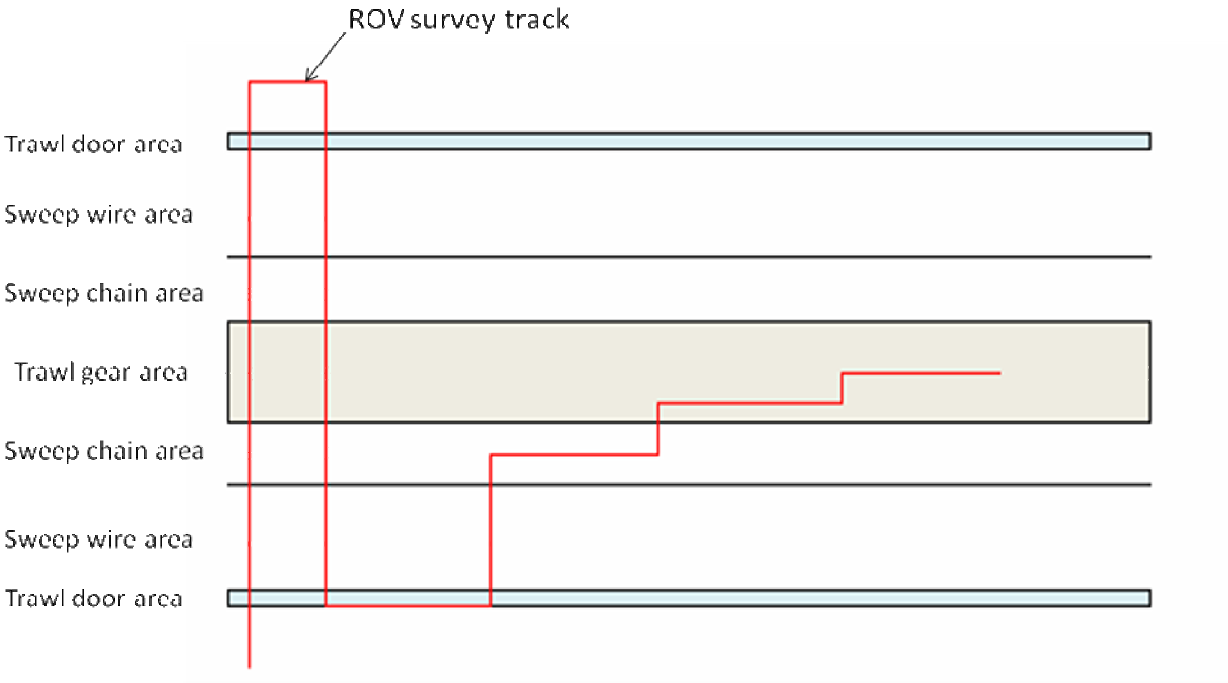


Figure 37 Principal outline of ROV survey relative to the bottom footprints of the different trawl components.

Analysis of bottom impact data
The video material from the survey was analyzed using the image processing and analyses program ImageJ. Two laser pointers, 10 cm apart horizontally, were used to measure cross section, width and breadth of the visible tracks where possible. Measurements of the depth of the tracks were more difficult, as the pictures only gave a two dimensional view of the bottom.

In order to compare the amount and possible differences between the two groundgears in catches of benthos and associated substrate, two collecting bags (opening 500 x 300 mm, mesh size 5 mm) were fitted inside the mouth of the trawl. One was placed just behind the groundgear on the middle of the trawl, while the other was placed 2.5 m further into the belly sheet of the trawl. After each impact haul, the species, number of species and total weight of the samples was identified.

A grab sample was also taken at each impact trawl haul. A sediment sample was taken out. Thereafter the sediments were washed away, and the remaining bottom dwelling specimens were identified and weighted.

A current meter was placed in the outskirts of the bottom impact study area and a turbidity meter (SAIV Ltd) was attached to one of the CTD rigs onboard the vessel. However, the frame could not be lowered closer than 5 m off the bottom. Turbidity was measured 5, 10, 20 and 30 m off bottom. First measurement was taken 45 min after trawling, and thereafter +1, +1½ and +2 hours after the first measurement. One set of measurements were taken at a plate gear track, one at a rockhopper track and one at a control site.

Results

Investigating trawl performance - Plate gear trawl behaviour
The door to door distance is represented in Figure 38 below. The distance increased until a speed of about 3 knots and then decreased at higher speed. This is caused by the effect of doors lifting off the bottom and the trawl drag increasing.

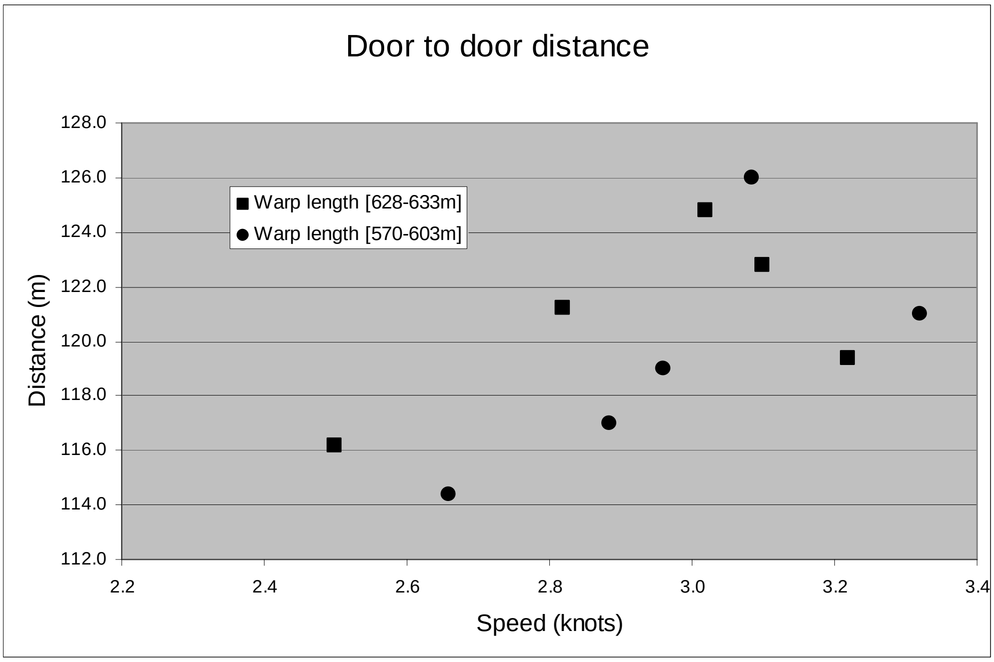


Figure 38 Distance between doors against speed over water for 2 warp length classes

The headrope height is represented is in Figure 39. There is no differentiation for warp length classes as the influence on headrope height of warp length, in the depth range [570 – 628m] is not very sensitive. In the speed range [2.5 – 3.0 knots], normal behaviour for headrope height when the speed over the ground increases was observed in that the vertical opening of the trawl slightly decreased because of the net drag increasing. At higher speeds the headrope height increased due to the doors and sweeps lifting off the bottom This was clearly observed on the headrope sensor screen for the highest towing speeds.

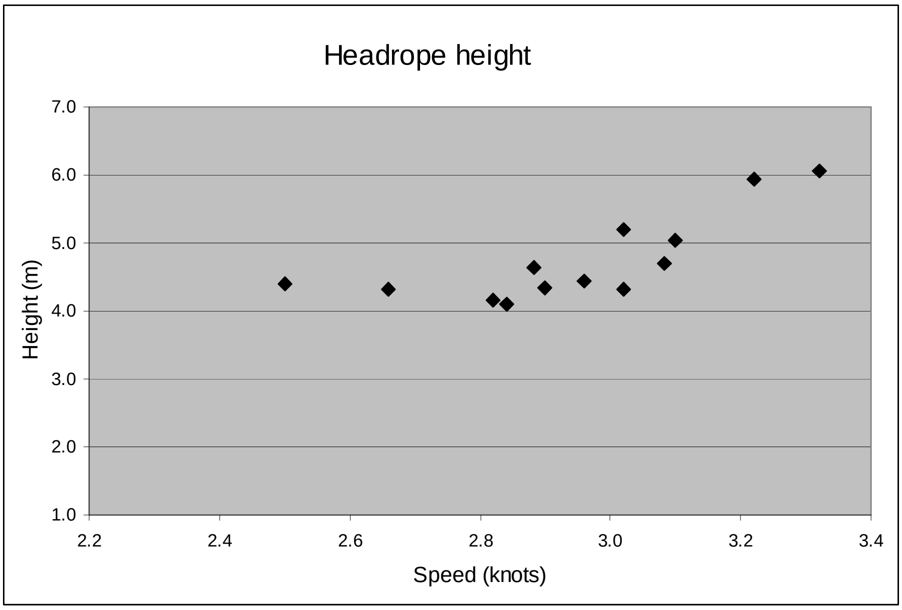


Figure 39 Headrope height against speed over water for different warp lengths

Figure 40 shows the door to bottom distance (blue bubbles) and headrope height (red bubbles). The diameter of blue bubbles directly equal to the average door to bottom distance. The diameter of the red bubbles is calculated in order to amplify the gap between the average headrope height in normal fishing conditions for this trawl (4.4m), and the height of the headrope in the case of high towing speed and/or warp:depth ratio being too short.

The "good combinations" can be seen in Figure 40 where we have a big blue bubble and no or almost no red bubble. These points are underlined in the Figure in the green area. It can be concluded from these trials that light fishing with doors off the bottom and groundgear on the bottom can be achieved using speed over water in the range 2.9 – 3.1 knots and warp length in the range 570 – 630m. These combinations are only for average depths in the range 200 – 230m.

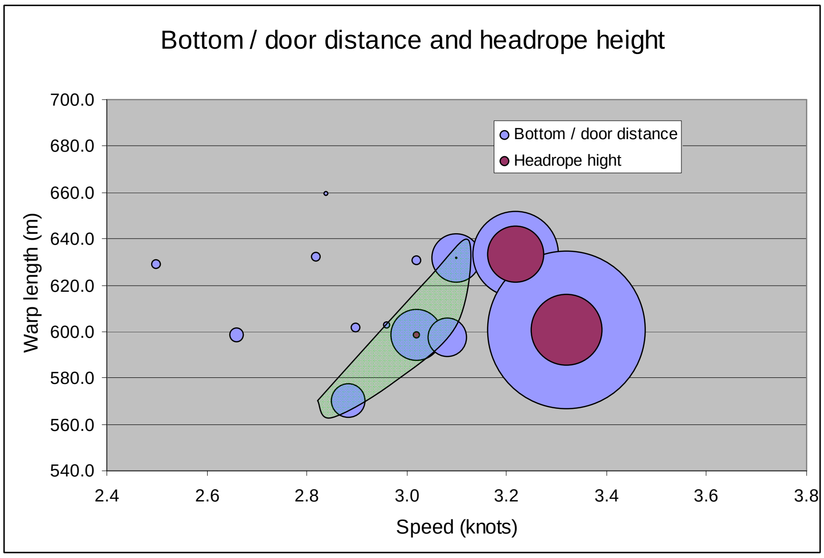


Figure 40 Door height and headrope height as a function of warp length and speed over the water

Basic measurements in the investigation area

The water temperature in the upper water layers (0–260 m) was +5.3°C. At 260– 270 m there was a thermocline with the temperature decreasing to about +4°C at the bottom. Likewise the salinity increased from just about 34.2 ppm in the upper layers to 34.6 below the thermocline. This pattern did not change much during the experiments. Current measurements showed that tidal currents were dominating in the experiment area, and that the currents were weak as may be expected inside a sheltered fiord. This also meant that the mud clouds made by trawling on the soft sediments used a long time to disperse. This presented visibility problems during the ROV surveys and meant that they could not be run until several hours after trawling. This slowed down operations and limite the number of replicates achieved.

Investigating biological impact

Only two valid hauls were taken with each trawl type, each one lasting for 30 minutes only. This limited the data collected and made it difficult to draw any firm conclusions as to whether there is a difference in catchability of fish. Table 10 shows the weight of the catch of the two gear types. The variability in the few hauls is more pronounced than difference in catch level. More hauls arre required in order to be able to compare the catchability of the two trawls. The fish catch was dominated by cod *(Gadus morhua)* and haddock (*Pollachius virens*), with a few individual flatfish (*Hippoglossoides platessoides* and *Glyptocephalus cynoglossus*) as bycatch.

Table 10 Total weight of fish catch in the four valid bottom impact hauls, each lasting 30 min with a towing speed of 3 knots.

Gear type	Haul no.	Weight [kg]

Plate gear	354	99.58
	364	389.4
Rock hopper	362	231.04
	363	288.56

As for the fish catches, the low number of hauls made it also impossible to draw any conclusion on statistical differences between the two gears in the amount of benthos caught in the collecting bags inside the trawl mouth. In both trawls the amount of catch was larger in the hindmost bag as shown in Table 11.

Table 11 Total weight of catch in collecting bags for benthos. Bag no 1 was placed immediately behind the ground gear, while bag no 2 was 2.5 m further behind in the trawl belly.

Gear type	Haul no.	Bag no.	Weight [kg]	Total weight [kg]
Plate gear	354	1	0.039	1.73
		2	1.263	
	364	1	0.023	
		2	0.406	
Rock hopper	362	1	0.406	2.14
		2	0.693	
	363	1	0.145	
		2	0.896	

Likewise, it was not possible to do any statistical comparison of the species composition between the bag samples from the two gear types because the number of hauls was too few. The samples were all dominated by tubes from sedentary *polycheatas*. Living *polychaet* were seldom seen. Figure 41 shows the number of specimens of the different benthic groups found in the collecting bags. The number of *bivalvia*, *eupausiidae* and *holothurioidae* were all more numerous in the bags on the rockhopper gear than on the plate gear trawl. This indicates that the rockhopper gear digs up more benthic species than the plate gear. The difference was particularly large in the bags placed right behind the groundgear.

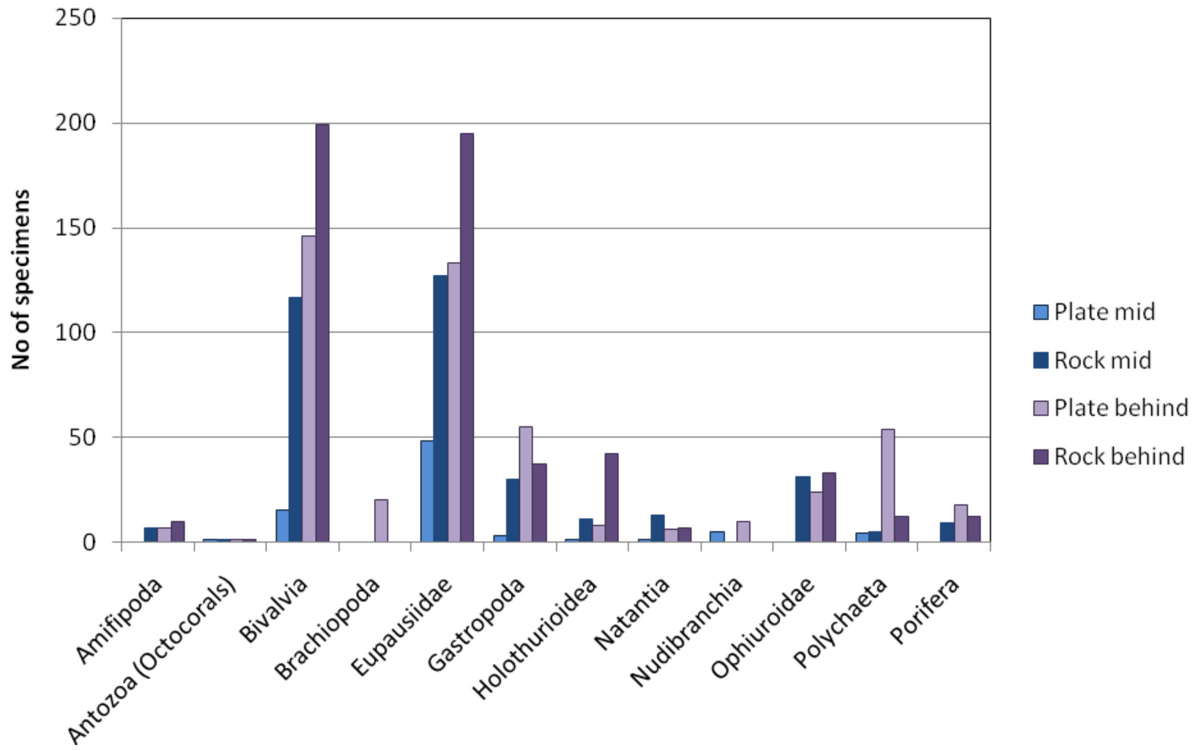


Figure 41 The number of specimens (sum of the two hauls of each trawl type) of benthic species caught in the collecting bags of the two trawl in the valid impact hauls.

* Plate mid and Rock mid refer to the bags attached in the belly close to the ground gear, while Plate Behind and Rock behind were placed 2.5 m further behind on the under belly.

<u>ROV observations of biological impact on bottom dwelling species</u>

The benthic fauna in the investigation area had a low biodiversity. The top substrate consisted of very soft clay with fine particles and the bottom was almost completely flat. This is a typical and favorable substrate for *polychaetas*. The tube dwelling sedentary *polychaet* - *Spiochetopterus typicus* totally dominated the visible benthic species. The tip of the tubes protruded from the bottom, and after passage of the trawl it could frequently be seen that the exposed part of the tubes had increased relative to the untouched ground. It also looked like the tube ends were bent in the towing direction of the trawl. It is difficult to know the biological significance of these findings. Most tubes seemed to be old and unoccupied, and it is not known whether the *polychaets* are able to dig down into the sediments at the passage of the trawl.

In addition to the *polychaets*, benthic *amphipodes* were frequently observed together with *euphausids, mysids* and shrimps (*natantia*). *Octocoralles, bivalves* and a few *brachiopods* were also observed. It was initially planned to identify and quantify the fauna along the ROV track, and quantify the damage inflicted by the different components of the trawl. As the species composition was so dominated by the *polychaete* tubes, where the living organisms could not be observed, this turned out to be an impossible task.

With respect to the grab samples as on the top bottom layer, the infauna seen in the sediments of the grab samples was totally dominated by the empty tubes of *Spirochaetopterus typicus*. Not many living specimens were found in any of the grab samples taken.

<u>Investigating physical impact</u>

The sediments in the investigation area consisted of very soft sediments with about 98 % of the particles smaller than 63µm (clay and silt). These were based on grab samples taken at each of the bottom impact hauls.

Turbidity measurements were also made after two bottom impact hauls, one with each trawl type. The bottom sediments were extremely soft, and even small disturbances of the sea bed (e.g. by a shrimp or fish touching the bottom) caused significant mud clouds. Table 12 shows the development of the turbidity 1, 2, 3, 5 and 12 hours after towing. For the plate gear trawl there seems to be an increase in turbidity at the lower measurement point 5m off bottom, decreasing with time after towing. For the rockhopper trawl the turbidity at the lower measuring point was much more variable. This may be caused by drifting of the particles due to currents, or they may be caused by artefacts like high densities of plankton and other organisms. The immediate impression was, however, that the rockhopper gear causes a higher turbidity, probably by digging more into the bottom sediments. More measurements should be done to verify these initial findings.

Table 12 Measured turbidity (Formazin Turbidity Units (FTU)) at one rockhopper and one plate gear trawl path. Measurements were done at different distances from bottom as well as at different times after trawling.

	Distance off bottom (m)	Control area		1 hour		2 hours		3 hours		5 hours		12 hours	
		Average	Std	Average	Std	Average	Std	Average	Std	Average	Std	Average	Std
Rock hopper	5	1.59	1.24	0.77	0.14	2.19	0.29	0.93	0.07	0.84	0.08	3.55	0.37
	10	0.66	0.19	0.92	0.14	0.65	0.07	0.72	0.07	0.81	0.07	2.24	0.19
	20	0.59	0.12	0.51	0.09	0.51	0.09	0.53	0.11	0.53	0.10	0.84	0.13
	30	0.55	0.07	0.43	0.07	0.46	0.05	0.52	0.05	0.57	0.18	0.53	0.14
Plate gear	5	1.59	1.24	1.79	0.37	1.10	0.10	1.01	0.10	1.15	0.11	0.98	0.07
	10	0.66	0.19	1.45	0.15	1.06	0.14	0.99	0.13	1.29	0.11	0.92	0.09
	20	0.59	0.12	0.82	0.10	0.64	0.11	0.93	0.15	0.95	0.09	0.78	0.10
	30	0.55	0.07	0.51	0.05	0.47	0.05	0.52	0.05	0.64	0.06	0.64	0.10

Investigating physical impact using ROV

When towing with the rockhopper trawl the doors had quite heavy contact with the bottom as shown in Figure 42. Initially it was planned to tow the plate gear with the doors having only minimal bottom contact, in the belief that it would be difficult to lift the doors while simultaneously keeping the door spread. The initial hauls inspected with the towed vehicle, Focus, showed, however, that the doors were actually “flying” clear of the bottom whilst still maintaining door spread. This lifting behaviour was confirmed during the ROV observations of the trawl paths. No tracks could be seen from doors in the path of the valid plate gear hauls. In the track where the plate gear trawl by mistake was run with longer warps (700 m instead of 600 m, i.e. as long as in rockhopper hauls), deep furrows from the doors were found.

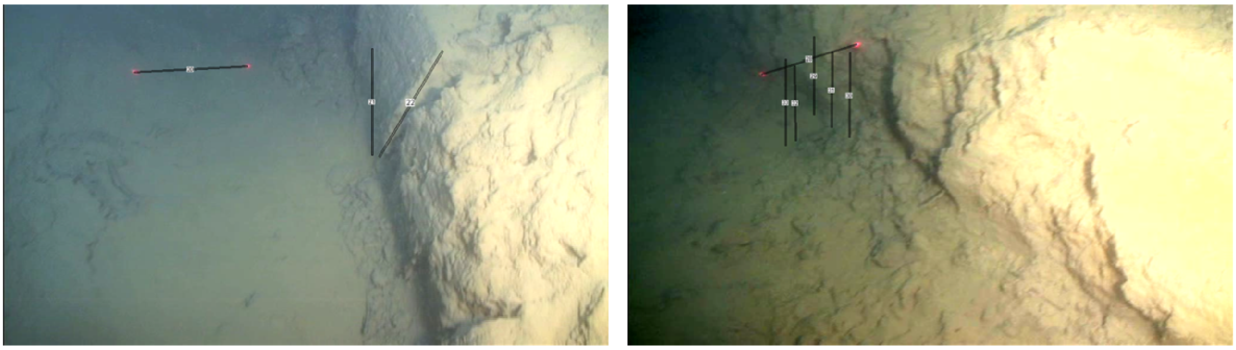


Figure 42 Tracks of door from the rockhopper trawl. The black bars shows measurements done to size the track. The distance between the red laser lights was 10 cm.

One interesting observation was that when the doors were fished tight on the seabed they did not seem to follow a steady track on the bottom. The depth of the door path varied, as did the amount of aggregated mud within the tow path. It appeared that the mud aggregated in front of the door while towed along until the pile of mud reached a certain size/weight (See Figure 43). The door then seemed to flip over the sediment pile, and flew above the bottom for some meters. It thereafter landed back on the bottom, started to dig into the mud and build up a new sediment pile. This appeared to be a cyclical process.

Figure 43 A pile of mud sediment deposited by a trawl door on the rockhopper trawl.

With respect to the sweeps, on the Focus footage it was observed that the wire part (closest to the door) did not touch the bottom. This was verified with the ROV, where only limited tracks were visible in the sediment. It seemed that the wire only touched the bottom infrequently, causing minor re-suspension or mud lumps to be scattered over the seabed. The chain component of the sweeps had much more bottom contact. In the tracks of both trawls the chain made a regular undulating pattern on the bottom where the dimensions of the waves fitted perfectly to the size of the chain links (See Figure 44). Small piles of mud were scattered irregularly over the bottom.

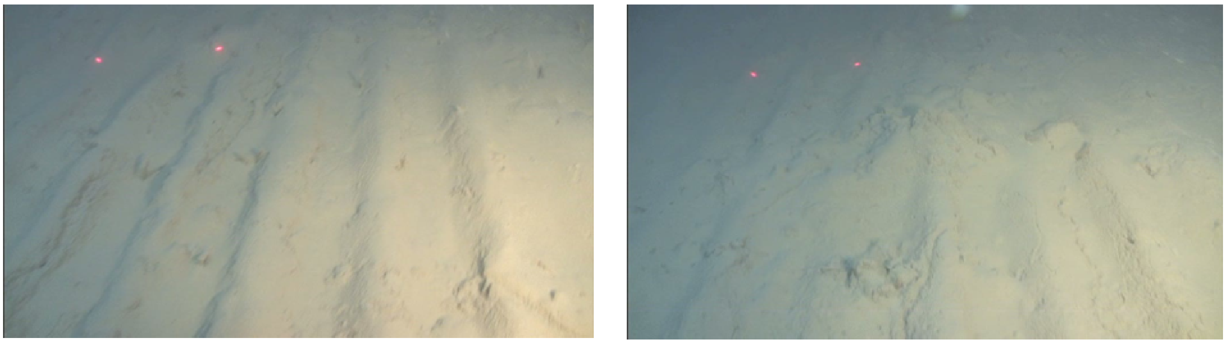


Figure 44 Track from chain part of the sweep. Small piles of mud can be seen scattered above the chain tracks. The distance between the red laser spots is 10 cm.

The different parts of the sweeps were linked with steel bobbins or rubber discs, which made clear tracks on the bottom as shown in Figure 45 below. These tracks had an average cross sectional area of between 15 and 25 cm, and were more or less identical for both trawls.

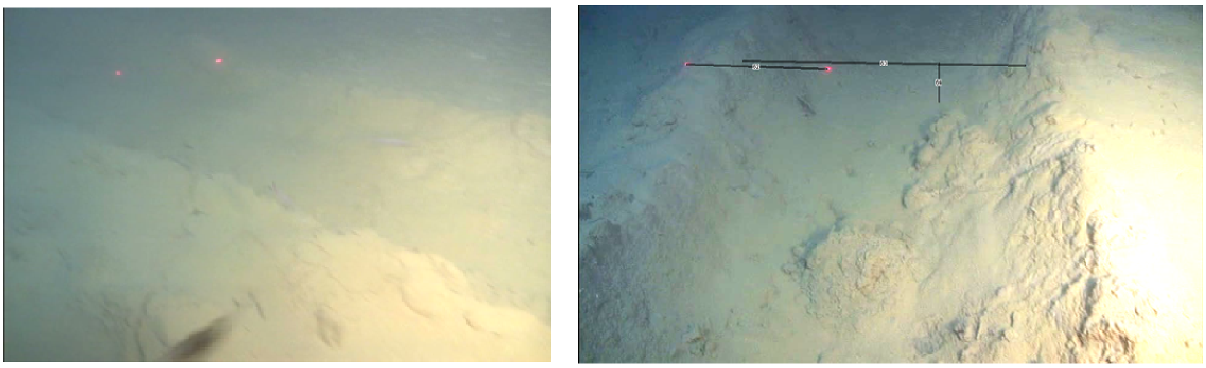


Figure 45 Two tracks from bobbins on the sweeps. Black bars are used for measuring of tracks. The distance between the red laser points is 10 cm.

<u>The rockhopper gear</u>

The rockhopper ground gear was observed to have a major impact on the sea bed sediments. The ROV inspections revealed that it fished heavily on bottom along its entire cross sectional area. The tracks from each individual rubber disc could be distinguished and the digging was so deep that even the spaces between the discs impacted on the seabed gear. It is clear that the rockhopper gear influenced the seabed across its total width as shown in Figure 46.

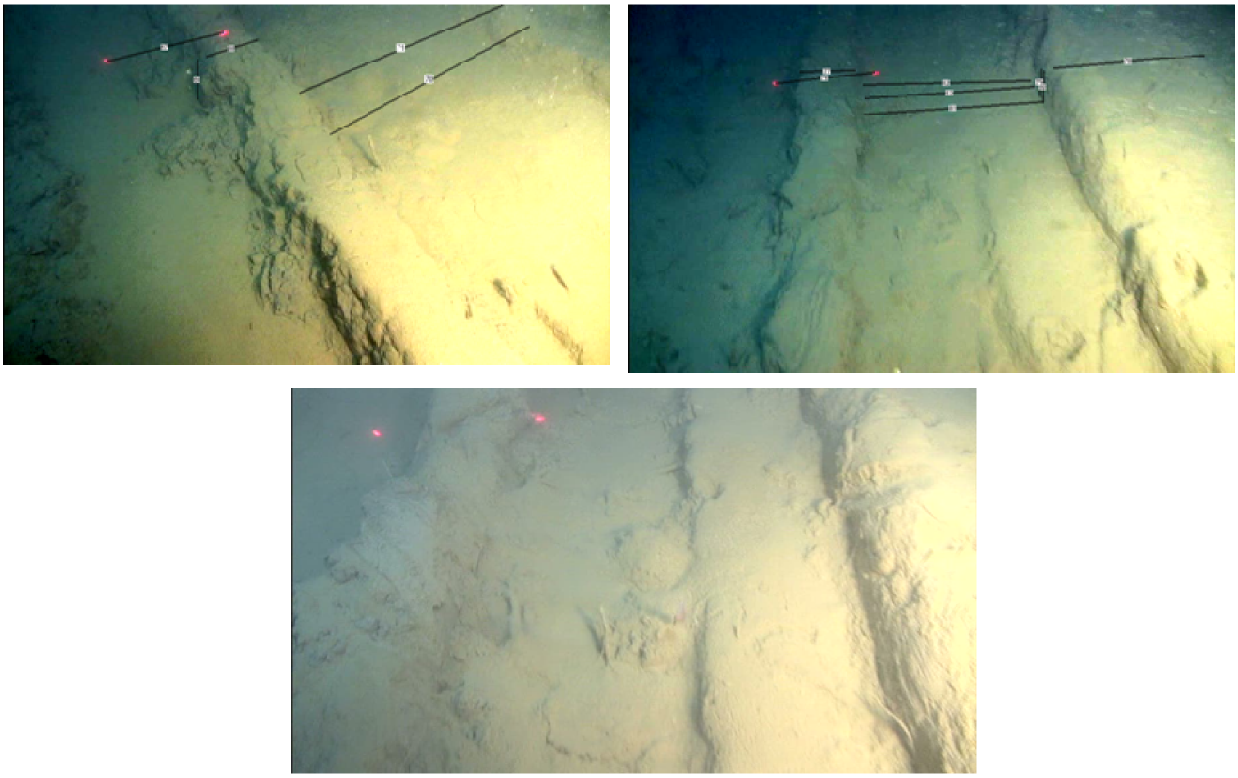


Figure 46 Tracks from the rockhopper ground gear, showing major impact on the sea bed. Tubes from tube dwelling polycheats have been stripped by the gear. Distance between the red laser pointers is 10 cm.

<u>The Plate Gear</u>

The track of the plate gear, consisting of 34 rubber plates, strapped between 7 bobbins (16’’) was also discernable on the seabed. While crossing over the path of the groundgear with the ROV, each individual bobbin track could be identified as illustrated in Figure 47, but the plate sections were more difficult to distinguish. Generally, the plate closest to the bobbins made a shallow track, while the other plates seemed to either not touch or barely touch the sediment (Figure 48). It also seemed that the gear must have had a somewhat undulating movement, as the depth and visibility of the plate tracks varied. However, anticipating that only the bobbins and the closest plates touched the bottom, a maximum of 50 % of the cross sectional area of the plate gear influenced the bottom sediment, contrary to the rockhopper where the whole cross sectional area impacted on the seabed. In addition the depth of the digging of the rockhopper gear appeared much more severe.

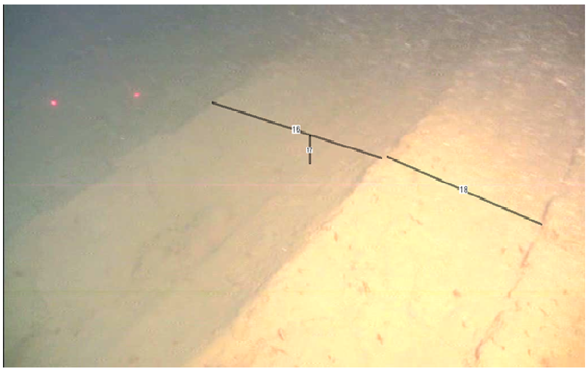
 

Figure 47 Tracks from the plate gear. One of the bobbins may be seen, and on the left picture, also one of the plates adjacent to the disc has made at track in the sea bed. The distance between the two red laser pointers is 10 cm.

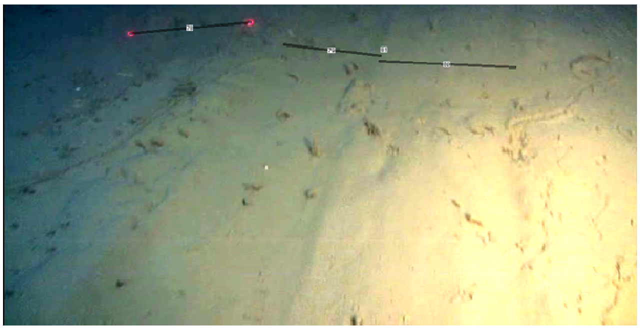
 

Figure 48 Tracks from plates on the sea bed.

In some areas the tubes of *Spiochaetopterus* could be seen protruding from the sea bed more than in the control areas, obviously exposed by the passage of the groundgear as shown in.Figure 48

Figure 49 Tracks from plates of the plate gear. Tubes from polychaets have been exposed by removal of sediments.

Measurements of tracks

Table 13 shows measurements of the tracks from the different trawl components taken from the ROV pictures. The accuracy of the width measurements may be considered relatively good, while the depth measurements are approximations based on the vertical lines fitted visually into the 2 dimensional photo frames.

Table 13 Average measurements of width and depth of the different trawl components from the ROV shots.
Note: The depth measurements have a low accuracy.

		Width			Depth		
Component	**Trawl type**	**N**	**Mean (cm)**	**SD**	**N**	**Mean (cm)**	**SD**
Door	Rockhopper trawl	2	(42.17)*		7	6.43	2.77
	Plate gear trawl		0.00			0.00	
Bobbins on sweep	Rockhopper trawl	8	20.20	4.86	6	3.08	0.60
	Plate gear trawl	7	21.43	2.28	7	2.68	0.59
Sweep chain part	Rockhopper trawl	13	5.37	1.14	13	1.27	0.22
	Plate gear trawl	6	5.32	1.22	6	1.26	0.27
Ground gear	Rockhopper discs	6	14.59	4.34	6	2.80	1.26
	Rockhopper: space betw discs	6	4.75	0.69			
	Plate gear: plates	8	10.15	1.10	7	0.68	0.06
	Plate gear: bobbins	12	19.20	4.27	12	3.46	0.77

The measurements of the width of the door tracks are approximate, as on most pictures only parts of the track could be seen simultaneously. With the plate gear trawl the doors did not touch the bottom at all and the impact of the doors with the rockhopper trawl was considerably more severe. As already mentioned, the sweeps were identical on both trawls and measurements of the physical impact of the sweeps did not differ much in either width or depth.

In addition to the doors, the impact of the groundgears was what most distinguished between the two gears. On the plate gear trawl, it was mainly the seven bobbins that made visible tracks on the seabed, while only a few of the plates could be traced on bottom. On average about 50% of the cross sectional area of the plate gear could be seen impacting the seabed, and the depth of the plate tracks was small (less than 1 cm as measured). The rockhopper groundgear made visible tracks all along its entire cross sectional area, and even the spacers between the discs seem to impact on the seabed. In addition the digging depth was significantly more severe.

6.8 Conclusions

6.8.1 General Conclusions

1. Given the differences in the design of trawls, trawl doors, sweep arrangements and actual fishing operations and the characteristics of the target species there is no universal solution to reducing bottom impact of towed gears but in many cases simple rigging changes can limit impacts.

2. It remains difficult to assess the physical and biological impacts of all components of towed gears accurately. Biological impacts are particularly hard to measure.
3. Acceptance by fishermen of gear modifications to reduce bottom impact will be dependent on the modified gears maintaining catch rates at economically viable levels.
4. Even though there is a greater awareness amongst fishermen of the need to reduce bottom impact, the main driver for using lighter or less impacting gears is potential reductions in fuel consumption.

6.8.2 Trawl Doors

1. Most existing trawl door designs can be modified to fish with light bottom contact but better results are theoretically obtained with high ratio (height/width) doors and centre of gravity at a higher position. Such doors are commercially available.
2. Working doors lighter on the bottom requires clear instruction on how to get a door to work in a stable way. The main faults include using overweight doors, not monitoring door spread and poor adjustment of the warp attachment points on the door itself.
3. Bottom impact of trawl doors can be controlled by altering the warp/depth ratio and/or towing speed.
4. Using pure pelagic trawl doors instead of traditional bottom doors may be an option for trawlers targeting specific species but may not necessarily be an option for targeting species that are herded by the sand clouds developed by the doors on the seabed.
5. The prototype doors designed by Partner 05 and 12 have shown that is feasible to construct low impact doors that have minimal bottom contact but can maintain gear efficiency in terms of door spread.
6. The main driver for adopting low impact trawl door designs will be reduced fuel costs rather than solely a need to reduce bottom impact for environmental reasons.

6.8.3 Groundgears

1. Standard rockhopper groundgears have been shown to have a major physical impact on soft sediments. It has been shown that the impact is across the whole cross-sectional area of the footrope, while the rockhopper footrope also created higher sediment displacement.
2. The biological impact of rockhopper footropes on such sediments is unclear as it has been found difficult to assess biological impacts accurately but the observations made during this project strongly suggest that impact on benthic organisms can be severe.
3. With the plate gear, it was observed that mainly the seven bobbins that made visible tracks on the seabed, while tracks from only a few of the plates could be observed. On average about 50% of the cross sectional area of the plate gear could be seen impacting the seabed, and the depth of the plate tracks was small (less than 1 cm as measured).
4. The prototype plate groundgear developed has proven technically feasible and does not appear to reduce catches of commercial species although it can be sensitive to small changes in rigging.
5. The rigging arrangement used on the final cruise on the "GO Sars" with the groundgear connected to a wire attached directly to the fishing line makes the plate gear less sensitive to changes.
6. Further work is needed to design an alternative danleno arrangement as the rolling bobbin concept tested on the "GO Sars did not work.

7. The physical impact of sweep arrangements on the seabed depends very much on their construction. Observations from the “GO Sars” cruise suggest that sections of chain seem to have more impact than wire.

7 WP4 – approach and results

7.1 Objectives

Task 4.1: To develop fully commercially acceptable designs of benthos release panels / zones or cod-ends for beam trawls.

Task 4.2: To carry out laboratory experiments on the effects of electrical stimuli on marine biota, and to evaluate the biological performance (and economic in WP 5) of electrified pulse beam trawls on board of commercial fishing vessels.

Task 4.3: To develop and test a low impact oyster dredge.

Task 4.4: To quantify the environmental impact reductions associated with the technologies developed in WP 4. Data from this task will feed directly into WP2.

Task 4.1: To develop fully commercially acceptable designs of benthos release panels / zones or cod-ends for beam trawls.

(a) PARTNER ILVO (BELGIUM)

7.2 Overview

For ILVO, following tasks were laid out in the work programme related to a more selective beam trawl:

i) Resolve the problem of weed build up in the panel joining meshes
ii) Adapt the technology so that it can be used in conjunction with a stone release gap
iii) Adapt the technology for full commercial use in the English Channel and Belgian chain mat beam trawl fisheries

With the support of the DEGREE project and other nationally financed projects, the “Alternative Beam Trawl” has been developed to a commercially acceptable concept. The fishing gear is a combination of different selective devices in different parts of the trawl aimed at different fish and invertebrate species. The idea to define a concept rather than a trawl is based on the aim to motivate skipper and crew to carry out responsible fishing and to have a voluntary uptake of the alternative beam trawl, including a change in behaviour towards handling the engine (reduced fuel consumption). The minimum requirements for this concept have been defined in an “industry accepted document”, supported by the national fisheries administration.

Details are given in DEGREE_PAR2_Annex 4.1.1_Specificaties Alternatieve boomkor-_ILVO.pdf to this report.

The experiments and the development of the concept have been guided by an industry working group, led by the producers organisation “Rederscentrale”, and called “Werkgroep Alternatieve Boomkor” that met four times during the project. The meeting reports are given in annex:

- DEGREE_PAR2_Annex 6.2.1 Report industry meeting 030708_ILVO.pdf ;
- DEGREE_PAR2_Annex 6.2.2 Report industry meeting 121108_ILVO.pdf ;
- DEGREE_PAR2_Annex 6.2.3 _Report industry meeting 160908_ILVO.pdf and
- DEGREE_PAR2_Annex 6.2.4 _Report industry meeting 290109_ILVO.pdf.

The Belgian fisheries administration is willing to support the alternative beam trawl by giving extra days at sea and/or quota to vessels that voluntarily adopt the concept. The project’s aims of adding a stone release gap to the panel, to reduce the weed problem and to develop the technology to full commercial use have been met. Several commercial trials have, however, indicated that different operational, geographical and seasonal conditions may alter the performance of the alternative trawl. It was therefore decided to define the alternative beam trawl not too strictly in order to allow fishermen to further develop the trawl and allow adaptation to particular conditions. After a (non-defined) trial period, a more strict definition will be laid out.

A full overview of experiments on selectivity improving devices carried out by ILVO is presented in a compilation report added in annex to this report (DEGREE_PAR2 _Annex 4.1.2_Alternative beam trawl compilation_ILVO.pdf). A selection of results partly financed by the DEGREE project is presented hereafter.

7.3 Sea trials Brixham

A week of sea trials organised by PARTNER CEFAS (UK) in Brixham on a commercial vessel was attended by two ILVO-Fishery technicians. The aim of the trials was to carry out underwater-observations of the benthos release panel (BRP) and to attain the optimal rigging.

7.4 Longer term commercial use T90 & BRP

The BRP was tested in Belgium aboard several commercial vessels. A number of sea trips were attended by a scientific crew to analyse the catches. Furthermore, the trawls of a commercial vessel were equipped with the BRP (together with a T90-cod-end and large meshes in the top panel) for longer term trials. The vessel has been fishing with the alternative beam trawls for four full years with good success. Economic and operational data were delivered to WP5 (CEMARE).

7.5 ILVO-T90 cod-end: RV trials

7.5.1 Introduction

The beam trawl fishery is a typical mixed fishery. Although they primarily target plaice and sole, the beam trawlers catch and land a wide variety of commercial fish and shellfish species, including rays, small sharks, gadoids, red mullet, gurnards, flatfish, anglerfish, scallops, whelk, cuttlefish, octopus, squids, Norway lobster, edible crab, etc. Catch statistics indicate that the total number of commercial species taken by the beam trawler fleet is around 40.

Discarding in the North Sea beam trawl fisheries (in general) is considerable. A dedicated STECF Sub-group, who was given the task of reviewing all discard information collected since the implementation of the EU Data Collection Regulation (2002), estimated the overall discard rate of the beam trawlers (for both target and non-target species, but exclusive of non-commercial species) to be between 40 and 60 % in weight (Anon., 2006). Discard rates strongly differ between species, with the lowest values being observed for cod (5-10 % in weight) and sole (10-15 %), and the highest for plaice (45-55 %) and whiting (65-80 %).

The main cause of discarding in the flatfish-directed beam trawl fishery is related to the use of the 80 mm cod-end mesh in the sole-directed beam trawl fishery (Grift et al., 2004). This mesh size is appropriate for sole, but too small to accommodate the 50 % retention for plaice. All plaice caught below the minimum landing size of 27 cm (mainly 1- and 2-year olds) are discarded (Grift et al., 2004). Most discards (ca. 90 %) do not survive, either because they are damaged in the net during fishing or during the sorting process on board. So far, data on the non-commercial by-catches in the beam trawl fisheries have mostly been collected within the framework of short-term studies aiming at the impact of beam trawling on benthic and/or demersal assemblages. These studies generally indicate discarding in the flatfish beam trawl fishery as problematic (Lindeboom and De Groot, 1998).

Besides the mesh size in the beam trawl fishery, the mesh shape is also a cause of high discard rates. Diamond meshes have the tendency to close when they are stretched. Stewart and Robinson (1985) showed during underwater observations of trawls that diamond mesh cod-ends get a bulbous shape by the drag force of the accumulated catch in the cod-end. The consequence is that only a few mesh rows in front of the bulge are open and unobstructed. All meshes in front of this zone are stretched and have a reduced mesh opening. The number of meshes through which fish can escape is thus seriously reduced (Wileman et al., 1996).

Experimental work (Dahm, 2004) has indicated that turning the diamond mesh netting by 90° (T90) may increase L50, compared to a similar cod-end with normal netting orientation. The shape of the knot makes a T0 mesh close when stretched and allows the T90 mesh to remain open to a certain extent, even when strong forces are applied (Figure 50). Herrman et al (2006) made a simulation with both types of meshes and showed that T90 meshes clearly have better selective properties for roundfish. Hansen (2004) extrapolated from flume tank tests that a T90 cod-end has better characteristics in terms of preservation of fish quality, selectivity, survival rate of escapees, efficiency and strength. Based on the apparent positive characteristics of the T90 mesh, it was decided to study the performance of T90 cod-ends in the beam trawl fishery.

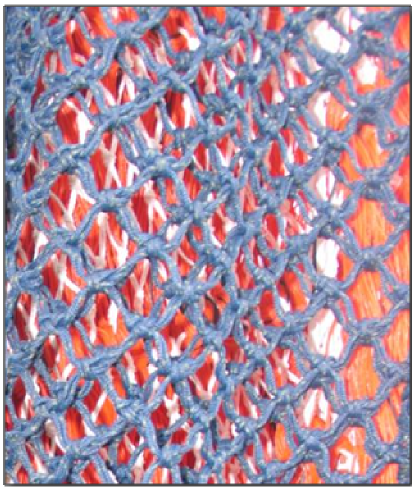


Figure 50 T90 and diamond meshes (top) and a T90 cod-end with a posterior sheet of netting (5 rows) with T0 orientation.

7.5.2 Materials and methods

Vessel and gears

The sea trials were carried out on board of the RV "Belgica" which has an overall length of 50.9 m, a GRT of 765 t and an engine power of 1154 kW. A commercial skipper was hired to select the fish tracks and to guide the fishing operations in order to match commercial conditions as closely as possible. The towing speed was on average 4 knots and the warp length was three times the water depth. The trials took place from 4 to 15 September 2006.

The gear studied was a commercial beam trawl with a beam length of 4m and a vertical net opening of 0.5 m. These gears are often used by Euro-cutters, small double rig beam trawlers allowed to fish within the 12-miles zone under certain conditions. The lengths of the headline and the ground-rope were 3.7m and 9.4m respectively. The ground-rope consisted of rubber bobbins. The net was made of knotted polyethylene netting with a nominal mesh size of 120mm. To reduce wear, the belly was constructed of double yarn netting and provided with bottom chafers made of polyethylene ropes. The double braided cod-ends had a nominal mesh opening of 80mm and a twine diameter of 4mm. The cod-end mesh sizes were regularly measured with the OMEGA-gauge, according to the ICES protocol (Fonteyne, 2005).
In contrast with commercial beam trawlers, RV Belgica is not equipped with derrick booms for towing two beam trawls at the same time. To enable simultaneous fishing with a standard and an experimental cod-end, two 4m beam trawls were attached next to each other to an 8m beam with an extra trawl-head in the middle. The two gears were identical, except for the cod-ends.

The standard cod-end was constructed along commercial practice. The experimental cod-end was constructed in diamond meshes turned by 90°, i.e. the so-called T90 mesh. A total of 14 and 21 valid hauls were carried out respectively for the standard and the T90 cod-end.

Catch analysis

The catches of the standard and experimental cod-ends and covers were collected in baskets and the total catch weights were recorded. All commercial fish species were sorted out of the catch. The fish were measured to the cm below. The rest of the catch was weighed to determine the non-commercial fraction of cod-end and cover catches. Of a selection of hauls, a sample was taken of the non-commercial fraction for further analysis in the lab. There, each species was counted and weighed.

The percentage “total catch” and “non-commercial catch” released by both the standard and the experimental cod-ends was calculated for each haul. The significance of the difference was estimated by the Mann-Whitney test. For each of the non-commercial species of which at least 50 animals were present in each cod-end, the percentage animals (in no’s) escaping from both cod-ends was calculated.

The cod-end selectivity was investigated for five commercial and one non-commercial fish species. The SELECT model was chosen to describe the selectivity. The standard methodology for selectivity of fishing gears is described in Wileman et al. (1996). Based on the deviance residuals obtained when calculating the selection curves, the logistic function was chosen as a link function to fit the retention points for each species and fitted the data very well. This function is the cumulative distribution function of a logistic random variable and is specified by the following equation:

$$RR(TL) = \exp(a + b \cdot TL) / (1 + \exp(a + b \cdot TL))$$

where RR(TL) is the probability that an animal of length TL (Total Length) is retained in the cod-end. a and b, which are the two parameters to be estimated, represent the intercept and the slope, respectively, after a logit transformation. These parameters were estimated with the maximum likelihood method by the CC software (Constat, Denmark). L25, L50 and L75 are the body lengths at which 25%, 50% and 75% of the shrimps are retained in the cod-end. SF is the selection factor and is the L50 divided by the mesh size. SR is the selection range and is equal to the difference between L75 and L25 and gives an idea of the slope of the curve. Single hauls were combined by the variance component analysis method of Fryer (1991) by the CC software. 95% confidence limits of the selection parameters are given in brackets.

7.5.3 Results

A standard 80mm beam trawl cod-end releases about 25% of the total catch weight entering the cod-end (Figure 51). For the non-commercial species this is almost 35%. The T90 cod-end releases about 45% and 60% of respectively the total and non-commercial catch weight. The Mann-Whitney U-tests indicated a highly significant difference ($p < 0.001$).

The selection ogives for both cod-ends, for sole, plaice, dab, lemon sole, poor cod and cod, are given in Figure 52 and the selection parameters in Table 14. For sole, the L50 is not significantly higher for the T90, but the selection range is. For plaice, no selection at all was observed for the standard cod-end. The T90 did allow plaice to escape, with an L50 of 15.3cm. For lemon sole and dab, the L50 is the same for both cod-ends. The selection range shows the same pattern as for sole, although no significant difference could be demonstrated. For roundfish, the T90 cod-end clearly performs much better than the standard cod-end. For cod, the L50 increases significantly from 14.7cm to 22.6cm. For poor cod, the increase goes from 12.9cm to 19.6cm.

Figure 53 gives the percentage of the total number of animals entering the cod-end that were released through mesh selection and were collected by the cod-end cover. The T90 cod-end proves to be superior in releasing non-commercial catch for all species observed. Due to the low number of hauls sampled for non-commercial species, no significance could be calculated.

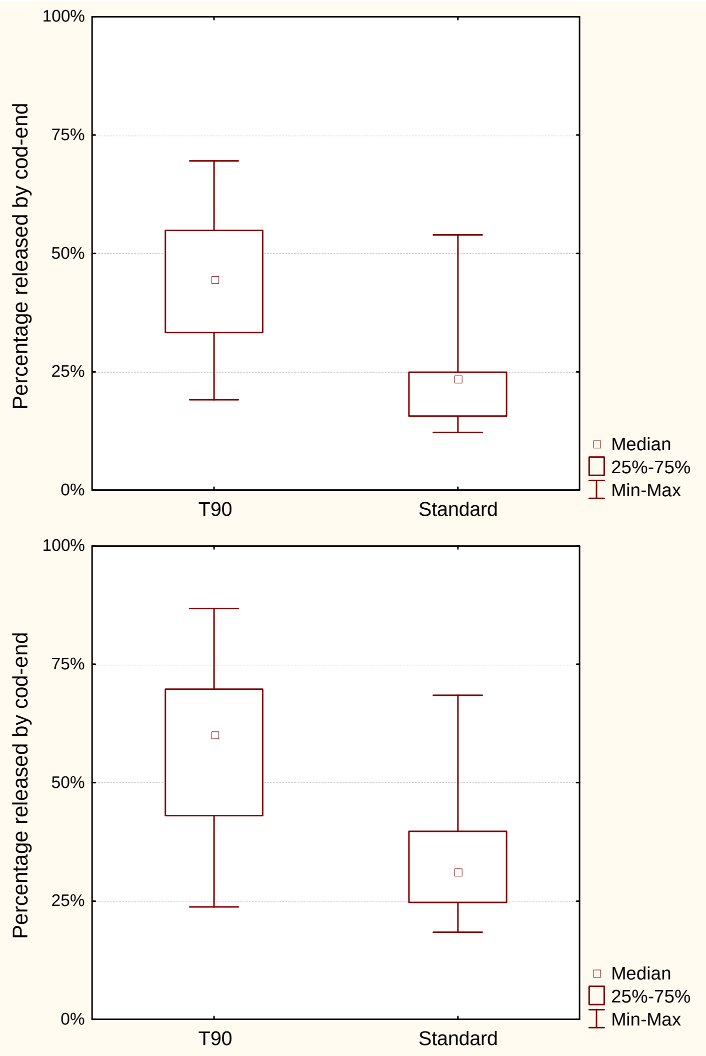


Figure 51 The percentage of “total catch”(top) and “non-commercial catch” (bottom)

Table 14 The selectivity parameters for a standard 80mm commercial cod-end and an 80mm T90 cod-end for five commercial and one non-commercial species.

		SF	L50	SR
Sole	Diamond mesh 80mm	0,27	21,3 (20,7 - 21,9)	5,9 (5 - 6,8)
	T90 mesh 80mm	0,28	22,3 (21,6 - 23,1)	3,6 (2,9 - 4,3)
Plaice	Diamond mesh 80mm	no selection	-	-
	T90 mesh 80mm	0,19	15,3	1,9
Lemon sole	Diamond mesh 80mm	0,20	15,9 (14,7 - 17,1)	3,6 (2,8 - 4,5)
	T90 mesh 80mm	0,19	15,7	1,6
dab	Diamond mesh 80mm	0,19	15,1 (14,3 - 16)	2,8 (1,7 - 4)
	T90 mesh 80mm	0,19	15,4 (14,9 - 15,8)	1,8 (1,3 - 2,2)
cod	Diamond mesh 80mm	0,18	14,7 (13,9 - 15,5)	2,3 (1,5 - 3)

		SF	L50	SR
	T90 mesh 80mm	0,28	22,6 (19,8 - 25,3)	4,1 (2,3 - 5,8)
poor cod	Diamond mesh 80mm	0,16	12,9	2,9
	T90 mesh 80mm	0,24	19,6	4,7

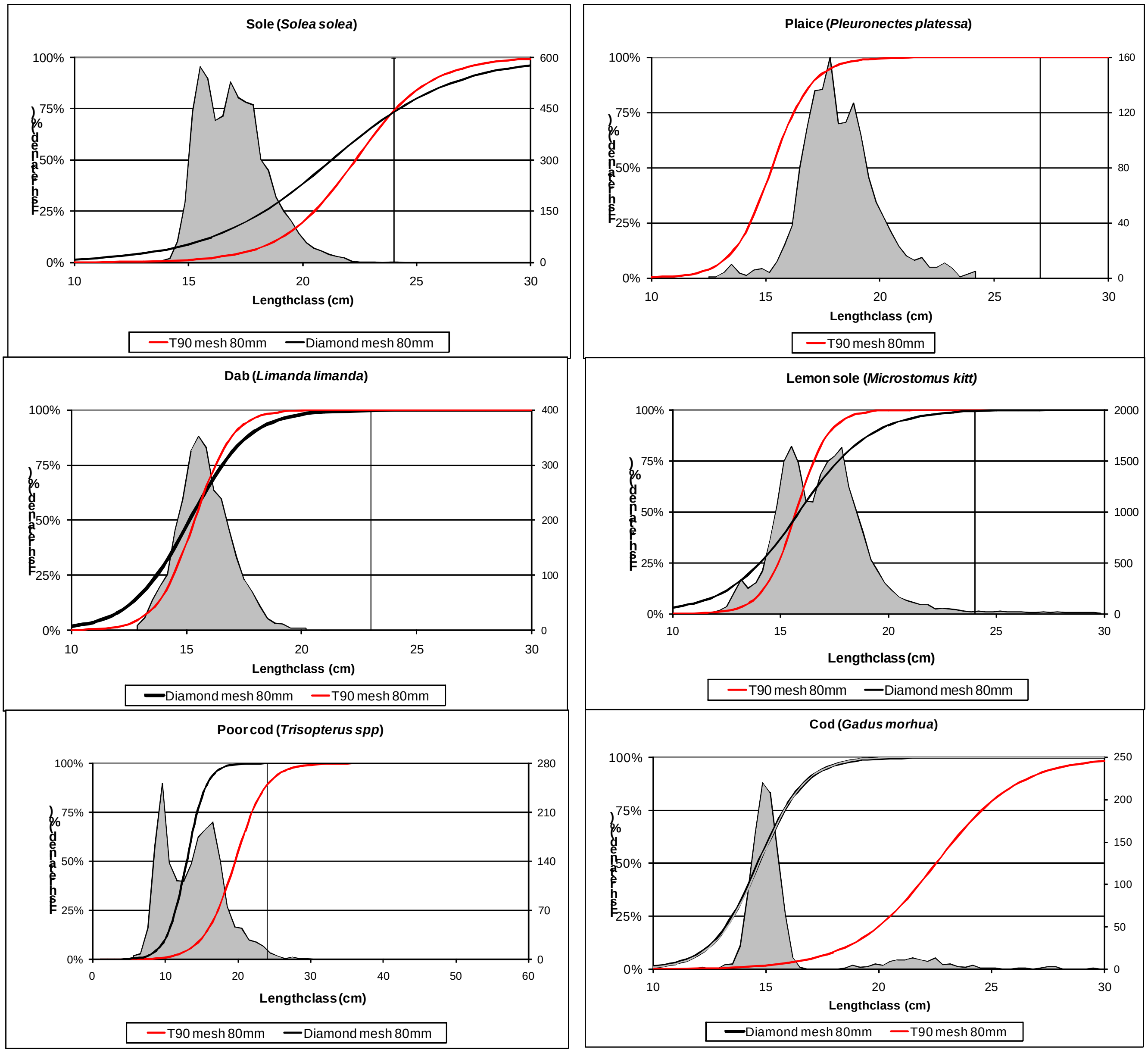


Figure 52 – The selection ogives for a standard 80mm commercial cod-end and a 80mm T90 cod-end for five commercial and one non-commercial species. For each species the length frequency distribution for the total catch (cod-end + cover) is given.

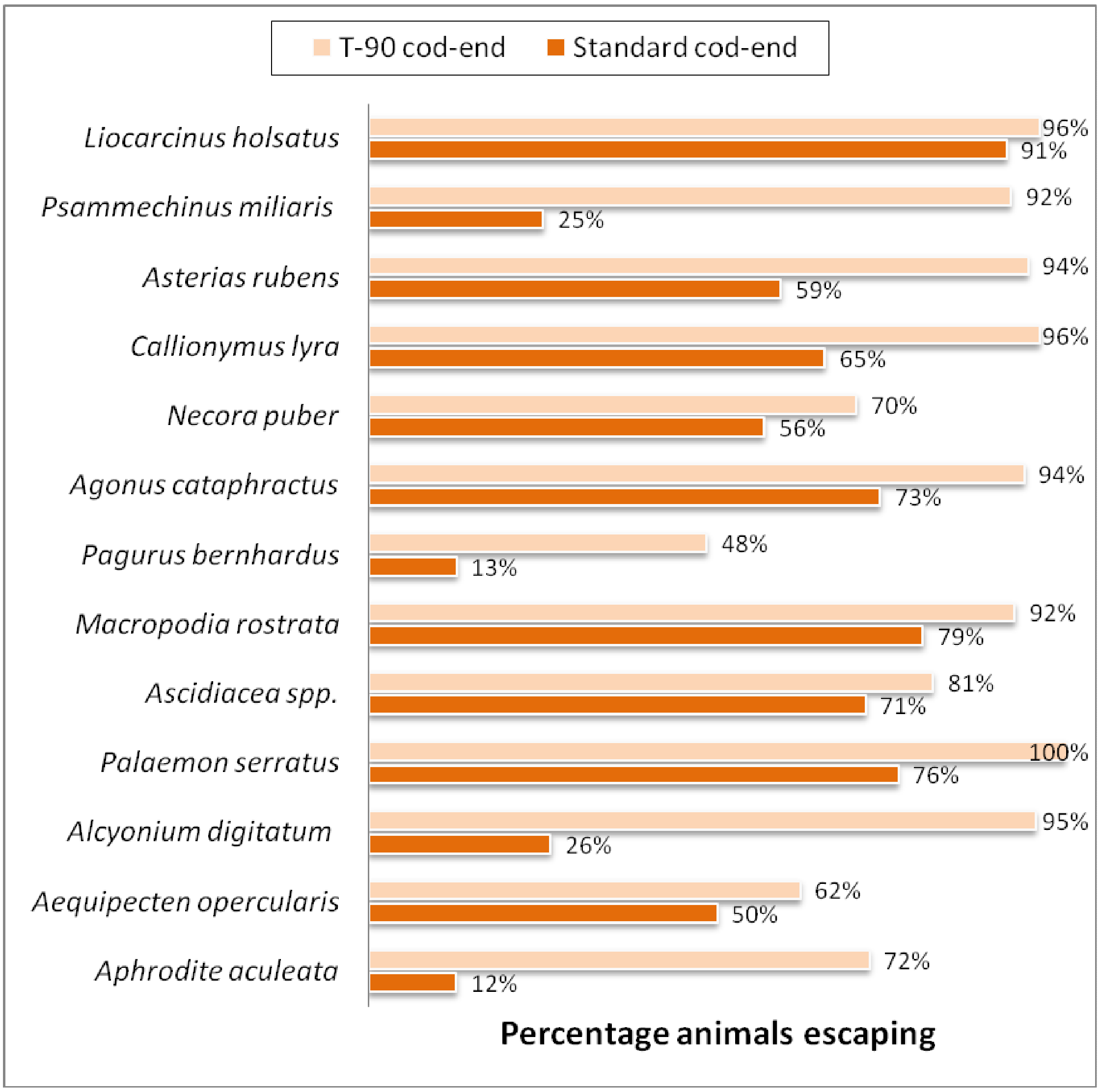


Figure 53 The percentage of the total number of animals entering the cod-end that were released through mesh selection and were collected by the cod-end cover

7.5.4 Discussion

Fonteyne and M'Rabet (1992) and Walsh et al. (1992) have shown that square meshes are less selective for flatfish compared to diamond meshes. The rationale behind it was that diamond meshes have a shape similar to the body shape of the flatfish, thus allowing an easier passage through the mesh compared to the square mesh. A similar rationale could apply for the T90 mesh because this mesh has less similarity with the flatfish body compared to the diamond mesh. The present trials have, however, indicated that the T90 mesh only leads to a sharper selection ogive with the ogive's centre of rotation between L50 and L75. This is the case for dab, lemon sole and sole. Particularly for sole, the most important commercial species for the beam trawl, this centre of rotation lies exactly on MLS. The consequence is that the application of T90 leads to an increased release of undersized fish and increased catch of fish just above MLS.

For roundfish there is no doubt that the T90 cod-end outperforms the standard cod-end. For benthos, the success rate of T90 is species dependent but for each of the species more animals escape through the T90 mesh. With a better retention of the most important commercial species, sole, and the release of many undersized commercial fish and many non-commercial animals, the T90 cod-end seems to be a good alternative for the standard diamond mesh cod-end.

It has to be noted, though, that these trials have been carried out on a research vessel. The results cannot as such be extrapolated to the commercial fishery. Commercial trials are essential for further evaluation of this cod-end. The disadvantage of commercial trials aboard beam trawlers, however, is the difficulty to work with a cod-end cover and the lack of controlled conditions. Detailed catch measurement is also often problematic.

7.5.5 Conclusions

The T90 cod-end has interesting selective properties for the most important commercial species for the beam trawl, i.e. sole. It allows more undersized fish to escape and more marketable fish to be caught. Roundfish species and non-commercial fish and invertebrates escape much more easily from a T90 mesh than from a diamond mesh in a typical beam trawl cod-end. It can thus be expected that the application of a T90 cod-end will result in less discards and cleaner catches.

7.6 ILVO-T90 & BRP: Commercial trials with observer

A short selection of results are shown below:

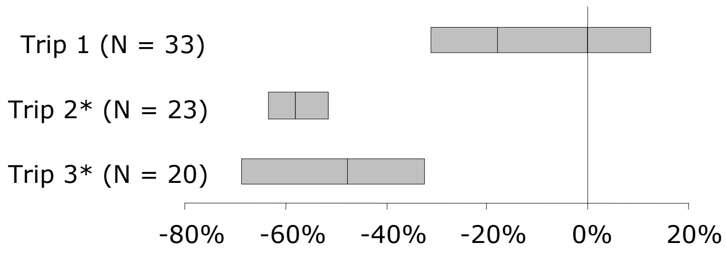


Figure 54 Percentage difference in non-commercial catch weight of the vessel N.58 (300 hp), experimental compared to standard cod-end (median en quartiles); * = significant diff. (Wilcoxon test); Trip 1: T-90; Trip 2: T-90 & BRP; Trip 3: BRP

This figure indicates a strong effect of the BRP on the non-commercial catch weight. The T90 cod-end does not produce a significant lower catch, but the combination of the two gives a good result.

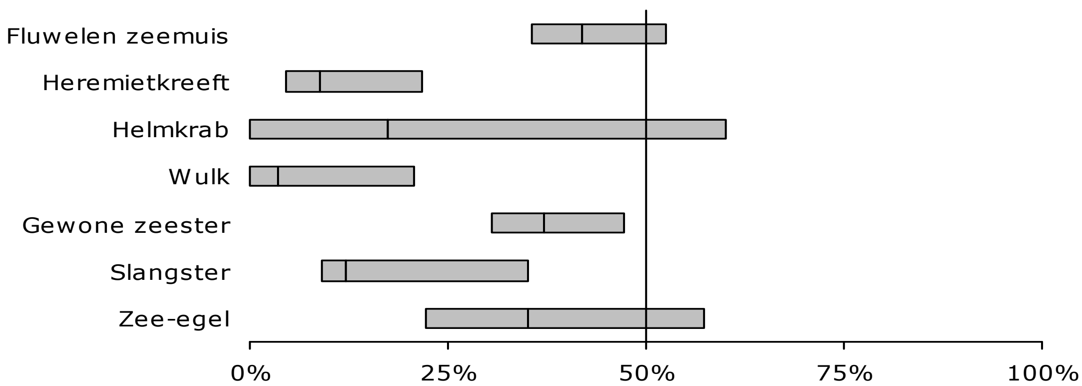


Figure 55 Separation of invertebrates (% by numbers) over experimental and standard cod-end (median en quartiles)

Fig. 55 shows that the effect of the BRP is strong species dependent. The higher the density of the animals, the stronger the release through the panel.

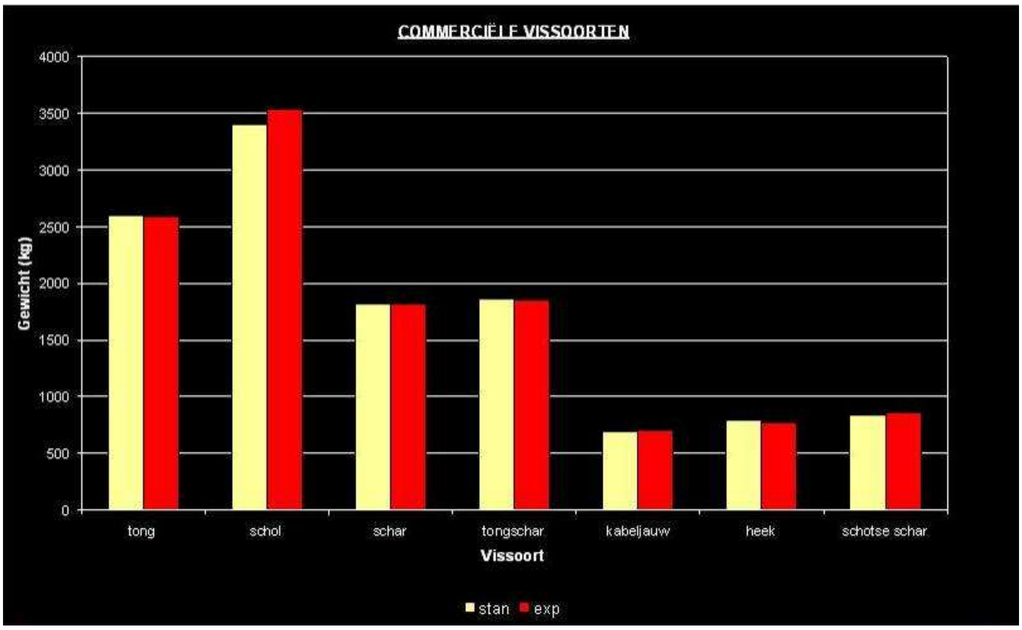


Figure 56 Comparison of the commercial catch weight for the experimental (BRP & T90) and standard gear for the vessel O.89 (1200 hp)

Fig. 56 indicates similar commercial catches for both gears. Fig. 57 and 58 show the length frequency distributions for respectively haddock and dragonet (*Callionymus lyra*) and show a catch reduction of both species in the experimental trawl.

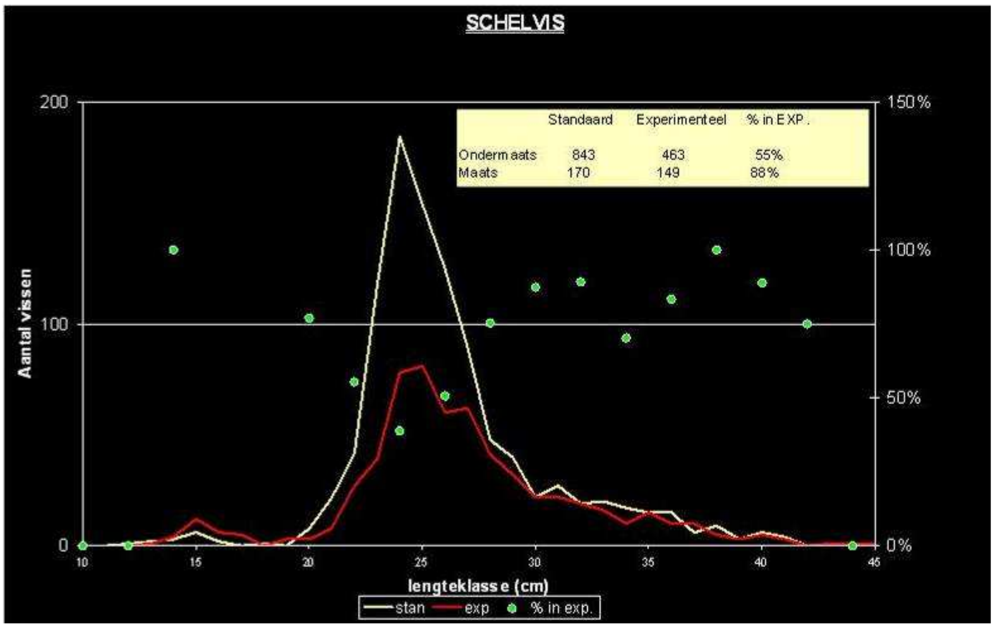


Figure 57 Comparison of the haddock length frequency distribution for the experimental (BRP & T90) and standard gear for the vessel O.89 (1200 hp)

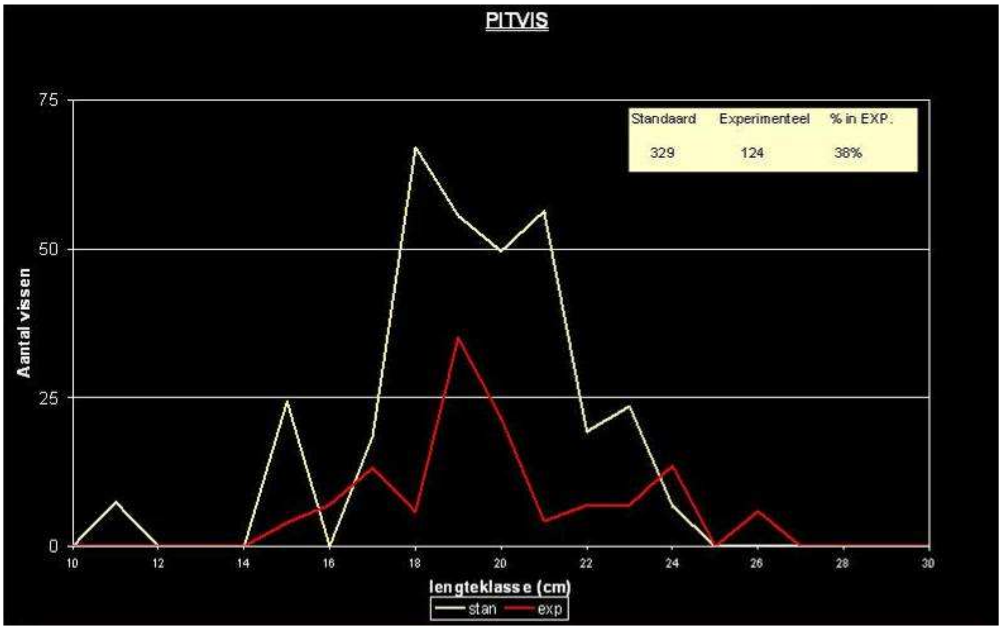


Figure 58 Comparison of the dragonet length frequency distribution for the experimental (BRP & T90) and standard gear for the vessel O.89 (1200 hp)

7.7 ILVO-benthos release panel: Commercial trials with observers

An extensive series of sea trials with benthos release panels in beam trawls have been carried out on board the commercial fishing vessels O 89, Z 48, Z 121 and N 58. The focus of these trials was on discard reduction.

7.7.1 Material and methods

During the sea trials, Z 121 was rigged with a benthos release panel on one side. The panel is constructed of doubly braided 120mm square mesh netting and inserted 10 meshes in front of the cod-end. Total catches, weight and length distribution of commercial species and weight and composition of the by-catch were recorded. This approach allows a catch comparison analysis to be made.

7.7.2 Results

Discards during the experimental sea trip consisted of 40 species of invertebrates and 40 species of fish. The benthos release panel appeared to have little effect on the discard composition. Starfish made up the bulk of the invertebrate discards and haddock, poor cod, lemon sole made up the bulk of the fish discards.

Figure 59 shows the number of invertebrates and fish in the discards, Table 15 shows the discard reduction (in numbers) for individual species. For three species of starfish and for the total number of invertebrates, a significant reduction in the number of discards could be observed.

Figure 60 shows the total weight of discards compared to the commercial catch weight, the weight of different fractions in the non-commercial catch and the weight of selected species (sole, scallops, gadoids) in the commercial catch. Table 16 shows the effect of the benthos release panel on the weight of different commercial and non-commercial species and fractions in the total catch. Catch weights were significantly lower for one species of starfish, inert material, scallops and total commercial catch. It was established that loss of scallops occurred due to improper rigging of the benthos release panel that caused a slack in the bottom panel of the net in front of the panel. No significant catch losses were observed for sole or other commercial species.

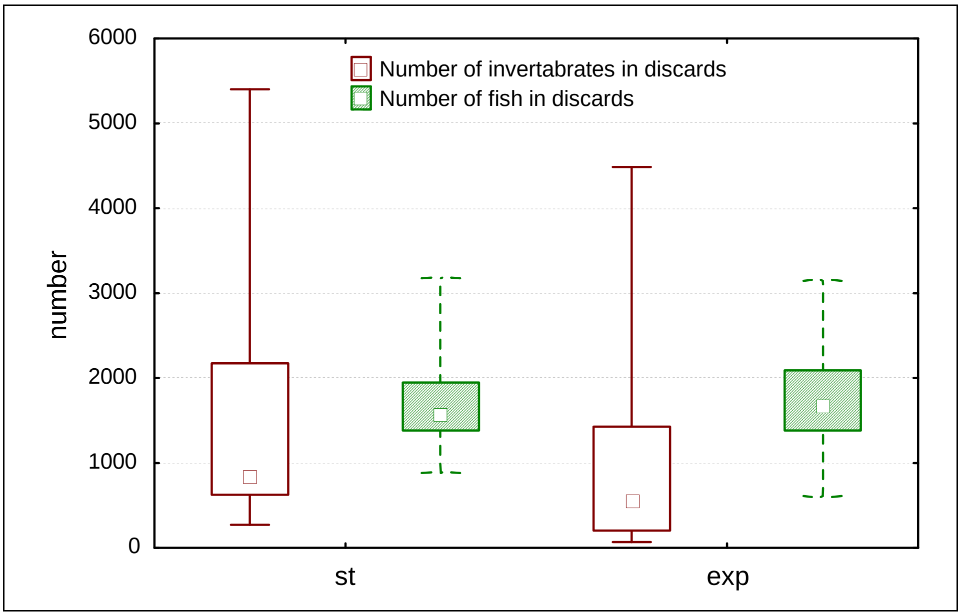


Figure 59 – Number of fish and invertebrates in discards for the standard trawl and the trawl with benthos release panel on board Z 121

Table 15 Effect of benthos release panel on discards (numbers) of different species (* significant, Wilcoxon, p<0.05)

	# hauls	Wilc p	median # st	median # exp	hauls with reduction (%)	median difference (%)
Asterias rubens*	**20**	**0.05**	**92.3**	**39.4**	**70**	**-70.4%**
Astropecten irregularis*	**20**	**0.05**	**157.0**	**52.9**	**75**	**-64.7%**
Cancer pagurus	20	0.83	9.9	11.3	45	0.0%
Crossaster papposus*	**20**	**0.02**	**16.3**	**7.3**	**65**	**-32.1%**
Inachus sp.	20	0.39	0.0	0.0	40	0.0%
Liocarcinus holsatus	20	0.53	25.7	45.6	35	17.6%
Luidia sp. (L. ciliaris + L. sarsi)	20	0.40	15.6	12.5	45	0.0%
Maja squinado	20	0.74	18.0	14.3	60	-18.9%
Marthasterias glacialis	20	0.09	263.8	239.1	65	-33.8%
Necora puber	20	0.40	26.2	13.0	55	-10.7%
Pecten maximus	20	0.11	34.2	15.4	60	-29.0%
Aspitrigla cuculus	20	0.16	14.7	29.8	25	40.5%
Buglossidium luteum	20	0.19	0.0	11.8	25	7.8%
Callionymus lyra	20	0.91	130.0	113.9	50	6.1%
Eutrigla gurnardus	20	0.57	11.8	12.5	30	2.0%
Glyptocephalus cynoglossus	20	0.69	9.7	6.3	35	0.0%

	# hauls	Wilc p	median # st	median # exp	hauls with reduction (%)	median difference (%)
Limanda limanda	20	0.72	153.9	95.4	50	-0.5%
Lophius piscatorius	20	0.84	12.1	13.0	45	0.0%
Melanogrammus aeglefinus	20	0.68	319.9	350.4	50	2.6%
Merlangius merlangus	20	0.26	159.4	189.3	35	19.0%
Microstomus kitt	20	0.63	198.7	239.1	55	-3.8%
Pleuronectes platessa	20	0.25	26.2	15.5	55	-18.1%
Raja brachyura	20	0.97	4.3	5.4	30	0.0%
Scyliorhinus canicula	20	0.31	170.7	148.8	60	-11.0%
Trisopterus luscus + T. minutus	20	0.50	201.3	155.3	55	-19.0%
Total number of invertebrates in discards*	***20***	***0.03***	***832.5***	***542.8***	***85***	***-45.8%***
Total number of fish in discards	*20*	*0.79*	*1569.0*	*1673.9*	*50*	*4.1%*

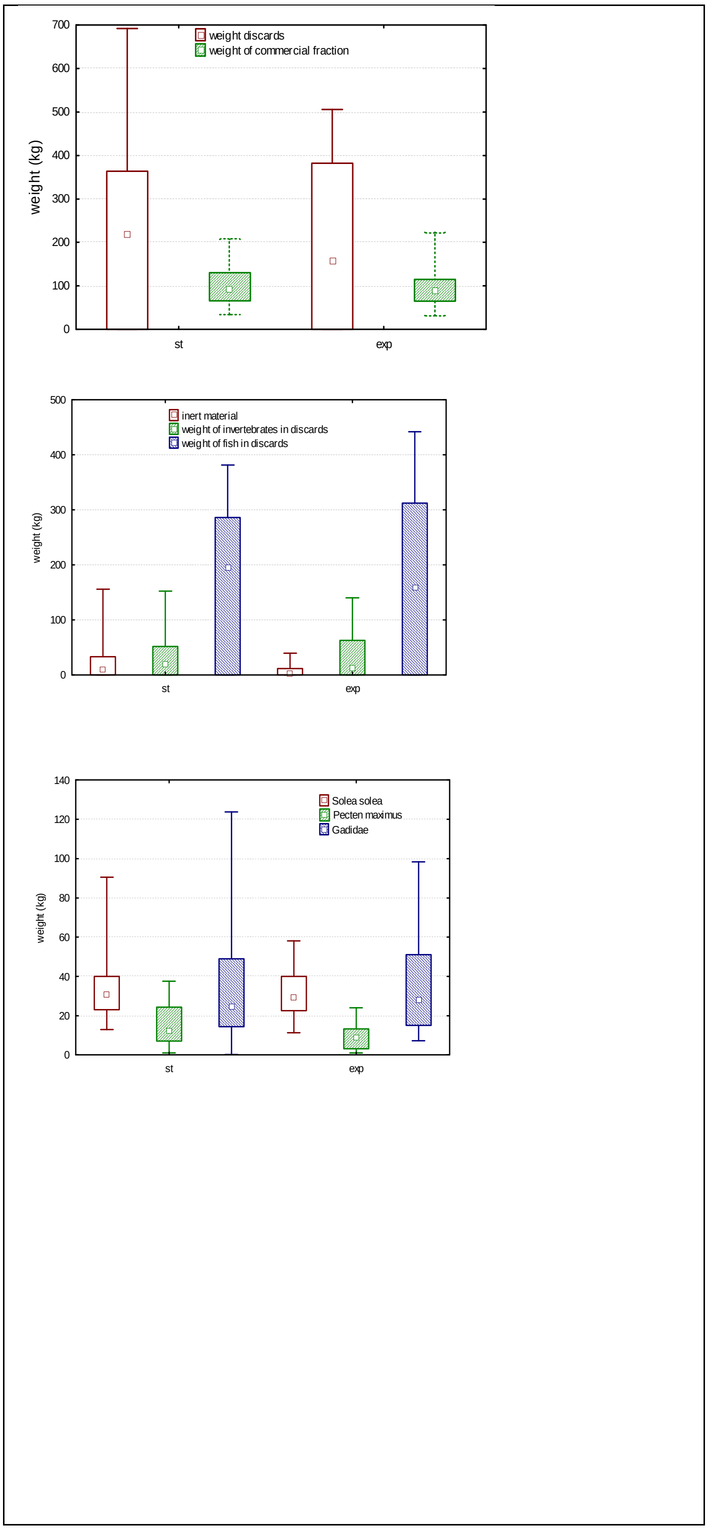


Figure 60 Effect of benthos release panel on weight of discards and commercial fraction (top), weight of different fractions of the non-commercial catch (center), weight of selected commercial species (bottom)

Table 16 – Effect of benthos release panel on weight of different species (kg) and catch fractions (* signigicant, Wilcoxon, p<0.05)

	# hauls	Wilc p	median weight st	median weight exp	hauls with reduction (%)	median difference (%)
Asterias rubens	20	0.26	1.24	1.08	45.5%	0.0%
Astropecten irregularis*	**20**	**0.01**	**2.47**	**1.07**	**63.6%**	**-46.5%**
Cancer pagurus	20	0.94	4.35	4.38	40.9%	0.0%
Crossaster papposus	20	0.14	0.00	0.00	31.8%	0.0%
Liocarcinus holsatus	20	0.60	0.00	0.00	13.6%	0.0%
Luidia sp. (L. ciliaris + L. sarsi)	20	0.46	0.00	0.00	13.6%	0.0%
Maja squinado	20	0.94	11.13	10.70	45.5%	0.0%
Marthasterias glacialis	20	0.56	21.64	20.01	54.5%	-6.0%
Necora puber	20	0.22	1.08	0.00	36.4%	0.0%
Pecten maximus	20	0.12	3.66	0.25	45.5%	0.0%
Aspitrigla cuculus	20	0.08	1.47	2.26	18.2%	5.6%
Buglossidium luteum	20	0.17	0.00	0.00	13.6%	0.0%
Callyonimus lyra	20	0.74	8.85	9.45	45.5%	0.0%
Eutrigla gurnardus	20	0.41	2.18	1.47	22.7%	1.5%
Glyptocephalus cynoglossus	20	0.83	0.00	0.00	36.4%	0.0%
Limanda limanda	20	0.31	8.64	9.09	31.8%	3.1%
Lophius piscatorius	20	0.95	2.17	2.96	36.4%	0.0%
Melanogrammus aeglefinus	20	0.60	69.37	85.58	45.5%	0.0%
Merlangius merlangus	20	0.22	16.64	25.14	40.9%	5.3%
Microstomus kitt	20	0.82	24.34	28.59	50.0%	-5.1%
Pleuronectes platessa	20	0.16	3.33	1.44	50.0%	-4.7%
Raja brachyura	20	0.61	0.00	2.53	31.8%	0.0%
Scyliorhinus canicula	20	0.79	81.49	73.62	50.0%	-2.2%
Trisopterus luscus + T. minutus	20	0.46	9.91	10.52	40.9%	0.7%
Inert fraction*	**20**	**0.01**	**26.25**	**10.67**	**77.3%**	**-48.6%**
Total weight invertebrates	20	0.68	48.89	50.98	50.0%	-3.9%
Total weight fish in discards	20	0.71	275.45	302.39	50.0%	-0.4%
Total weight discards	20	0.63	372.46	388.14	50.0%	-0.4%
Solea solea (comm)	35	0.29	31.00	29.60	42.9%	3.4%
Pecten maximus* (comm)	**35**	**<0.001**	**12.40**	**8.00**	**88.6%**	**-44.6%**
Gadidae sp. (comm)	35	0.83	24.30	28.00	45.7%	11.4%
Total weight commercial fraction*	**35**	**0.02**	**90.90**	**88.90**	**68.6%**	**-6.9%**
Efficiency (comm/total)	20	0.79	25.3%	23.0%	55.0%	-1.1%

7.8 Conclusion

RV trials and commercial trials have shown that the application of a benthos release panel in front of the cod-end can drastically reduce by-catch of inert material and benthic invertebrates. This may improve fish quality and reduce catch handling time. The reduction of benthic invertebrates appears to be strongly species specific, with relatively heavy and small species and individuals yielding the best results.

The observations for commercial species give a mixed picture. On euro-beamers, there appears to be an unacceptable loss of commercial sole (similar observations were made on board the research vessel that is rigged with trawls of comparable size). Whereas the benthos release panel performs better on large beam trawlers. This may be due to the length of the trawl which is needed for the catch to settle after the chain matrix or the tickler chains or it may be due to the length of the panel in comparison to the length of the trawl.

Task 4.1: To develop fully commercially acceptable designs of benthos release panels / zones or cod-ends for beam trawls.

(b)PARTNER CEFAS (UK)

The funds from the EU DEGREE programme, together with national funding were used to develop commercially acceptable beam trawl modifications which would release benthos and other unwanted discards, such as juvenile fish.

The focus of the work was always to engage fully with the UK beam trawl industry sectors and collaboratively develop the required solutions to this issue (i.e. commercially acceptable trawl modifications). We saw little point in developing solutions if no-one would use them. To this end, the following approaches were used:

Year	Event	Result	Industry uptake
2006	Underwater Filming Some basic research was undertaken on a charter beam trawler to gain underwater footage of various benthos release panels working in beam trawls	Good footage obtained of several designs and provided some insight on how effective benthos release zones can be fitted to beam trawls	Little interest from industry
2007	National Competition Monetary prize given to beam trawler skipper who could design release panel and demonstrate its efficacy for a continuous period of six-months	Successful prize winner (skipper Mike Sharp) benthos and discards reduced by over 60%. Good publicity obtained	Plenty of interest but uptake by other skippers negligible
2008	Demonstration trials Two beam trawlers were chartered (from Devon and Cornwall) and rigged with benthos release modifications. The idea being to further publicise the efficacy of these gear modifications	Both successfully reduced discards and benthos by over 60%. Good publicity obtained. Results of work published in scientific journal (Fisheries Research)	Uptake remained at minimal levels
2009	Intensive third party industry consultation (Social marketing agency) A specialist company was engaged to identify why uptake of gear modifications was low, despite solutions being available. A social marketing approach was used, which identified the incentives and disincentives that were affecting uptake	Very interesting results obtained including a broad range of issues which were influencing uptake. Results were published on Cefas web site (see below) and several feedback sessions were given to industry and stakeholders.	Industry expressed an overall willingness to participate in a generic discard and benthos reduction programme. Programme given the name ‘PROJECT 50%’
2009	Ten beam trawlers engaged in Project 50% - each using there own designs of benthos and discard reduction trawl modification.	Good industry participation. Discard and benthos reductions achieved on each vessel of over 60%.	Many of the issues raised in the social marketing consultation have been / are being addressed, which has greatly increased industry take up and participation.

Summary information

CEFAS (UK) 2007- National Competition

12 **BRIXHAM** www.fishingnews.co.uk 15 June 2007

Clean Fishing awards bring real technical advances

A Westcountry beam trawler fisherman has developed an innovative way to fish more 'cleanly' and greatly improve the quality of his catch.

Michael Sharp, part owner and skipper of one of Brixham's biggest beam trawlers, *Lady T Emiel*, received an award on 31 May from CEFAS after winning its Clean Fishing competition (*FN* 8 June), which was launched in July last year to encourage South West beam trawlermen to design novel modifications to their fishing gear.

Presented by the world famous chef Rick Stein, the award celebrates a modification in beam trawl design that can reduce the by-catch of unwanted fish and other benthos by 60% and also, Skipper Sharp says, greatly improve catch quality.

Three South West skippers were short-listed for the final, each of whom had put considerable work into making their fishing less damaging to by-catch species.

Dr Andrew Revill, senior scientific officer at CEFAS and key instigator of the competition said: "The capture of 'non-target' marine species is a major fisheries management problem.

"Reducing unwanted by-catch lessens the overall environmental impact of the fishery on the supporting marine ecosystem and helps to conserve precious stocks. Cleaner fishing methods potentially result in higher-quality catches and better prices paid at fish market."

Skipper Michael Sharp, together with Lyme Regis inshore skipper John Walker and Newlyn beam trawler skipper Terry Bristow (who operates the WS&S vessel, *Twilight*), heard how fisheries minister Ben Bradshaw agreed that discarded fish "is a waste that no one wants to see".

Ben Bradshaw told CEFAS that he greatly welcomes the enterprising efforts of fishermen to tackle the problem of threatened species being caught up in other catches.

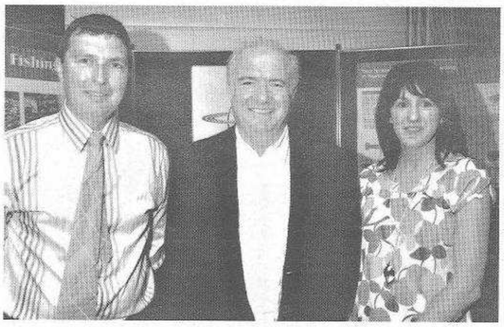
While runners-up Skipper John Walker developed a novel dredge mechanism and Newlyn Skipper Terry Bristow experimented with square mesh panels in his nets to allow small fish and shellfish to fall through, Skipper Sharpe's trials of square mesh panels – traditional diamond meshes hung by the square – has really paid off and eight other South West beam trawler skippers have already turned to that method.

Although the use of 'square' instead of diamond shaped meshes in critical parts of a trawl net is not new, until now that technique has largely been alien to beam trawling, *FN* was told.

Skipper Sharp said: "By using a square mesh panel in the belly of the nets and similar, but stronger, panels in the lower part and back of the codends, we found a reduction in by-catch of over 60% and a lot of that was undersized marketable fish, those normally discarded dead, so the use of square mesh panels has to be the way forward.

"The quality of our catch has greatly improved; so much so that Mitch Tonks of FishWorks – a firm owning restaurants, fish cookery schools and a fish sales business at Brixham – recently sent me a letter saying he owes me (and other beam trawler skippers using square mesh panels) an apology.

"His letter was a bit of fun but said something rewarding about our work. He commented how his first choice has always been fish from day-boats – those landing their catch within 24 hours of capture – but now he has to think again because the quality of beam trawled fish using nets with square mesh panels is so good.

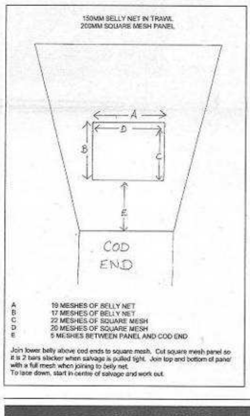


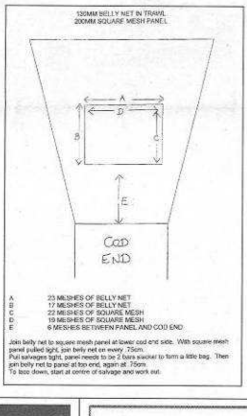
(L-R) Michael Sharp, winner of CEFAS' clean fishing competition, with celebrity chef Rick Stein and his wife Claire Sharp.

"The practical aspect of using square mesh panels is no different to using traditional diamond meshes, it's simply the same net hung by the square so mending is no problem. A square mesh panel is just as strong, it doesn't wear out any faster and I think the idea will become very popular; we certainly won't go back to the old method. Discards are a fraction of what they were before and the quality improvement can be seen on the first use. We were amazed."

Former Brixham beamer skipper and independent evaluator John Hingley, who during six months of sea trials often sailed aboard each boat to gauge the entrants' ideas, said: "I think this is a worthwhile and positive idea from CEFAS and because fishermen were involved and proactive, the results of the trials have opened-up a new world of possibilities.

"Potentially, there may not only be benefits for catch quality, but also reduced wear and tear on the trawls and possibly even fuel savings. I am pleased to be involved with this competition," he said.





Square mesh panels make a difference

"There's nothing special about the square mesh panels that were used, it's just 200mm diamond mesh (made of single 6mm diameter strand) hung square, each bar measuring 100mm," said Skipper Sharp, winner of CEFAS' Clean Fishing competition.

Independent assessor John Hingley explained: "On the times I was present on *Lady T Emiel* we took data from using a traditional net on one side and one with square mesh panels on the other and immediately saw clear differences in both the discard rate and the quality of the fish retained.

"We also looked at similar data when using square mesh panels on both sides. Data from all of the Cleaner Fishing trials on all boats that took part will be so important to the future of beam trawling.

"I was very impressed with what I saw with the square mesh panel trials and will not be surprised if it sets a trend and many other beamer skippers follow suit."

Runner-up in the competition, Newlyn Skipper Terry Bristow, was making ready to begin a trip on *Twilight II* when he told *Fishing News*: "We were all pleased to have taken part in the competition and I am already making plans to use the panels that proved their worth on *Lady T Emiel*. It's the way to go, improving the quality of fish can only be a good thing."

Skipper Sharp added: "From the very first tow we could see a great reduction in the amount of rubbish coming out of the codend, like shells, benthos of all sorts, and a reduction of discards of about 60% is bound to make a difference in the final quality of the fish.

"It took quite a lot of work trying different types of rigs and where best to put the panels; and we may well try different combinations at a later date. I know that eight more beam trawler skippers in Brixham are now using square mesh panels.

"The Cleaner Fishing competition was a real boost for the beam trawling industry, which has had so much bad press for so long.

"Statements made by people who are ill-informed have done a lot to hurt to what remains of the core of the South West fishing industry. Anything that helps to bridge any gap between the industry and its opponents is always a major step forward."

For further information and more detail see FPAR ANNEX 4.1.3 and 4.1.5

CEFAS (UK) 2008- Demonstration trials

For further information and more detail see FPAR ANNEX 4.1.3. and 4.1.6

CEFAS (UK) 2009 – Social Marketing consultation with industry

For further information and more detail see:

Project 50% on CEFAS web site INITIAL SCOPING STUDY
http://www.cefas.co.uk/data/fishing-gear-technology-at-cefas.aspx

CEFAS (UK) 2009 – Project 50% Public newsletter

*Project Fifty Percent?

Giving smaller a fish a fighting chance

Trawlermen in Plymouth and Brixham often go out to sea for five days at a time in all weathers to bring back their favoured catch of sole, plaice and turbot.

It can be a dangerous occupation and all these local fishermen have stories to tell about someone close to them who has been lost at sea. Many have worked on beam trawlers for decades and have followed in the footsteps of other family members. They use their local knowledge and years of experience to locate areas which they hope will land a high quality haul of fish and secure a good price back on land.

An avoidable waste

Even with this knowledge they cannot dictate what fish or other sea creatures end up being caught in their nets. When these are hauled onto deck, the catch is sifted by hand, with fish that can be sold being kept and everything else discarded over the side. The term 'discard' therefore means any part of the catch that is not kept for sale and returned to the sea. This has two important elements – benthos and juvenile fish.

Identifying the problem

Beam trawler nets tend to have a mesh size of at least 8cm, so benthos typically includes larger starfish, other seabed creatures, decaying matter, shells, plants and debris. Benthos on deck is a real nuisance to fishermen as it takes so much time to sift it out and return it over the side. More important though is the issue of juvenile fish, which are too small to be sold commercially or legislation forbids their landing and sale. There is much debate whether these smaller fish live to grow bigger or die as a result of being landed on deck. Even so, it is claimed that they can make up almost 50% of the total catch.

It is clear that no-one wants to land juvenile fish, especially environmentalists but also the fishermen themselves who want a sustainable industry for themselves and future generations. Now in a ground-breaking experiment, trawlermen from Plymouth and Brixham are voluntarily working to reduce the amount of juvenile fish that are discarded. They aim to trial different net configurations and mesh sizes to reduce discards by an impressive 50%. Hence the name 'Project Fifty Percent' and the title of our newsletter.

Meeting the target

The trawlermen are working with expert scientists from the Centre for Environment, Fisheries and Aquaculture Science (better known as Cefas), who are painstakingly tracking the catches. They are working on board in partnership with the fishermen, to understand the best modifications to achieve this self-imposed target, including bigger mesh sizes on their nets to let juvenile fish escape. So far, ten crews are participating and the final results are expected by the end of the year. Watch this space.

Cefas is the Centre for Environment, Fisheries and Aquaculture Science. It is the UK's largest and most diverse applied marine science centre, working in fisheries management, environmental protection and aquaculture. **www.cefas.co.uk**
If you have comments or questions please call **020 7566 3415**.

Cefas

For further information and more detail see: FPAR ANNEX 4.1.4
Or go to Project 50% on CEFAS web site
http://www.cefas.co.uk/data/fishing-gear-technology-at-cefas.aspx

Task 4.1: To develop fully commercially acceptable designs of benthos release panels / zones or cod-ends for beam trawls.

(c) PARTNER CNR-ISMAR (IT)

Different types of beam trawl are currently used in the Mediterranean Sea: Provençal (from the Southeast of France) *"gangui"* and Catalan (NW Spain) *"ganguils"*, Greek *"kankava"* for sponges, Italian *"Rapido"* for the sole and Sicilian-Sardinian *"gangamo"* for prawns and sea urchins are the most common examples.

The Rapido trawl (Figure 61) is commonly used in muddy inshore areas in the Central Adriatic Sea to fish for flatfish (common sole *Solea solea* is the main target species) and in the north Adriatic for scallops (the great scallops *Pecten jacobaeus* is the main target species). Rapido trawl is a sort of beam trawl, which consists of a box dredge of 3 m wide and 170 kg weight, rigged with teeth of 5-7 cm long and a lower leading edge and net bag to collect the catch. A single vessel may tow four and even six gears simultaneously. The towing speed is about 6-7 knots.

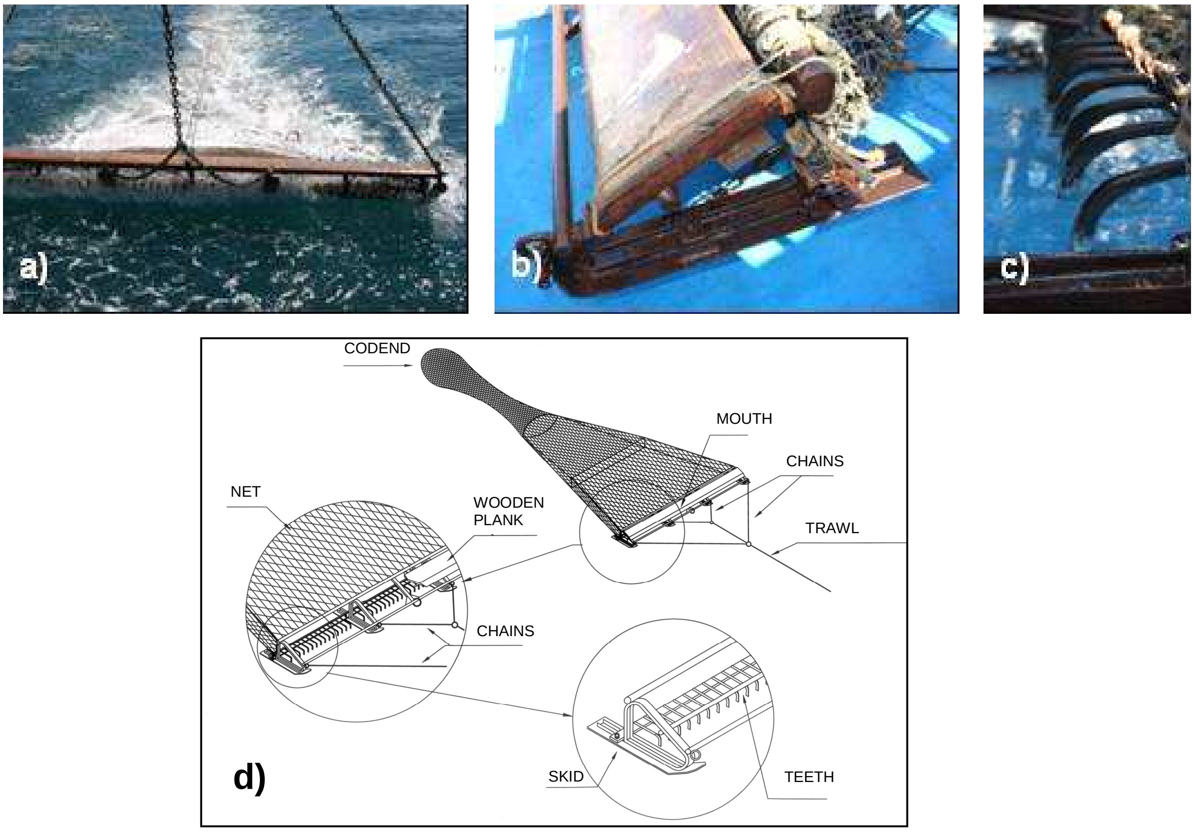


Figure 61 a) Commercial Rapido trawl used in GSA 17; b) particular of the inclined wooden board fitted in front of the metallic frame act as depressor; c) teeth; d) scheme of Rapido trawl.

In 2006, CNR-ISMAR (Participant 12) jointly collaborated with ILVO (Participant 8) and CEFAS (Participant 2) in the development of a chain matrix beam trawl and a tickler chain beam trawl. Afterwards in 2007 the design of the first tickler chain beam trawl has been changed to try to improve catch performance (see Figure 62).

The results of the trawling trials (both with Rapido and beam trawl) carried out off Ancona showed that a considerable fraction of the catch was composed of species of no commercial value, either because they were undersized or because they were unmarketable.

Beam and Rapido trawl catches reflected the multispecies nature of the fishery in this area. In terms of biomass and abundance, catches were dominated by Molluscs, mainly *A. pespelecani*, *A. demiri*, *Scapharca inaequivalvis*.

Most of the Rapido trawl catch was discarded at sea (more than 55% and 80% of the catch respectively in the first and in the second cruise). While for the beam trawl the catch discarded at sea was around 50% (43% in the first and 59% in the second cruise). In the same way Pranovi *et al*., 2001 observed that Rapido trawl fisheries seemed to exert a strong selective pressure on the macrobenthic community, being able to modify the epibenthic fauna structure which, in heavily exploited fishing grounds, was dominated by bivalves, gastropods, crabs, starfish and brittlestars.

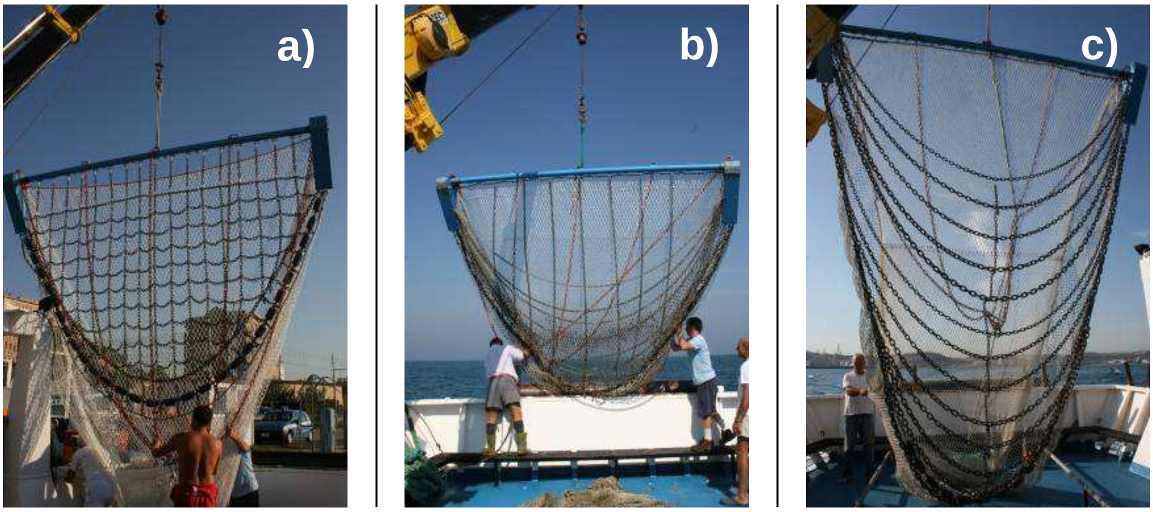


Figure 62 Different prototypes of the light beam trawls tested in the Adriatic Sea. a) Chain matrix beam trawl (CMBT06); b) tickler chain beam trawl (TCBT06) tested in 2006; c) tickler chain beam trawl (TCBT07) tested in 2007 (the number of chains was progressively reduced to one chain).

Rapido trawl catch was characterised by species living strictly associated to or within the substratum whilst beam trawl hauls were characterised by a wider array of species inhabiting very different realms of the ecosystem (from benthic to demersal to pelagic). These differences were dependant both upon differences in species behaviour and differences in selectivity with respect to different species.

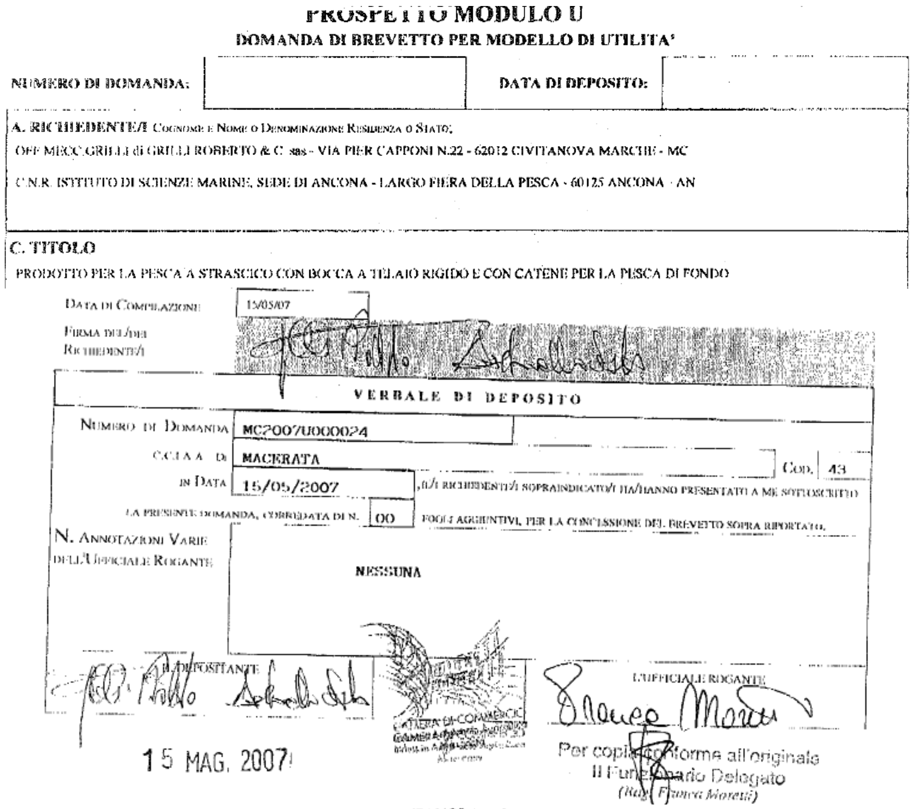
Rapido trawl was more efficient also for commercial species even if the performances of the light beam trawl improved during the second fishing trip. Recently some fishermen agreed to use the light tickler chain beam trawl and they improved their performance increasing the vertical opening with the aim of catching demersal and pelagic species. It can be notice that the mean duration of Rapido haul is around 50 minutes and this leads to very hard work shifts. Thus a reduction of the time for sorting the catch represented a very good option for fishermen. Moreover we noticed that the reduction of the discarded portion of the catch improved the quality of fish.

Finally the physical impact of light beam trawl on the sea bed was lower than that observed with Rapido trawl. In fact Rapido trawl showed the highest values of both total warp drag and net drag resistance (recorded with the electronic load cells). This means that Rapido trawl highly impacted the seabed and it needs the highest power to be towed.

The main results can be drawn:

- the sea trials conducted so far evidenced that in the Adriatic Sea the Rapido trawl targeting common sole was characterised by multi-species catches;
- although about 70% of the commercial catch was discarded, the Rapido did not seem to have a heavy impact on this fraction, as most of the species were alive when returned to the sea;
- both in the Rapido and beam trawl, the catch rates of non-target benthic invertebrates in the modified square-mesh codend were consistently lower;
- the towing speed of the beam trawls were always lower than Rapido as well as the towing forces. A reasonable amount of fuel was saved by switching to beam trawl;
- the first prototype of chain matrix beam trawl was inefficient and replaced by a tickler chain beam trawl.

In light of the results obtained in the current study the Italian door manufacture "Grilli" SAS and the CNR-ISMAR patented the experimental beam trawl which is now used by several fishing boats in the Adriatic Sea.



PROSPETTO MODULO U

DOMANDA DI BREVETTO PER MODELLO DI UTILITA'

NUMERO DI DOMANDA: | DATA DI DEPOSITO:

A. RICHIEDENTE/I COGNOME E NOME O DENOMINAZIONE RESIDENZA O STATO:

OFF MECC.GRILLI di GRILLI ROBERTO & C. sas - VIA PIER CAPPONI N.22 - 62012 CIVITANOVA MARCHE - MC

C.N.R. ISTITUTO DI SCIENZE MARINE, SEDE DI ANCONA - LARGO FIERA DELLA PESCA - 60125 ANCONA - AN

C. TITOLO

PRODOTTO PER LA PESCA A STRASCICO CON BOCCA A TELAIO RIGIDO E CON CATENE PER LA PESCA DI FONDO

DATA DI COMPILAZIONE 15/05/07

FIRMA DEL/DEI RICHIEDENTE/I

VERBALE DI DEPOSITO

NUMERO DI DOMANDA MC2007U000024

C.C.I.A.A. DI MACERATA COD. 43

IN DATA 15/05/2007, IL/I RICHIEDENTE/I SOPRAINDICATO/I HA/HANNO PRESENTATO A ME SOTTOSCRITTO LA PRESENTE DOMANDA, CORREDATA DI N. 00 FOGLI AGGIUNTIVI, PER LA CONCESSIONE DEL BREVETTO SOPRA RIPORTATO.

N. ANNOTAZIONI VARIE DELL'UFFICIALE ROGANTE

NESSUNA

IL DEPOSITANTE

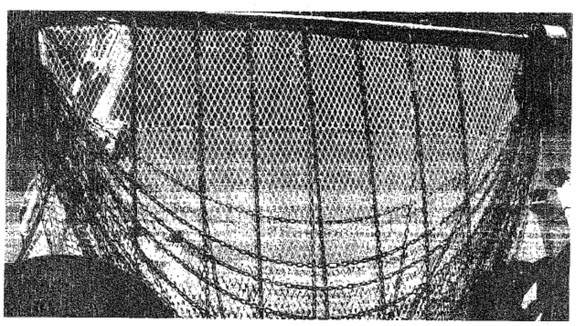
L'UFFICIALE ROGANTE

15 MAG. 2007

Per copia conforme all'originale
Il Funzionario Delegato

TAVOLA n. 3

fig. 4



Full details are contained in Annex 4.1.8

Task 4.2: To carry out laboratory experiments on the effects of electrical stimuli on marine biota, and to evaluate the biological performance (and economic in WP 5) of electrified pulse beam trawls on board of commercial fishing vessels.

(d) PARTNER IMARES (NETHERLANDS)

7.9 Research in relation to ICES Advice

In response to questions asked by ICES on the effects of pulse stimulation in commercial beam trawling on components of the marine ecosystem a number of preliminary studies were undertaken in the period between 31 May and 5 October 2007.

These activities involved:

1. Measurements on the detailed stimulus applied in the pulse trawling system developed by the company Verburg-Holland Ltd., i.e. the amplitude, pulse width, rise and fall times, repetition rate and field strength along the electrodes. These measurements were done onboard of the commercial fishing vessel MFV “Lub Senior” (UK153), and in tank facilities of the manufacturer of the pulse beam trawl.
2. Simulation of this stimulus in the recirculated aquaculture system available at IMARES
3. Development of a protocol for keeping small-spotted catsharks alive and well, including dietary requirements.
4. The exposure of catsharks (*Scyliorhinus canicula* L.) to a simulated pulse under laboratory conditions and observation of behaviour, including foraging, and monitoring mortality
5. Investigation of possible spinal damage of cod caught by a commercial vessel using pulse beam trawls by X-ray photography.

The electric pulse characteristics were measured onboard MFV “Lub Senior” UK153 at sea. Shortly after these measurements the complete system including trawl winch became available for measurements in the Verburg-Holland Ltd. reference basin with fixed salinity (specific conductance). Based on this outcome a pulse simulator system was developed to be used in the experiments on fish in tanks of IMARES. This stimulus of this system was proven to be electrically equivalent.

Measurements of the electrical stimulus focused on the main parameters:

- Amplitude;
- Pulse width;
- Rise and fall times;
- Repetition rate;
- Electric field strength measurements between the electrodes.

The analysis of X-ray scans revealed that 2 out of 25 fish had a dislocated spine. In addition 6 animals out of the group of 25 showed deformations which can be attributed to natural causes. Although the sample size is small any effect from the pulse stimulation can not be ruled out, but it appears to be low in percentage, and still needs to be compared to fish caught with the conventional system. Therefore any definite conclusions can not be drawn at this stage.

Guidelines for husbandry and assessment of responses in behaviour, including foraging, to exposure of the electric field were developed. A first experiment involved two single fish. An individual tagged catshark was exposed to the electric field and its behaviour was compared to that of a control fish. No response in behaviour in this fish could be observed, and mortality did not occur. Based on this preliminary trial a protocol was drafted to assess effects in behaviour of groups of sharks to the electric field. A second experiment was done later on two groups of catsharks, one group exposed to an electrical stimulus and the other not, thus serving as a control group. From this it was found that transferring these fish from a holding tank to a separate tank in which the stimulus can be applied does affect feeding behaviour. This finding will be used to improve the experimental design. In addition no mortality was seen in the two groups, indicating that the stimulus did not have a noticeable immediate effect.

The results obtained were of a preliminary nature. By actually carrying out these experiments the researchers learned more about the difficulties of keeping fish alive in good condition and inferring from their behaviour and mortality the effects of the electrical stimulation on these species. It was then decided to use an adapted research protocol, in which individuals were restricted in movement and placed in certain positions relative to the electrodes, where the field strength of the pulse could be measured, and therefore the exposure known.

Further studies were done financed by the Dutch Ministry of Agriculture, Nature and Food Quality, again using the stimulus of the Verburg-Holland system, in 2008 on cat sharks and cod (*Gadus morhua* L.), and in 2009 on six benthic invertebrate species: ragworm (*Nereis virens* L.), common prawn (*Palaemon serratus* L.), subtruncate surf clam *(Spisula subtruncata* L.), European green crab (*Carcinus maenas* L.), common starfish (*Asterias rubens* L.), and Atlantic razor clam (*Ensis directus* L.). This work is currently under review by ICES.

7.10 Monitoring of sea trips on commercial vessel fishing with pulse beam trawls

The catches in terms of landings and discards were monitored onboard MFV TX68, fishing with two pulse trawls using the Verburg-Holland system during four weeks in June-August 2009. The average fishing speed was about 5 nautical miles per hour. The fishing area of the four trips was east of the coast of England and fishing depth was 36 m on average with a minimum depth of 20 ms and a maximum depth of 46 m.

For this survey the standard sampling procedure for the yearly monitoring of discards of conventional beam trawl fleet was applied (Helmond and van Overzee, 2008). For each sampled haul, a representative sub-sample of the discards was taken from the conveyer belt. All fish in the sub-sample were counted and length of the fish were measured. Benthic invertebrates were only counted. Total and sampled volume of discards was recorded. In addition, sub-samples of the landed fish were measured, and total and sampled landings weight were recorded. All data was entered into a computer program on haul-by-haul basis and later transferred into a central database.

Sampled numbers of fish per haul were raised to numbers at length, for both discards and landings. Numbers at age landed and discarded are raised to fleet level by effort-ratio: multiplying total numbers at age in the sampled trips with the ratio of hp_effort (effort in days at sea multiplied by the engine power of the vessel in hp) of the fleet to hp_effort of the sampled trips.

The four trips led to a total of 103 valid hauls for analysis, with a total fishing duration of 186 hours. The number of hauls per trip varied between 17 and 38.

The average number of plaice landed per hour was 58 or, in weight 19 kg plaice per hour. The average number of plaice discarded per hour was 164 or, in weight 18 kg plaice per hour. This resulted in an average discard percentage for plaice of 74% in numbers and 49% in weight.

The average number of sole landed per hour was 208 or, in weight 53 kg sole per hour. The average number of sole discarded per hour was 54 or, in weight 5 kg sole per hour. This resulted in an average discard percentage for sole of 21% in numbers and 9% in weight.

Comparing the landings with that of conventional beam trawl discard surveys in 2007 leads to the general impression that with the pulse more sole was caught and less plaice than with a conventional beam trawl. The range of numbers of plaice caught was 101 - 561 per hour on the conventional beam trawls monitored in 2007 (Helmond & van Overzee, 2008), whereas during this survey between 14 – 106 plaice where caught per hour. The range of number of sole caught was 45 - 149 per hour on the conventional beam trawls that were monitored in 2007, whereas during this survey between 142 – 259 number of sole where caught per hour.

However data from 2009 was not yet available, also it has to be taken into account that area has influence on fishing. The comparison of pulse beam trawling vs. conventional beam trawling in 2006 showed that the pulse trawl caught less sole in kg per hour, i.e. 12.87 vs. 16.45 (ratio 78.2%), and fewer plaice, i.e. 29.76 vs. 46.13 kg per hour (ratio 64.5%), see Van Marlen et al., 2006.

The total discards per trip (trip 1 and 4) were within range of the discards per trip in earlier years, but the average discard percentages of as well plaice as sole were lower for the pulse beamtrawl than the average percentages in 2005, 2006 and 2007 (Table 17).

Table 17 Comparison of discard percentages of plaice and sole with those of conventional beam trawls in the years 2005, 2006, and 2007

	% D Plaice		% D Sole	
	n	w	n	w
BT 2005	83	52	23	11
BT 2006	86	54	29	13
BT 2007	77	46	23	10
TX68	**56**	**34**	**17**	**7**

In 2006 the workers found on the UK153 the average discard number/hour for sole 14.6 (pulse) vs. 19.4 (conventional), and the average weight in kg/hour: 1.4 (pulse) vs. 1.8 (conventional). For plaice these were in numbers/hour: 997 (pulse) vs. 948 (conventional), and in weight: 68.1 vs. 66.9 kg/hour. The differences were statistically significant for sole, but not for plaice (Van Marlen et al., 2006).

It was concluded that the pulse trawl used on MFV TX68 showed lower percentages of discards for plaice, i.e. 56% in numbers vs. 77-86% (conventional) over the years 2005-2007, and 34% in weight vs. 46-54% (conventional). For sole these percentages were 17% (pulse) vs. 23-29% (conventional), and 7% (pulse) vs. 10-13% (conventional). Compared to the earlier version of pulse trawl used in 2006, more sole was caught and fewer plaice per unit of time.

Task 4.3: To develop and test a low impact oyster dredge.

A prototype of a box dredge with an expected low impact on the seabed has been developed in national Danish programs. Its impact on benthos and sediment as well as its fishing properties were thoroughly tested in DEGREE.

The new box dredge (low impact) was tested in several different ways during 8 days of experimental fishery in July 2008. The choice of fishing grounds was based on expected catch of all size groups of oysters and the diversity of sediment. Three areas; Nissum West, Nissum East and Venø, all located in the Western part of the Limfjord,were chosen (Figure 63).

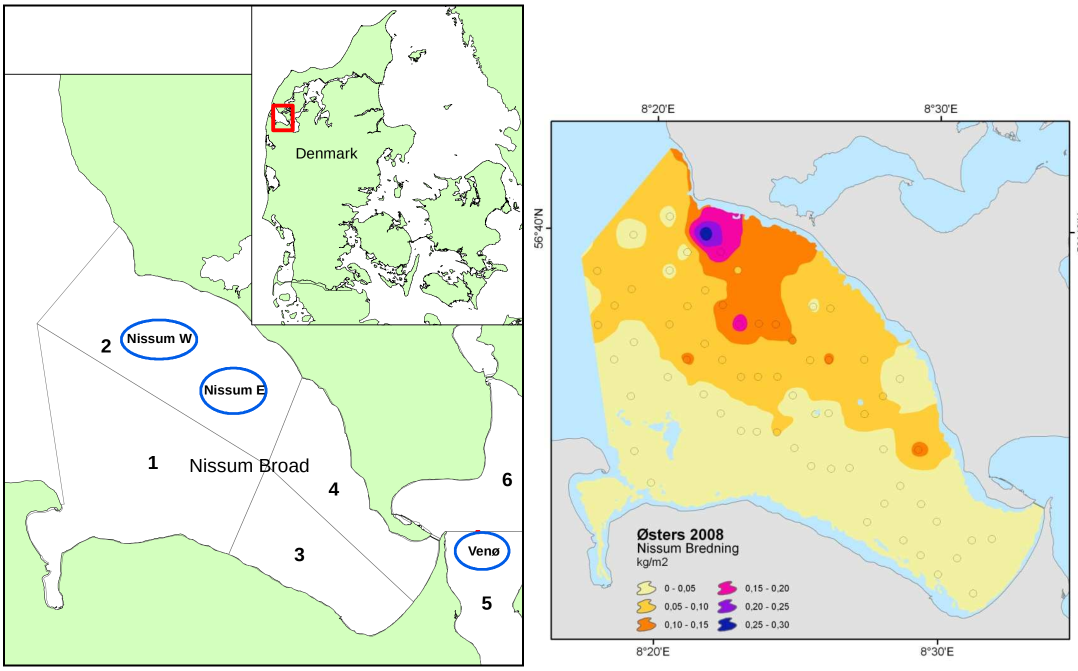


Figure 63 Left: Map of Denmark with experimental fishing grounds indicated by blue circles. Right: Density map of oysters from assessment in June 2008. The density of oysters at the experimental fishing grounds was approximately 0.1 kg m^{-2}

<u>Box dredge tests</u>

i. The size selectivity of oysters (*Ostrea edulis*) was tested by use of the covered coded technique. The abilities of different panels of the gear to retain different length classes of oysters were estimated by enclosing the gear in fine meshed covers designed to retain all oysters, in the selective range, that are sorted out through the gear.
ii. The catchability of oysters and other epifauna of the box dredge were tested against the standard dredge in a catch comparison setup. The two gears were towed simultaneously and the catches compared as described by Wileman et al. (1996). No cover was used in this experiment.
iii. Input data for a model assessing the degree of physical disturbance of the bottom caused by the two dredges (WP2) was collected. These included measurements of the track profiles after dredging and drag forces of the gears throughout the tow.
iv. Input data for a model assessing the impact on benthos of the two dredges (WP2) was collected. Mega fauna was sorted and counted and weight of shells and pebbles which serve as attachment sites and refugees for several species, were weighted.

Box dredge

The new design is a box dredge where the catch is lifted into a collection box which has no contact with the sea bed. The dredge has two 8 cm wide runners and is towed in four points – two points just in front of the knife and two points on top of the rear end of the box (Fig. 64). The tested box is made of stainless steel.

The knife is relatively high and lifts the catch 13.5 cm off the bottom and into a collection bag / box. The knife has elongated holes that helps sorting out mud at an early stage and reduce pressure on the gear (Fig. 65A).

The knife at the box dredge is attached to the box by links of chains at the centre of rotation of the knife (Fig. 65B). This design allows the knife to move independently of the box which ensures optimal bottom contact. The upper rear edge of the knife is attached to the inside of the box with straps of rubber. The knife alone weighs 12 kg.

Figure 64 Box dredge. Photo: Per Dolmer

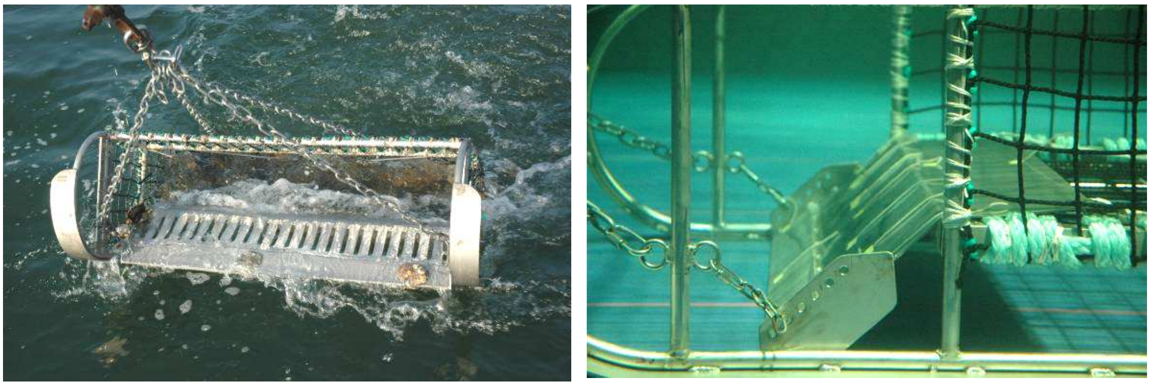


Figure 65 Knife seen from front (A) and from side (B). Photo: Per Dolmer.

Conclusions

i. The box dredge catches more large oysters (>10 cm) and less small oysters than the standard dredge (catch comparison).
ii. The selectivity of the box dredge? – results from covered cod end experiment are still to be analyzed in detail, but simple catch comparisons with a standard dredge shows improved selective properties.

iii. Track profile analyses indicate a lower impact of the box dredge compared to the standard dredge in terms of removing and compressing sediment, but the drag force measurements showed slightly higher values for hauls with the box dredge.
iv. The catch comparison experiment showed no marked difference, but indicated that the box dredge catches less megafauna, stones and shells. Apparently some variation between species occurred.

Full details are contained in Annex 4.1.7

Task 4.4: To quantify the environmental impact reductions associated with the technologies developed in WP 4. Data from this task will feed directly into WP2.

This work was undertaken by Partner IVLO (Belgium) and the data collected are presented in WP4, Task 4.1 and in Annex "Alternative beam trawl compilation DEGREE.pdf".

7.11 Deviations from the project work-programme in WP4, and corrective actions taken/suggested

Partner 01
Due to the ICES advice on pulse trawling issued in 2006 the plan of ten trips to be monitored by IMARES was changed and money allocated to tank experiments of fish and invertebrates under electrical stimuli after consultation with the EU. An agreement to receive detailed information of the stimulus used in these experiments with the producing company was reached after four months of debates and negotiations. Measurements on the electrical field were conducted in 2007 in the lab and in situ at sea, and tank experiments were carried out on small-spotted cat sharks (*Scyliorhinus canicula* L.) using a pulse simulator based on these measurements. The occurrence of spinal damage of cod caught by a commercial vessel using pulse beam trawls was studied by X-ray photography. In consultation with LEI some of the original budget was reallocated to these tank trials. The Technical Annex of the project was adjusted to these changes.

8 WP5 – approach and results

Objectives
Task 5.1: To assess the economic feasibility of the alternative gears and gear modifications developed in WP3, and WP4 from the perspective of the fisher.
Task 5.2: To estimate the cost effectiveness of alternative gears
Task 5.3: To assess the wider economic implications of adoption of these gears.

Partner 01
A comparative assessment of performance between the electric (pulse trawl/pulskor) beam trawl and the existing conventional beam trawl (as currently employed by the Dutch fleet) was completed by partner 01 (LEI) and is given in:.

The economic performance and the environmental impact of the Pulse trawl in comparison to the conventional Beam trawl (WP 5.1 and WP 5.2.), by Ellen Hoefnagel and Kees Taal. LEI/ Wageningen UR. September 2009

Abstract
The aim of this work package is to assess the economic feasibility of the alternative gear, the pulse trawl, for the Dutch beam trawl. In a separate paragraph the environmental impact of the pulse trawl in comparison to the conventional beam trawl will be assessed by looking at the change in fuel consumption and the change in catch composition, discards and benthos impact. Next to this the cost effectiveness of the pulse trawl will be assessed.

1. The economic performance of the Pulse trawl in comparison to the conventional Beam trawl

1. 1. Introduction

The willingness of fishermen to adopt the pulse trawl will largely depend on the impact that the gear will have on their own economic performance. Gear that results in decrease of revenues below costs would not be accepted by any fisherman, while gear that enhances profitability will be readily adopted. Gear that results in lower levels of profitability than the current beam trawl would also not easily be voluntarily adopted. Compliance with any legislated gear restrictions would depend, at least in part, with the degree by which profits fell. It is therefore important to understand this impact when assessing the likelihood of adoption and compliance with any legislated requirement to use the pulse trawl.

This paragraph presents estimates of the economic impact of adoption of the pulse trawl (PT) from the perspective of the fisherman. It presents a measure of the financial profitability of an individual fisherman adopting PT, which can be compared with the profitability of using the Beam trawl (BT). For modifications to existing gear, this involves estimates of changes in the revenue and costs from using the gear. The impact on revenue is based on changes in catch rates and catch composition observed in the sea trials. In the case of the pulse trawl change in fuel consumption has a large impact on costs. Estimates of gear costs are derived based on the gear specifications. The economic results from the sea trials are applied to cost and earnings data collected from a sample of four similar vessels operating in the same fishery as the sea trial vessel (PT1), during the period 2004-2006.

Next to this economic results of another pulse trawl vessel (PT2) in 2009 has been compared to the results of the same vessel (BTx) that operated in 2007 as a beam trawl vessel. Cost data collected from the sea trial vessel also provide an indication of the relevance of the derived cost per day to the alternative application of the gear. Catch and revenue information are based on the sea trials, however the pulse trawl that operated in the period 2004-2006, operated only in 2006 on a commercial basis. It is likely that the revenue information obtained from the sea trials may underestimate the revenue that could be achieved once fishers gained experience in the use of the gear. That is why the first three quarters of 2006 are considered to deliver reliable and valuable data, since ‘growing pains’ in the experimental phase were conquered. The fishermen of PT2 started in May 2009 with the commercial exploitation of the pulse trawl, and data from the period 4 May till 2 October 2009 is compared to the data of BTx in the same period in 2007.

1.2. General setting of Dutch fishery

The Dutch fleet fishes its coastal waters (12 miles zone), the mid-distant waters (North Sea), and the high seas. The cutter fleet fish mainly for demersals, like sole, plaice, cod, whiting, and shrimps, and also pelagic fish, like herring. These North Sea stocks are joined with some of the European Union Member States bordering on the North Sea, namely Belgium, Germany, Great Britain, and Denmark, and to a certain extent with the non-Member States Norway, for plaice.

In 2005 the cutter fishery existed of 342 vessels of which 242 were beam trawlers (large beam trawlers and Euro cutters). Other vessels were: three otter trawlers, one round fish pair trawlers, one herring pair trawlers, 47 shrimp vessels and several other gear vessels (like twin rig, Danish seine and fixed net fishing for langoustines, red gurnard, red mullet, dab, plaice and sole). Next to this Dutch fishery consists of 15 high seas pelagic trawlers and 64 mussel vessels. Total engine power of the Dutch fleet is 332,000 HP. 2263 Fishermen find employment on the Dutch fleet (Taal et al 2006). The number of vessels in the active cutter fleet in 2009 decreased to 308 cutters while the total engine power declined by 36% to 268,000 HP (Taal et al. 2009).

In general the cutters are property of (extended) fishing families, on which father and sons complemented with other fishermen, work. Together they fish in a partnership in which the owner(s) bring in their vessel(s) and ITQs, while the other fishermen bring in their labour. Together they agree on a division of the revenues.

1.3. Beam trawl cutter fleet

The beam trawl cutter fleet consisted in 2005 of 102 large beam trawlers and 140 Euro cutters, also operating with a beam trawl, total 240 beam trawlers. Since then the number of large beam trawlers decreased to 80 and the number of Euro cutters (seasonally targeting flatfish) to 70 in 2008. Cutters fish the coastal waters (12 miles zone) and the mid-distant waters in the North Sea: Dogger Bank, German Bight, and north of Friesland. Deeper parts of the North Sea and parts with a lack of streams are seldom fished. “Although there are relatively few restrictions on the areas that can be fished by beam trawlers, the distribution of fishing activity is patchy on many scales (Rijnsdorp et al., 1998). For instance, more than half the North Sea is not fished by the beam trawl fleet and yet small areas in the south-eastern part are trawled more than 10 times per year (Rijnsdorp et al., 1998)”. The cutter fleet fishes mainly for demersals, like sole, plaice, cod, whiting, and shrimps, and also pelagic fish, like herring. Total engine power of the Dutch beam trawl fleet is estimated at a maximum of 181.000 HP. Revenues in the cutter fleet as a whole decreased in 2008 by 7% to € 252 million. The financial position of the cutter sector is rather bad since the year 2002 (Taal et al 2009).

1.4. The evolution of the fishing techniques in the Netherlands

Dutch fishers used until circa 1960 the otter trawl (borden trawl) to fish for flatfish. Dutch shrimp fishermen from the Wadden sea imported the shrimp beam trawl from Germany. They improved the beam trawl and went for shrimp in the North Sea from 1950 on. Because results of this technique were very good, one tried to catch flatfish as well with some extra features added to the beam trawl. Before 1960 some fishermen that used the otter trawl switched over to beam trawling and from 1960 on the otter trawl became outmoded[1.]

The beam trawl became very popular and successful in Dutch flatfish fishery. Catches were high, however since introduction of the quota system fishermen have had to adapt learning not to fish as much as possible, but to fish within their ITQ limits. The beam trawl's reputation changed for the worse a number of years ago. The technique is now considered to be environmentally unfriendly because the benthos is damaged by the trawling and it generates a lot of by catch. Some fishermen have already switched over to twinrig, hydrorig, Danish seine, otter trawl (again) and fixed net fishing. A new technique, the pulse trawl, has been tested on an experimental basis. Two vessels have recently, respectively in 2006 and in 2009, been using this technique on a commercial basis and others would like to follow. Since the pulse trawl is using electric pulses to startle the flatfish and electric fishing is forbidden in Europe, every year a dispensation from this rule is needed. ICES is looking at the effects of the pulses on the ecosystem. Whether the pulse trawl will be allowed is still uncertain.

2. Pulse trawling compared to beam trawling

2.1. Two periods of comparison

The performance of two pulse trawl vessels (PT1 and PT2) will be compared to the traditional beam trawl in two ways:
1) PT1 will be compared to four reference vessels (BT1, BT2, BT3 and BT4) and to the average of these BTs in 2006 (paragraph 2.2).
2) The performance of PT2 in 2009 will be compared to the performance of the same vessel that operated in 2007 as a beam trawl (paragraph 2.3).

2.2. Main characteristics of the pulse trawl vessel (PT1) and the four reference vessels (BT1-4) 2004-2006

The PT1 was built in 1998, has a length of 42.4 meter and an engine of 2000 HP. The PT1 will be compared with the average of the four reference beam trawl vessels. The average of the reference vessels differ slightly from the PT1 (see table 1).

Table 1: Characteristics of the vessels.

	PT1	4 Reference Vessels	Difference in %
Length	42,40	41,44	+2
GT	508	466	+9
HP	2000	2224	-10

1 Source: de Vleet, Ecomare

Year hull	1998	1991	-7 Years
Year engine	1999	1995	-4 Years

2.2.1. Pulse trawling 2004-2006

During the period 2004-2006 the pulse trawl (PT1) was in its experimental phase, it had to overcome many growing pains. Various changes and improvements were made to the system and in 2004 and 2005 pulse trawling did not perform economically better than the beam trawlers. However, costs for PT1 were lower than of BTs due to a lower fuel consumption of 50%-60% next to high fuel prices. Savings were up to 300,000 € in 2005. Fuel costs for BTs increased in 2005. In this period the pulse trawl technique was not yet fully developed. In fact catches stayed behind the BT catches and as a consequence revenues were low, no profits were made, although fish prices were good.

Conventional beam trawling however has not been economical profitable for some years now. Costs are high; in 2005 the BT fleet (on average) suffered losses weekly. High costs are mainly caused by high fuel prices and the high fuel consumption of beam trawling. This is why an alternative to beam trawling is economically necessary. The costs of investing in pulse trawl gear are high (circa 400,000 €), however some enterprises are confident that revenues will improve and consequently investment in PT will become feasible. In the middle of 2006 PT1 started operating on a commercial base. The fishing enterprise using the pulse trawl gear, was allowed to rent the gear from the ministry that owns the pulse trawl gear.

2.2.2. Pulse trawling on a commercial basis in 2006

In the third quarter of 2006 of the test phase of PT1 came to an end and the fishing enterprise continued using the alternative gear on a commercial base. If we compare the average revenues in the first three quarters of 2006 of PT1 with the third quarter of 2006 we see an increase in revenues.

Table 2: revenues for first three quarters of 2006

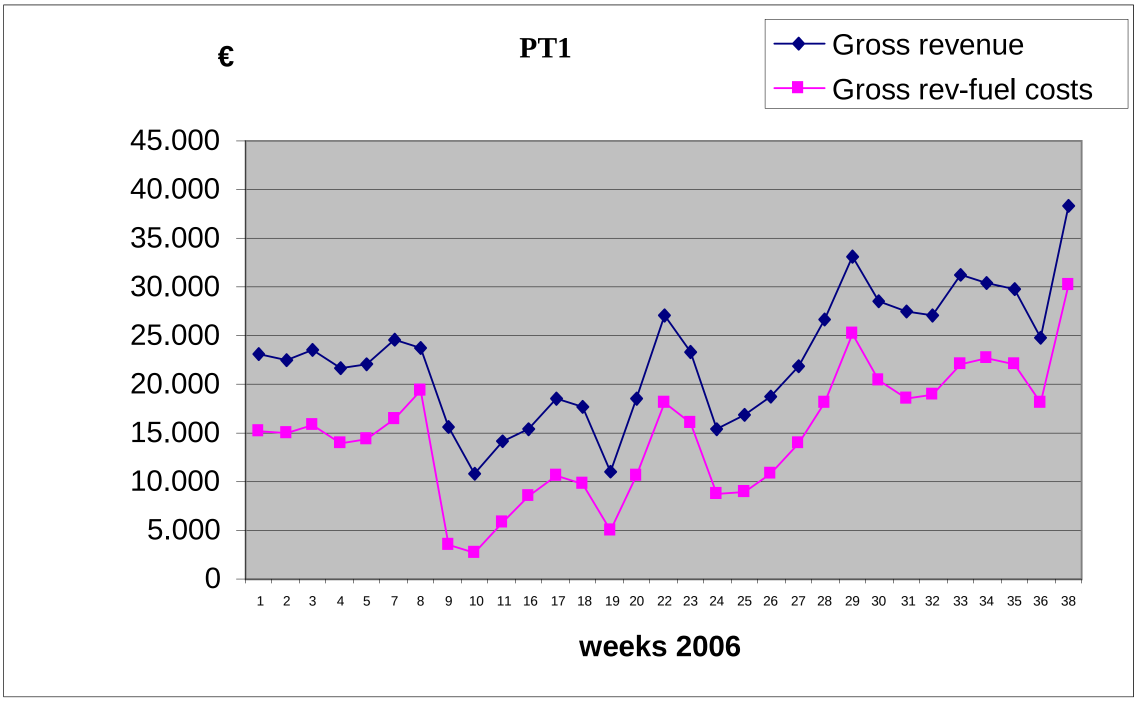
PT1	**Week 1 till 38 of 2006 (1 January till 30 September)**	
	Per day	Per week
Average revenues	5.772	23.087
Fuel costs	2.001	8.004
Revenue minus fuel costs	3.771€	15.083€

Table 3: revenues 3rd quarter of 2006: commercial base

PT1	**Week 27 till 38 of 2006 (1 July till 30 September)**	
	Per day	Per week
Average revenues	7.264	29.057
Fuel costs	2.030	8.119
Revenue minus fuel costs	5.234€	20.938€

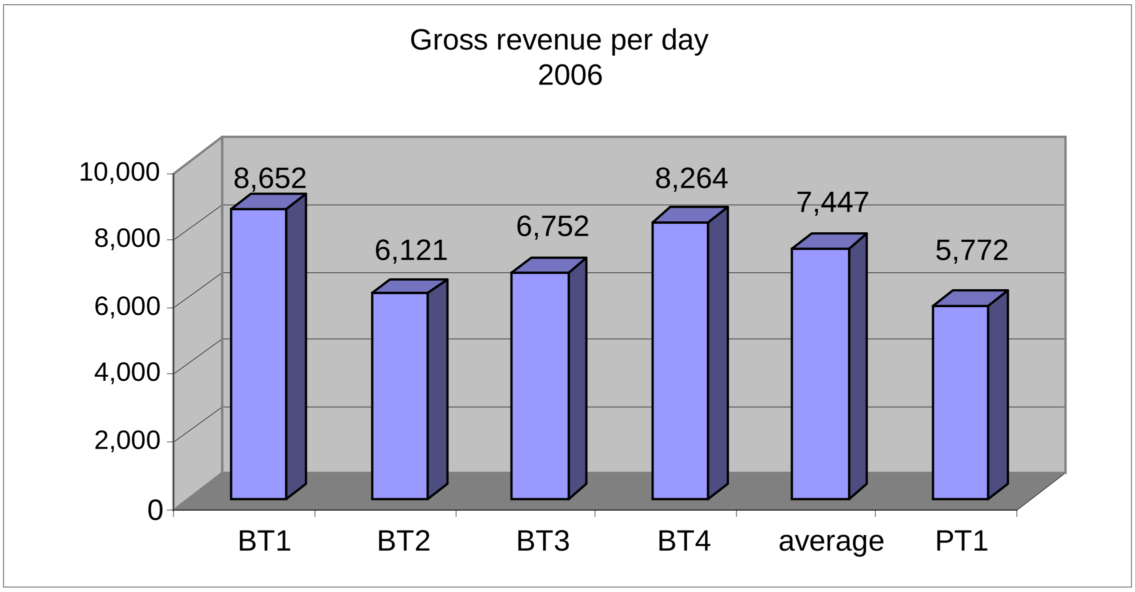
In the third quarter of 2006 no technical problems occurred. An increase in catches and revenues of 25%, without an increase in costs made PT1 a competitor of the reference vessels (see below). Profitability seems to be better in this period than average Dutch beam trawler, especially in the sole fishery.

Figure 1: Gross revenue and gross revenue minus fuel costs for first 3 quarters of 2006



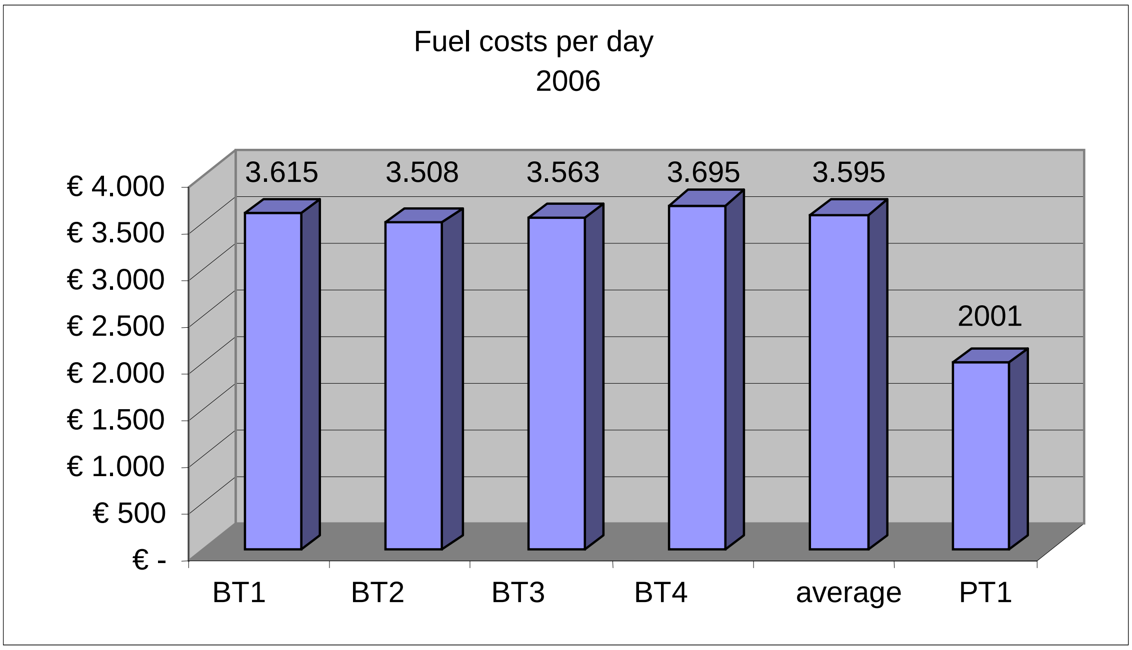
In next figures results of 2006 per day of PT1 compared to four reference BT vessels and average of the reference vessels are presented.

Figure 2: Gross revenue per day in 2006



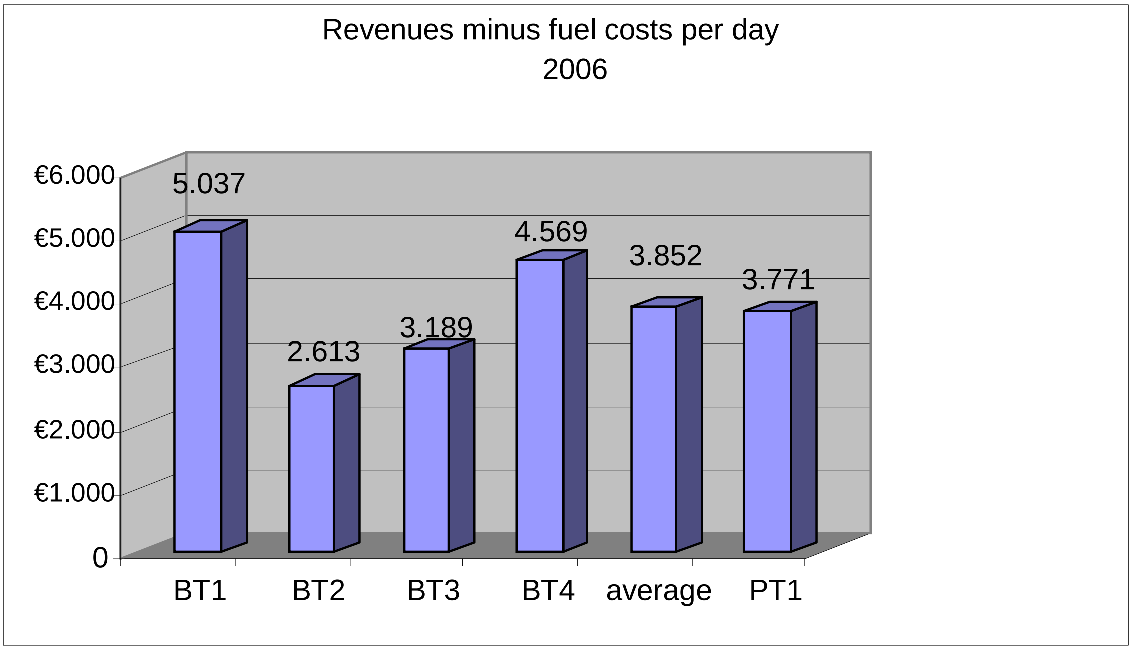
Catches and revenues of PT1 are lower than the BT reference vessels. Fuel costs, however are much lower for PT1.

Figure 3: Fuel costs per day in 2006



If revenues minus fuel costs per day in 2006 are calculated, it shows that PT1 can compete with beam trawlers.

Figure 4: Revenues minus fuel costs per day in 2006



In next graphs result of 2006 per week of PT1 compared to four reference BT vessels and average of the reference vessels are presented. Normally a week consists of 4 fishing days.

Figure 5: Gross revenue per week in 2006

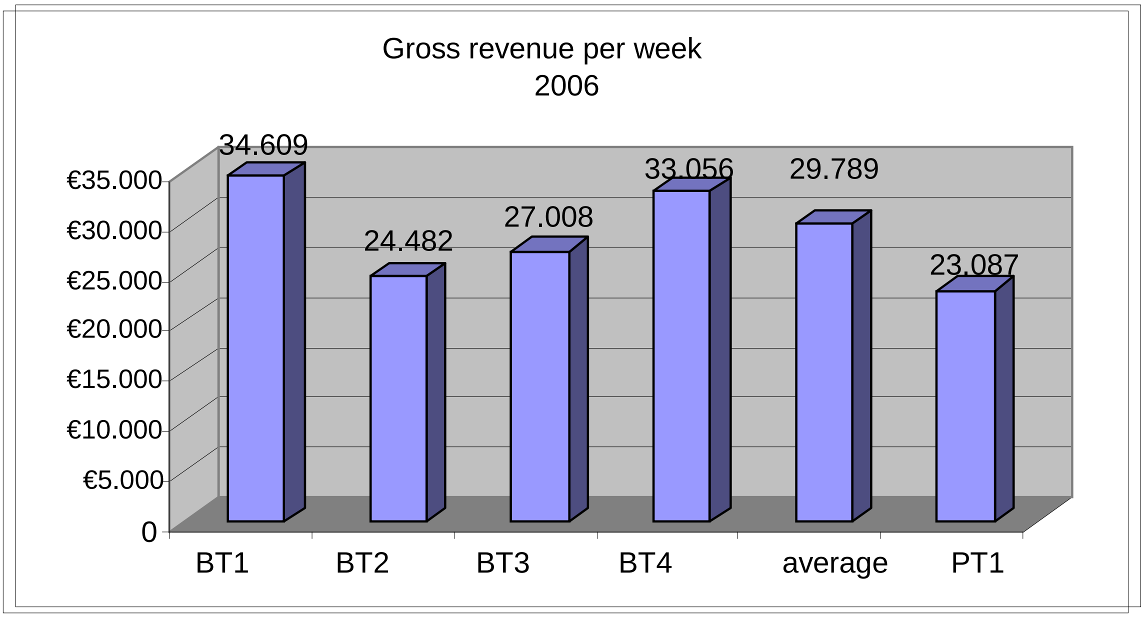


Figure 6: Fuel costs per week in 2006

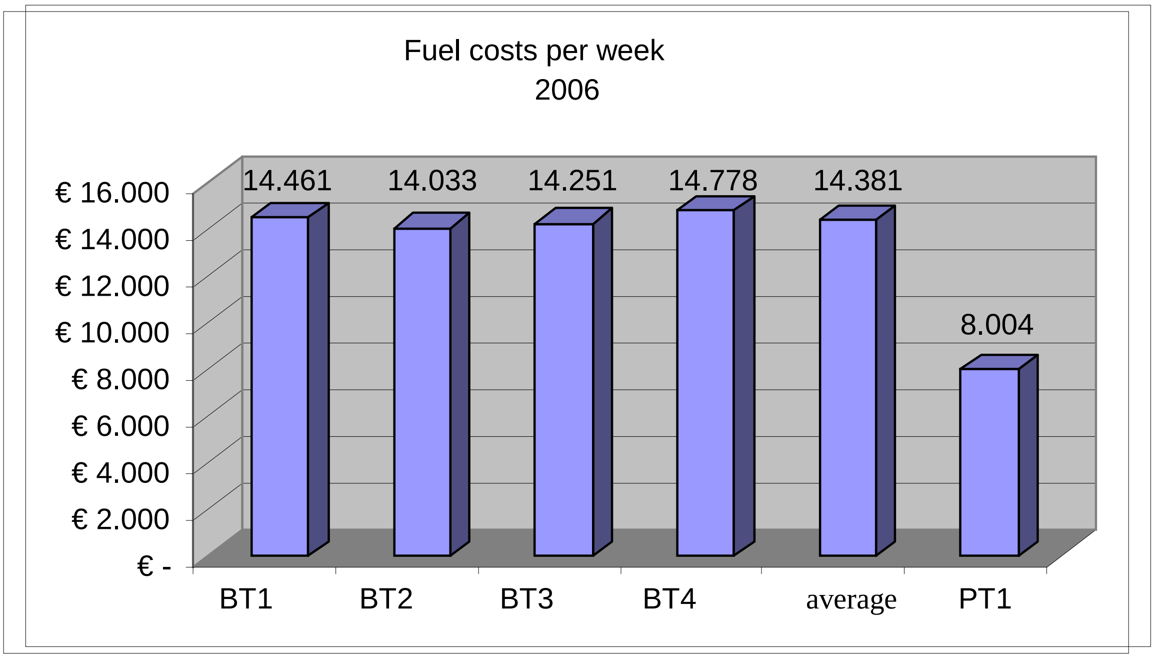
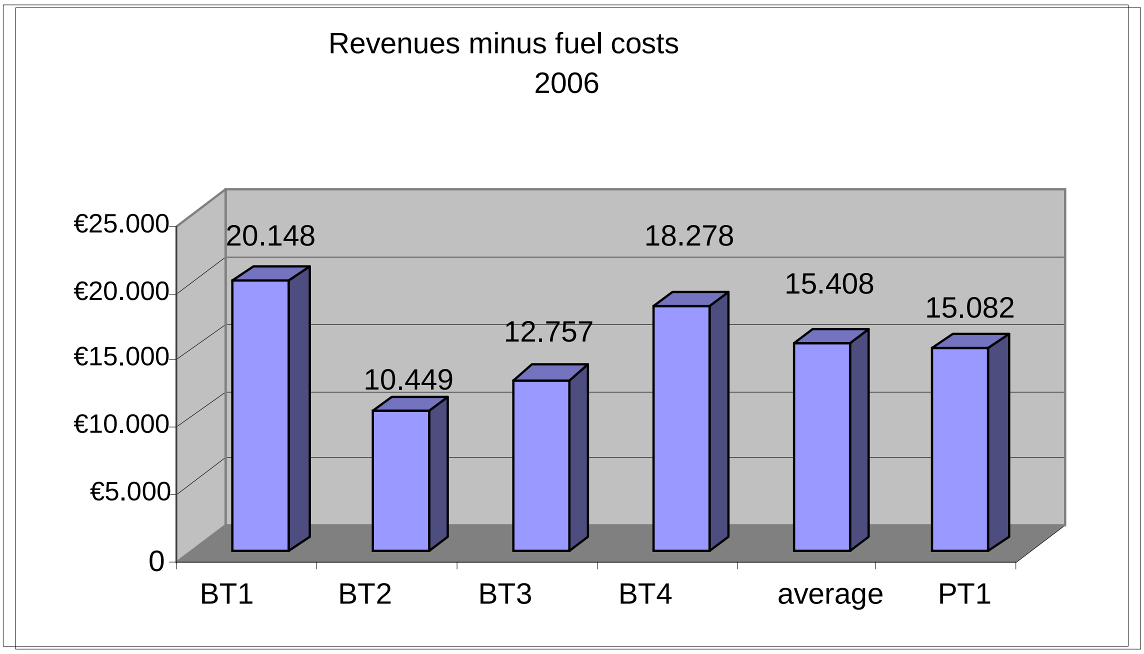


Figure 7: Revenues minus fuel costs per week in 2006



2.2.3. Costs of the Pulse system 2004-2006

An indication of the purchasing costs of the pulse system of 12 meter of Verburg for one vessel.

The system consists of the following parts:

■ On board system	€ 124.404,-
■ Underwater system	€ 215.354,-
Total selling price VAT excl.:	€ 339.758,-

Installation	
System tests and on deck provision cable winches	€ 100.000,-
Total	€ 439.758,-

Per vessel costs may vary. For instance, if a vessel does not possess sufficient electrical power an extra generator would need to be installed, bigger vessels will have sufficient electrical power. Risks to the system are mainly external, such as; obstacles on the benthos, fishing in too deep waters, inexpert operation, improper speed.
Maximum yearly costs of operating a pulse trawl system will be globally presented in table 4:

Table 4: Maximum yearly costs of PT in €

	adaptation vessel	purchase and costs	Total
■ Depreciation	10.000	66.400	76.400
■ Interest	1.500	6.000	7.500
■ Maintenance and repair	0	80.500	80.500
Total	11.500	152.500	164.000

Minus: Saving of existing gear costs (circa 20%)	-14.000
Extra costs per year subsidy excluded	150.000
	======

In the following table it is assumed that gross revenue of PT1 is on the basis of the number of days at sea of the reference vessels (204 days at sea in 2005) 1.578.000€ then the net result of PT1 will be 56000 €.

Table 5: Nett revenues in €	PT	BT (av.2005)
■ Gross revenue	1.578.000	1.578.000
■ Total costs, inc. labour.	1.372.000 -	1.624.500
■ result	206.000	-46.500
Extra costs pulse system	150.000 -	0
Nett result	56.000	-46.500
	========	======

Since under this assumption there is no lower level of profitability this could stimulate certain fishermen to adopt pulse trawling.

2.2.4 The main conclusions from the economic performance of PT1 in 2006

The main conclusions from the economic performance study 2006 are:

- Nett result is almost at the business economical neutral level
- PT1 is competitive with the reference vessels
- Profitability of PT better than of BT
- Fuel costs of PT is remarkably lower than of BT
- PT1 seems to be an alternative for BT that is mainly directed towards sole
- Catches of plaice lack behind
- Further development is necessary to improve results

2.3. Main characteristics of the pulse trawl vessel (PT2) 2009

In august 2007 the owner of PT1 sold the vessel and pulse trawling consequently ended at that time. However, pulse trawl fishing started again in the beginning of 2009. Another fishing enterprise started to fish with a different pulse trawl on a commercial base in the first week of May 2009. At that moment the fisherman did not have any experience with pulse fishery, before he used the beam trawl as fishing method to catch flatfish in the past thirty years.

The vessel BTx was built in 1993 as a beam trawler, it has a length of 41.15 meter and an engine of 2.000 HP. In 2008 the beam trawl BTx has been modified to a pulse trawl (PT2).

Engine power has been limited to 1.300 HP. The results of PT2 in 2009 are compared to the results of the BTx in 2007. The year 2008 was not representative for this vessel because of a long stay in dock for maintenance and refit.

Table 6: Characteristics of the vessel PT1/BTx

Length	41,15	
GT	438	
HP	2.000	(maximised to 1.300 HP in 2008)
Year hull	1993	
Year engine	1993	

2.3. 1. Pulse trawling on a commercial basis in 2009

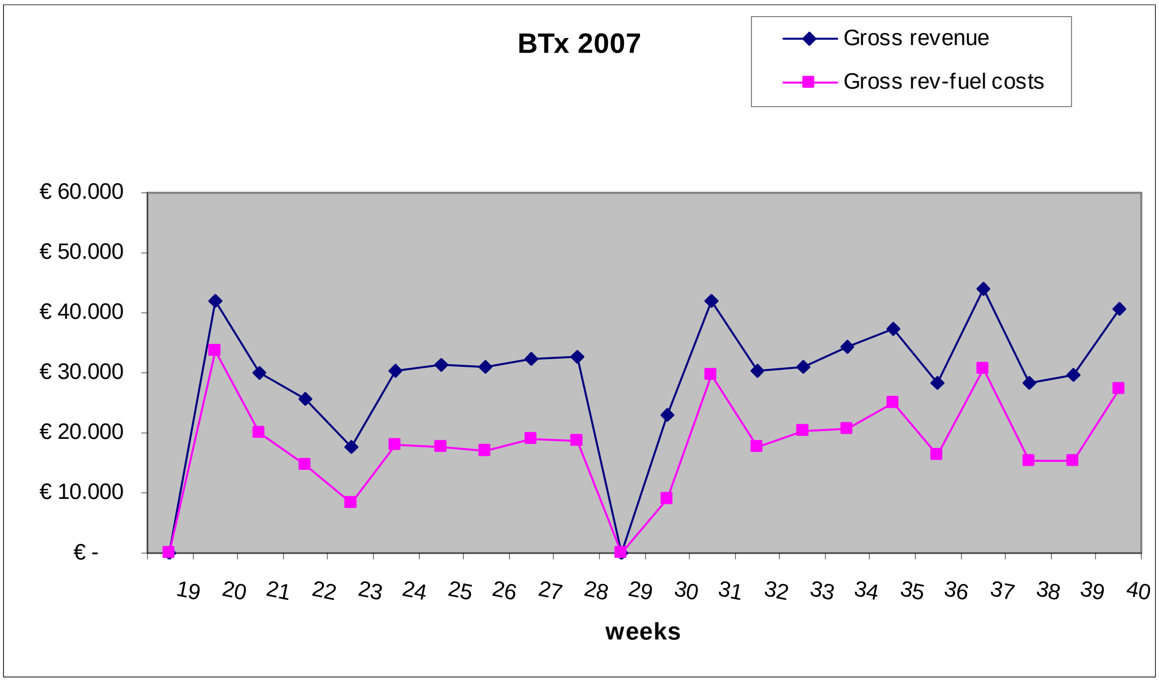
The vessel PT2 started fishing with pulse in the first week of May in 2009. If we compare the average revenues in the period May 4th till October 2nd (21 weeks) with the same period of the year 2007 we see an increase in revenues.

Table 7: revenues in 2009 (21 weeks):

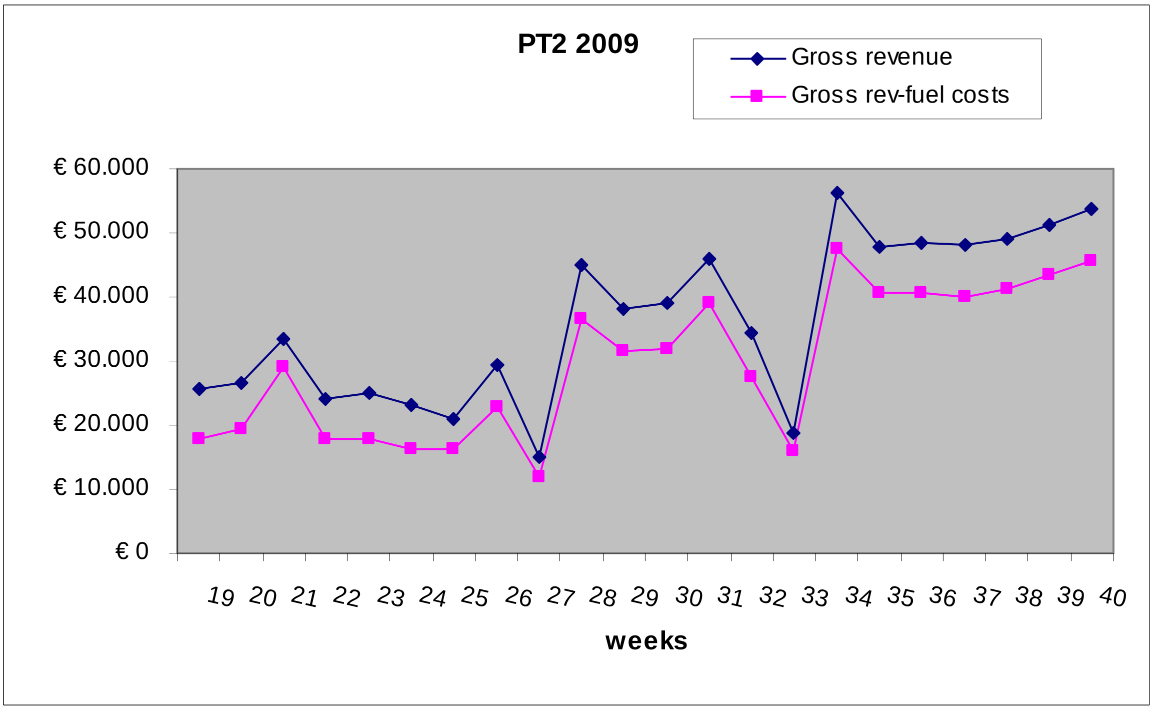
	Pulse trawl		Beam trawl	
	Week 19 till 40 of 2009 (4 May till 2 October)		**Week 19 till 40 of 2007 (4 May till 2 October)**	
	Per day	Per week	Per day	Per week
Average revenues	8.743	34.972	7.986	31.945
Fuel costs	1.498	5.993	3.182	12.730
Revenue minus fuel costs	7.245€	28.979€	4.804€	19.215€

During the 21 weeks period in 2009, several times technical problems occurred. Revenues could have been higher because of inefficient effort of the vessel. Effective hours of fishing were lower as a result of experiments done and also because of some cases of (small) damage of the gear. Particularly in week 27 and week 33 troubles caused low revenues. Despite mentioned problems, catches and revenues raised by 10% during the whole period. Fuel consumption decreased by approximately 45%. Profitability was much better in this period than in the year 2007.

Figure 8: Gross revenue and gross revenue minus fuel costs in 2007 and 2009 week 19-40 of BTx

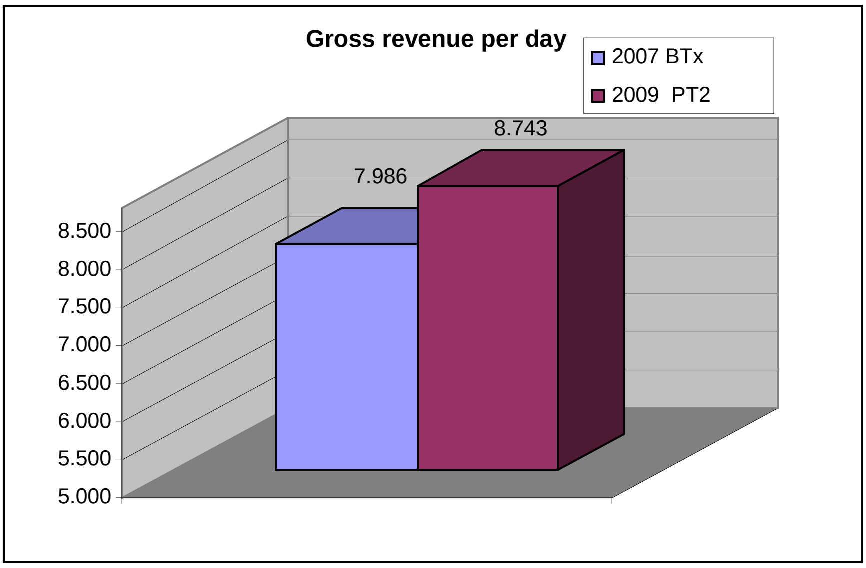


And of PT2:



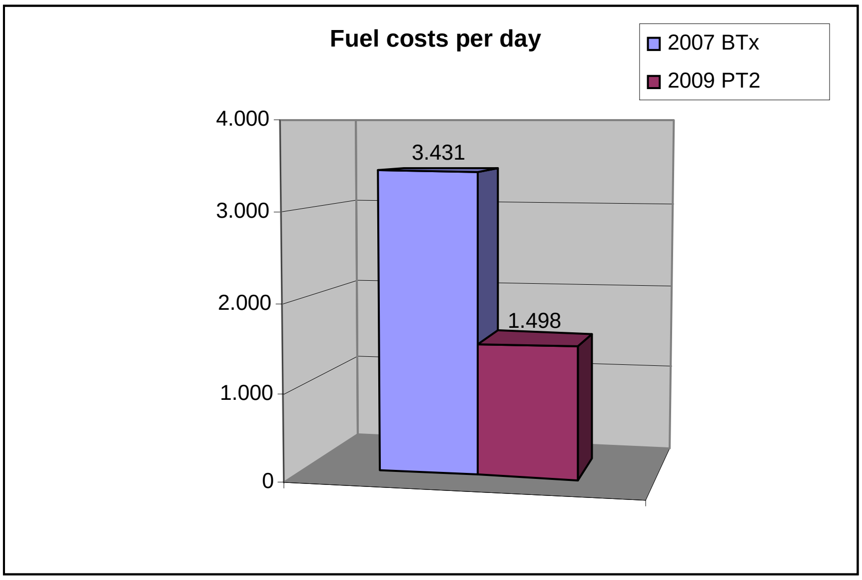
In the next figures results of 2009 per day of PT2 are compared to BTx per day in 2007.

Figure 9: Gross revenue per day in 2007 and 2009



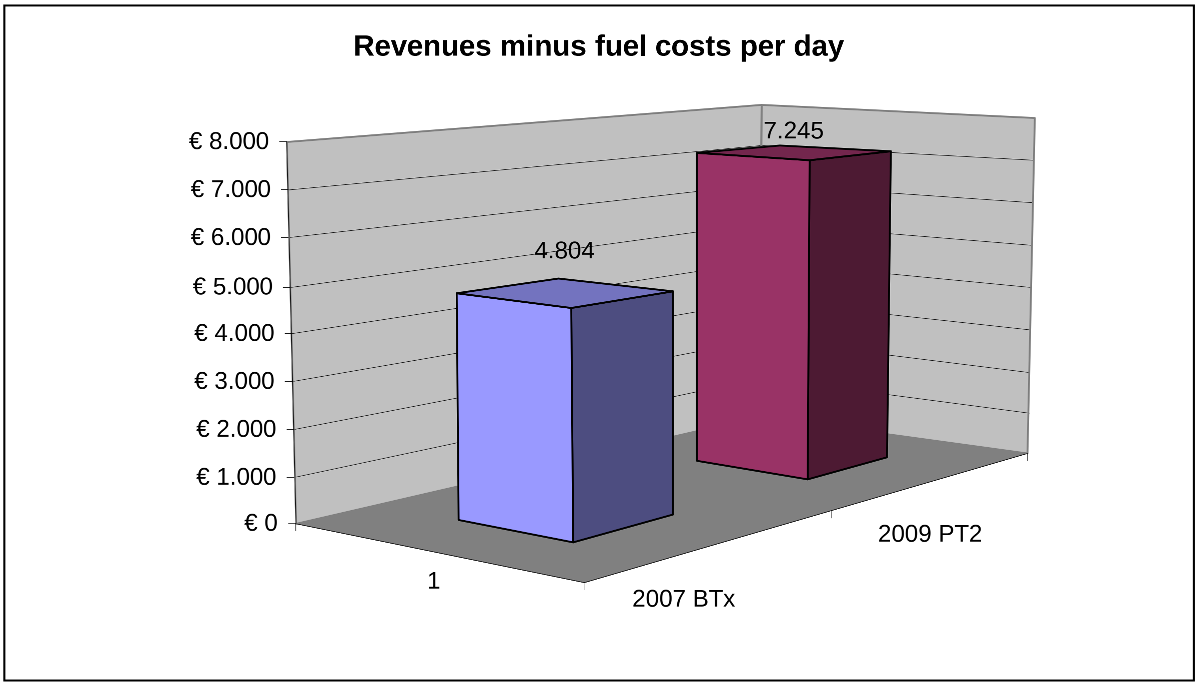
Revenues of PT2 were higher than with BTx while fuel costs were much lower for PT2.

Figure 10: Fuel costs per day in 2007 and 2009



If revenues minus fuel costs per day in 2007 and 2009 are calculated, it shows that PT2 can compete with beam trawl.

Figure 11: Revenue minus fuel costs per day in 2007 and 2009



In the next graphs results of 2007 and 2009 per week of PT2 and BTx vessels are presented. A week consists of 4 fishing days.

Figure 12: Gross revenues per week in 2007 and 2009

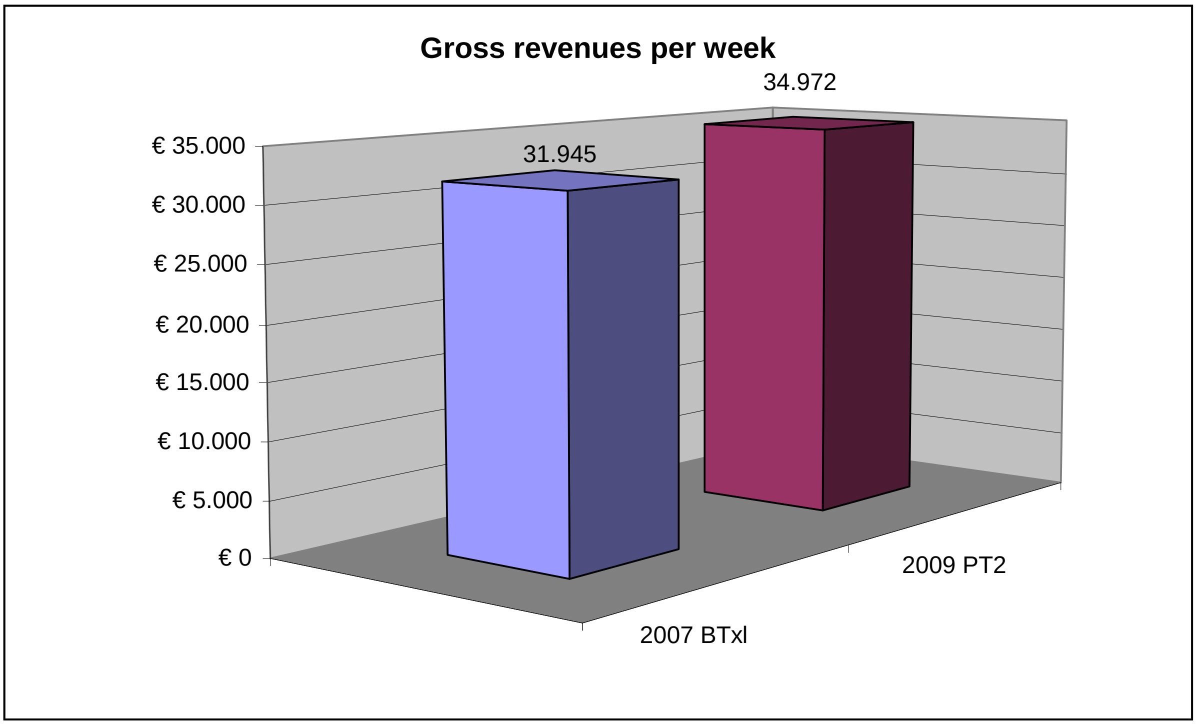


Figure 13: Fuel costs per week in 2007 and 2009

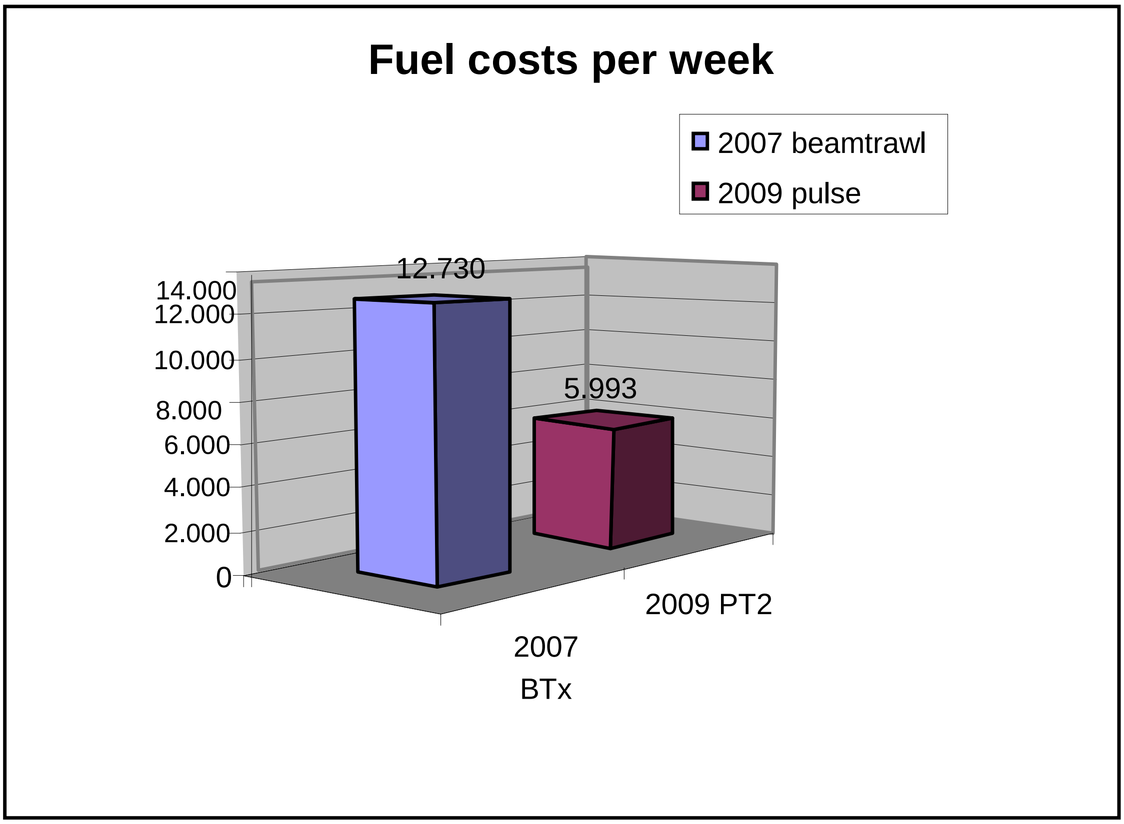
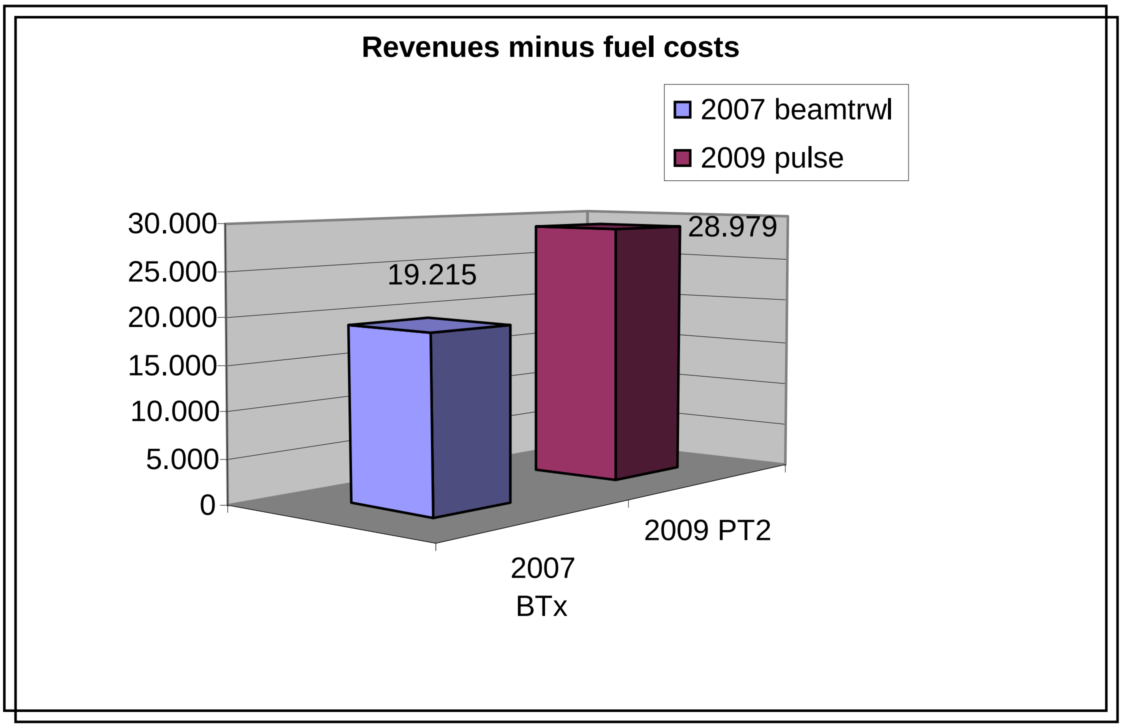


Figure 14: Revenues minus fuel costs per week in 2007 and 2009



2.3.2. Costs of the Pulse system in 2009

An indication of the purchasing costs of the pulse system of 12 meter of Verburg for one vessel is assumed to be about the same as in 2006, namely € 439.758. Extra costs per year subsidy excluded will be 150.000 € (see par. 2.2.3)

In the following table it is assumed that gross revenue of PT2 will be € 1.790.000 on basis of the same number of days at sea (204 days in 2007). Taking into account all savings but also all extra costs for pulse, on balance total costs will decrease by € 200.000. The net result of PT2 will then be € 140.000, which means a substantial better performance compared to the year 2007 fishing with the beam trawl. It can be concluded that the vessel will operate much more profitable by using the pulse trawl rather than the beam trawl.

Table 8: Nett revenues	PT2	BTx (2007)
■ Gross revenue	1.790.000	1.722.000
■ Total costs, inc. labour *)	1.500.000 -	1.700.000
■ result	290.000	22.000
Extra/less costs pulse system (balance)	150.000 -	0
Nett result	140.000	22.000
	========	======

*) Total costs; fuel costs for PT 2 will be much lower compared to BTx, on the other hand labour costs will rather be higher. However, on balance, savings for PT2 will be positive substantially. This result should stimulate beam trawl fishermen to adopt pulse trawling.

2.3.3.The main conclusions from the economic performance of PT2 in 2009

The main conclusions from the economic performance study 2009 are:

- PT2 is competitive with BTx in 2007
- Nett result is better than in the year 2007
- Profitability of PT2 is better than of BT
- Fuel costs of PT in 2009 is circa 50% lower than of BTx in 2007
- PT2 is developed for sole fishery and is an alternative for BTx towards sole
- Catches of plaice lack somehow
- Further development is necessary to improve results, especially towards the catch of plaice

3. The environmental impact of the Pulse trawl in comparison to the conventional Beam trawl

3.1. Fuel consumption

Fuel consumption of beam trawlers is very high, over 8000 litres a day. On average a beam trawler > 1501 HP consumes 1,5 million litres on a yearly basis. Current high oil prices are a problem for conventional beam trawlers. Oil prices remain high and volatile making it necessary for BTs to consume oil efficiently. As a measure of fuel efficiency the following variable has been constructed by LEI (Taal et al, 2006): Fuel efficiency= value of the catch (in Euro)/fuel costs (in Euro).

Figure 3.1 shows the frequency distribution of the efficiency measure for fuel of 49 beam trawlers in 2005. On average the consumption of € 1.000 fuel yielded circa € 2.500 in catch revenues. A relatively high number of vessels have a low degree of efficiency in fuel consumption, fuel costs are relatively high with respect to the value of catch.

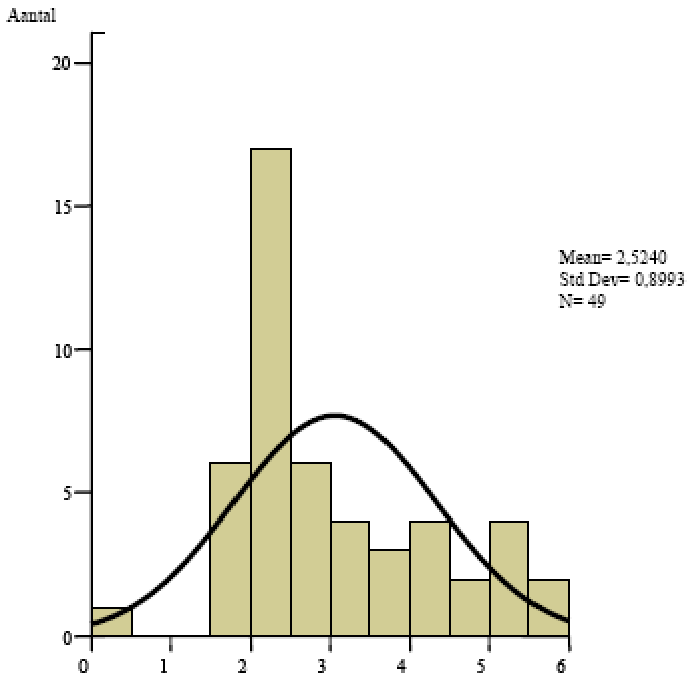


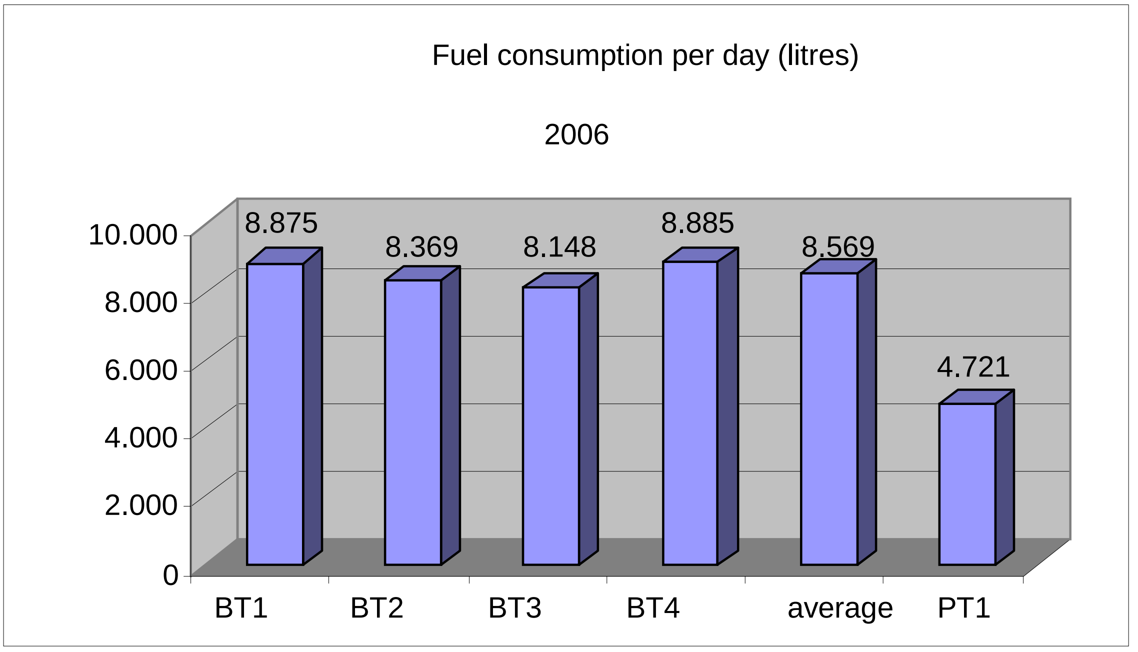
Figure 15: Distribution measure efficient fuel consumption of beam trawlers, 2005 (weighted with gross revenue)

Vessels with >1501 HP are less fuel efficient than smaller beam trawlers. The pulse trawler consumes less fuel than a beam trawler.

3.1.2. Fuel consumption PT1 2006

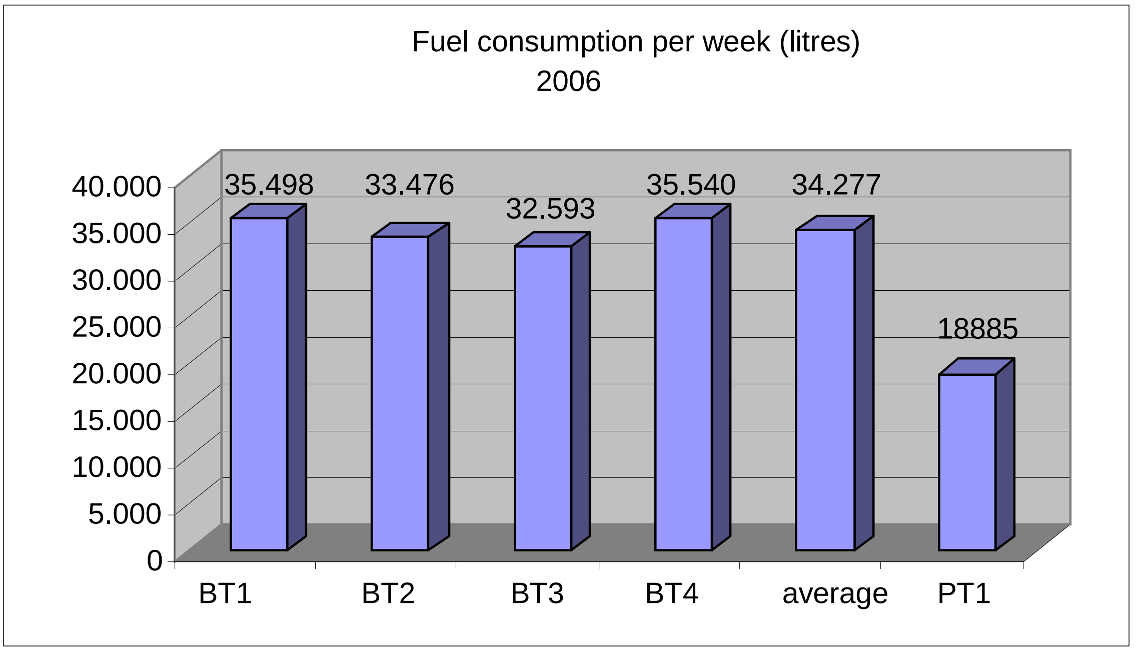
Fuel consumption of PT1 in 2006 is remarkably lower than the oil consumption of the four BTs:

Figure 16: Fuel consumption per day, beam trawlers compared to pulse trawl



Fuel consumption per week:

Figure 17: Fuel consumption per week, beam trawlers compared to pulse trawl

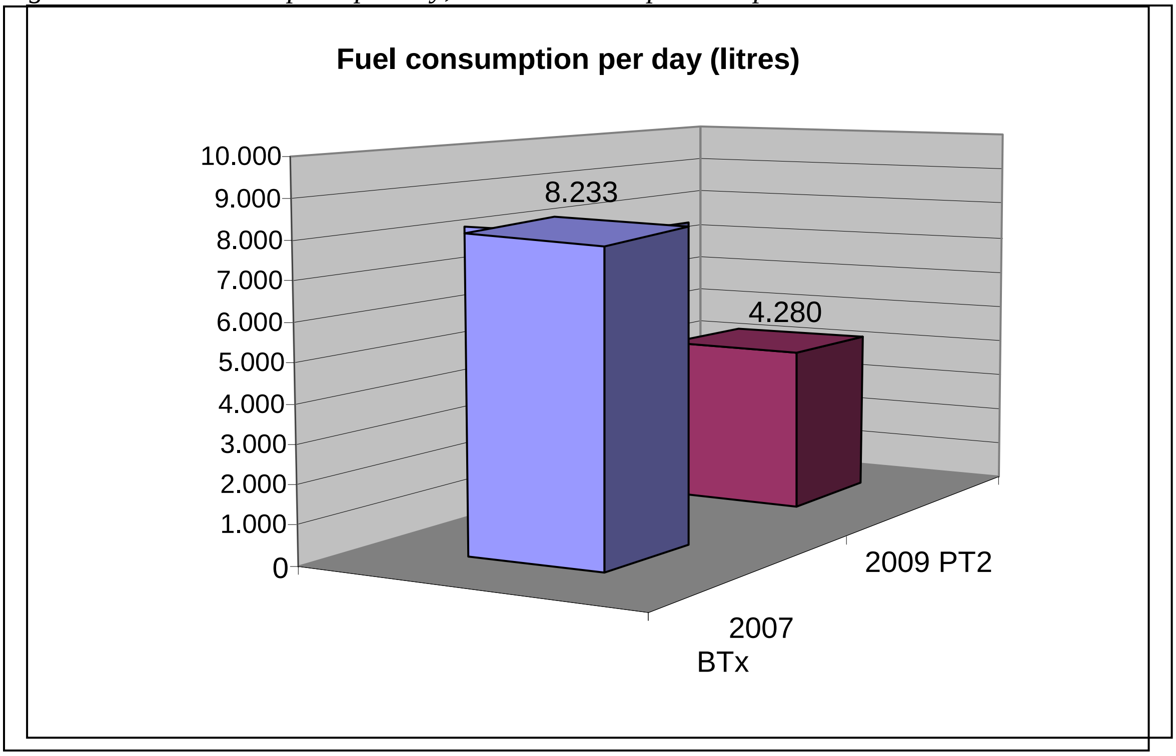


The use of PT1 generates consequently less emission of CO2 than the use of the beam trawls.

3.1.3. Fuel consumption PT2 2009

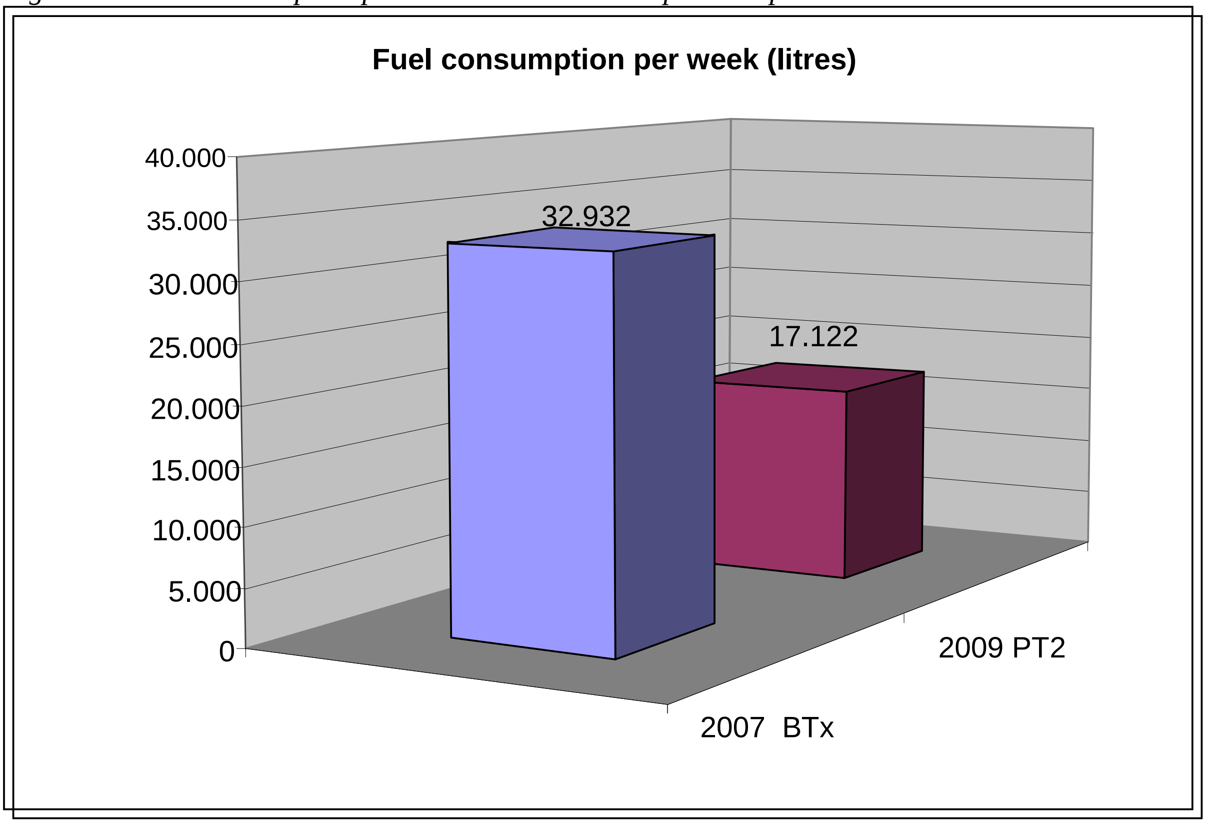
Also the fuel consumption of PT2 in 2009 is remarkably lower than the oil consumption of BTx:

Figure 18: Fuel consumption per day, beam trawl compared to pulse trawl



Fuel consumption per week:

Figure 19 : Fuel consumption per week beam trawl compared to pulse trawl



Fuel consumption of PT2 in 2009 is 45-50% lower than of BTx in 2007.

It can be concluded from the oil consumption of PT1 and PT2 that the use of a pulse trawl compared to the use of a beam trawl consequently has a positive effect on the emission of CO2.

3.2. Change in catch composition, discards and benthos[2]

A series of nine fishing trips with on board observers were carried out by IMARES on the same pulse trawl PT1 and two other beam trawlers (BTa, BTb) of comparative engine power and size to appraise the performance of pulse beam v.s. conventional tickler chain beam trawls. Five comparative trips, carried out in the period between October 2005 and March 2006, were analysed for catch rates of marketable plaice (Pleuronectes platessa L.) and sole (Solea vulgaris L.), undersized plaice and sole and benthic fauna. It has to be taken into account that this IMARES research was conducted in a period previous to the period the pulse trawl operated on a commercial basis. In this period the pulse was not yet as developed as in the commercial period. The data of the economic performance section (above) is from the later period (3 quarters of 2006).
In paragraph 3.6 catch composition and discards of plaice and sole in 2009 from an IMARES survey onboard of PT2 will be presented[3].

Table 9: Vessels used and main particulars

Vessel ID	Year built	Loa	GT	kW
BTa	2003	39.67	418	1471
BTb	1993	42.36	501	1467
PT1	1998	42.40	508	1471

Effect on landings based on auction data
Except for the first trip, the pulse trawls caught considerably less landings, about 60-70% of that of the conventional trawls. When lumped together (gear test 6) the overall ratio is 68% (Table 10). These data were consistent with the views expressed by the skipper and the crew on PT1. (gross revenue PT/BTav= 77%)

Table 10: Overall landings LpUE comparison

Gear test	Trip	Pulse kg/hr	Conv kg/hr	Ratio
1	1	65.7	69.3	94.8%
2	2	57.8	87.8	65.8%
3	3	86.2	145.7	59.2%
4	4	50.2	75.5	66.5%
5	5	61.2	87.4	70.0%
6	1 to 5	64.6	95.4	67.7%

Effect on summed landings of single species based on auction data
The differences between the pulse trawl and conventional beam trawl were substantial for various species. It appeared that the pulse trawl performed best for turbot and brill with ratios

[2] This part is based on: *Performance of pulse trawling compared to conventional beam trawling.*B. van Marlen, R. Grift, O. van Keeken, M.S. Ybema, R. van Hal , IMARES, 2006

[3] On board of PT2 were during four trips IMARES observers.

ranging from 78% to 131% of the conventional landings, while cod landings were considerably lower, between 15% and 60% of that of the beam trawl.

Effect of gear type on market grades based on auction data
Only in a few market categories a significant difference could be found between the pulse and the conventional gear type, i.e. for plaice cat5 where the pulse trawl caught more, sole cat2 with the pulse trawl catching less, turbot cat2 (more), and cod cat2 (less) and cat4 (more). All other differences were not statistically significant, but the number of observations was limited with five trips analysed.

Sole landings based on paired hauls
The analysis of haul-based data showed that for all trips, except no 1, the pulse trawl landed significantly less sole than the beam trawl, with ratios ranging from 66.1% to 93.1%. For the complete dataset of all five trips combined (gear test 6) the ratio pulse/conventional was 78.2% for sole landings (Table 11).

Table 11: Landings in kg/hr of sole based on paired hauls

Gear test	**Vessels**	**Wk, year**	**No of hauls**	**CPUE** in kg/hour **mean PULSE**	**CON**	**PULSE/ CON**	**stdev PULSE**	**CON**	**p-value**
1	PT1-BT2	41, 2005	34	19.30	20.74	93.1%	6.52	7.17	0.251
2	PT1-BT3	44, 2005	41	17.52	21.74	80.6%	5.95	6.4	0.000
3	PT1-BT1	05, 2006	35	**8.51**	**11.92**	**71.4%**	**2.76**	**3.94**	**0.000**
4	PT1-BT2	09, 2006	38	**7.93**	**11.66**	**68.0%**	**2.95**	**4.43**	**0.000**
5	PT1-BT1	11, 2006	27	**10.33**	**15.62**	**66.1%**	**2.86**	**3.03**	**0.000**
6	PT1-Both	All	175	**12.87**	**16.45**	**78.2%**	**6.64**	**6.87**	**0.000**

Plaice landings based on paired hauls
Similarly the plaice landings fell behind for the pulse trawl, with ratios ranging from 52.8% to 89.5% of beam trawl landings. For the complete dataset of all five trips combined (gear test 6) the ratio pulse/conventional was 64.5% (Table 12).

Table 12: Landings in kg/hr of plaice landings based on paired hauls

Gear test	**Vessels**	**Wk, year**	**No of hauls**	**CPUE** in kg/hour **mean PULSE**	**CON**	**PULSE/ CON**	**stdev PULSE**	**CON**	**p-value**
1	PT1-BT2	41, 2005	34	**25.56**	**28.56**	**89.5%**	**13.8**	**8.97**	**0.047**
2	PT1-BT3	44, 2005	41	**24.69**	**46.79**	**52.8%**	**10.91**	**15.37**	**0.000**
3	PT1-BT1	05, 2006	35	**56.02**	**93.43**	**60.0%**	**23.17**	**25.56**	**0.000**
4	PT1-BT2	09, 2006	38	**21.66**	**29.85**	**72.6%**	**13.64**	**11.18**	**0.000**
5	PT1-BT1	11, 2006	27	**20.09**	**28.87**	**69.6%**	**5.84**	**6.61**	**0.000**
6	PT1-Both	All	175	**29.76**	**46.13**	**64.5%**	**19.75**	**29.07**	**0.000**

3.3 Effect on discards of plaice and sole

In these analyses no significant difference was found in the number or in the weight of the plaice discards between both gear types. On average, the pulse trawl and beam trawl caught 68 and 67 kg/hr of undersized plaice respectively.

The pulse trawl caught significantly less undersized sole than the conventional beam trawl (1.4 kg/hr in comparison with 1.8 kg/hr for the beam trawl). For this analysis, only data from the last three trips were used because it was only in these trips that the numbers of discarded sole were counted accurately .

3.4. Impact on benthos

The main benthos species caught were: sandstar (Astropecten irregularis L.), common starfish (Asterias rubens L.), and swimming crab (Liocarcinus holsatus L.). These were caught in almost all hauls. The analysis of variance for these species shows that the pulse trawl caught significantly less numbers of these species. On average, catch rates of sandstar in the pulse trawl were 24% of that in the conventional beam trawl and of common starfish 75% and of swimming crab 53%.

With regards to the benthos species there was special interest for quahogs (Arctica islandica L.) and prickly cockles (Acanthocardia echinata L.). These species are slow growing and have a low recruitment, because of this they are threatened by fishing methods disturbing the sea bed. These species however only sporadically occurred in the catch; therefore it was not possible to use them in an analysis.

The extent of damage of plaice fluctuated with higher percentages class A (in good shape) and lower C for the pulse trawl, but unclear results in class B and D (severely damaged). Regarding the mean percentages there were more fish in class A, about comparable numbers in B, and less fish in C and D in the pulse trawl (Table 22). When using these means with the survival rates found in 2005 for the categories A, and B+C, the survival of undersized plaice in the catch after 192 hrs of observation of a pulse trawl is nearly doubled to 28% (Van Marlen et al., 2005b).

Table 13: Estimated survival of plaice on experiments in 2005

Species	**plaice**			
Gear	PULSE		CONVENTIONA L	
Catergory	% in catch	% survival	% in catch	% survival
A	36.22%	13.61%	6.4 9%	1.84%
B+C	51.40%	14.47%	73.51%	13.04%
D	12.38%	0%	20.00%	0%
% overall survival in catch		**28.09%**		**14.88%**

The hypothesis concerning survival of discard fish is that the pulse trawl would catch less debris and benthos and that this would positively effect the damage done to the fish species and would increase the survival rate of the fish. The method of classification however is subjective and depends on judgement of the person classifying the damage. These persons differed per trip, causing variability in results. The condition of the fish also depends on handling on board and the lay-out of the processing line, which differed per ship. Taking fish from the conveyor belt does not exclusively show the effect of the pulse or conventional beam trawl, but includes effects caused by processing as well. In spite of these caveats the results show, not statistically tested, more lightly damaged fish in the discards of the pulse trawl. When using the average percentages with the survival rates found in 2005, the percentage survival of plaice in the catch can be substantially higher, meaning a smaller impact on the plaice population by fishing with pulse trawl, because there is no difference in the number of plaice discards. This is a finding justifying further study.

3.5. The main conclusions from the IMARES study from 2006

The main conclusions from the IMARES study from 2006 are:

1. The landings of plaice and sole were significantly lower in the pulse trawl when compared to the conventional beam trawl (in 2005/2006). Both the auction data as the haul-based data showed a reduction of LpUE of particularly sole and plaice, contrary to the findings of earlier paired experiments onboard FRV (fishing research vessel) "Tridens". Over all species landed, the pulse trawl about 68% in kg/hr. (The economic performance study showed an improvement in landings.)

2. There was no significant difference in the catch rates of undersized (discard) plaice between the pulse trawl and the conventional trawl.

3. In the pulse trawl, the catch rates of undersized (discard) sole were significantly lower than in the conventional beam trawl.

4. Catch rates of benthic fauna (nrs/hr Astropecten irregularis, Asterias rubens, and Liocarcinus holsatus) were significantly lower in the pulse trawl compared to the convent-ional beam trawl.

5. There are indications that undersized plaice are damaged to a lesser degree in the pulse trawl and will survive better in the pulse trawl. Based on previous research, these results would indicate a survival rate of plaice in the pulse trawl that is twice as high as in a conventional beam trawl. But since the method of determining damage to fish by visual observation is subjective, this conclusion should be treated with caution.

3.6 Catch composition and discards of plaice and sole in 2009 [4]

The catches in terms of landings and discards were monitored onboard PT2, fishing with two pulse trawls using the Verburg-Holland system during four weeks in June-August 2009. The average fishing speed was about 5 knots. The fishing area of the four trips was east of the coast of England and fishing depth was 36 m on average with a minimum depth of 20 m and a maximum depth of 46 m.

For this study the standard sampling procedure for the yearly monitoring of discards of conventional beam trawl fleet was applied (van Helmond and van Overzee, 2008). Sampled numbers of fish per haul were raised to numbers and weight per hour, for both discards and landings.

The four trips led to a total of 103 valid hauls for analysis, with a total fishing duration of 186 hours. The number of hauls per trip varied between 17 and 38.

[4] Steenbergen, J. and Marlen, B. van, 2009. Landings and discards on the pulse trawler MFV "Vertrouwen" TX68 in 2009. IMARES Report C111/09, 20 pp.

The average number of plaice landed per hour was 58 or, in weight 19 kg plaice per hour. The average number of plaice discarded per hour was 164 or, in weight 18 kg plaice per hour. This resulted in an average discard percentage for plaice of 74% in numbers and 49% in weight.

The average number of sole landed per hour was 208 or, in weight 53 kg sole per hour. The average number of sole discarded per hour was 54 or, in weight 5 kg sole per hour. This resulted in an average discard percentage for sole of 21% in numbers and 9% in weight.

Comparing the landings with that of conventional beam trawl discard surveys in 2007 leads to the general impression that with the pulse trawl more sole was caught and less plaice than with conventional beam trawls. The range of numbers of plaice landed was 101 - 561 per hour on the conventional beam trawls monitored in 2007, whereas during with the pulse trawl between 14 – 106 numbers of plaice where landed per hour. The range of number of sole landed was 45 - 149 per hour on the conventional beam trawls that were monitored in 2007, whereas during with the pulse trawl between 142 – 259 numbers of sole where landed per hour.

The total discards per trip were within range of the discards per trip in earlier years. When compared with conventional beam trawls in previous years it seems that with the pulse trawl more sole in number and weights per unit of time was discarded and less plaice was discarded. However, the average discard percentages of as well plaice as sole for the pulse trawl of this study were within range with the average discard percentages of conventional beam trawls in 2005, 2006 and 2007 (van Keeken, 2006; van Helmond and van Overzee, 2007; van Helmond and van Overzee, 2008) .

Data from 2009 was not yet available and year can have influence on the differences. Another important factor is the fishing area, just east of the coast of England, which probably in this case has influenced the catch composition and the fact that sole was more abundant in as well the landings as the discards. The comparison of pulse beam trawling vs. conventional beam trawling in 2006 showed that the pulse trawl caught less sole in kg per hour, i.e. 12.87 vs. 16.45 (ratio 78.2%), and fewer plaice, i.e. 29.76 vs. 46.13 kg per hour (ratio 64.5%), see van Marlen et al., 2006.

This study gives a general impression of the performance in terms of catches of fishing with a pulse trawl using the Verburg-Holland system. However it is recommended to conduct a comparative study on performance of a beam trawl and a pulse trawl, where the two vessels of similar size fish simultaneously. This is to exclude the effects of time and area of fishing.

4. Future

At the moment of writing just one vessel (PT2) was operating with the pulse trawl. It is expected that at least three other vessels will be equipped with pulse in the last quarter of the year 2009. These three vessels intend to combine pulse technology with SumWing gear instead of beam trawl gear.

It is expected to obtain higher prices for pulse trawl landings through labelling in the future.

Research is done on the effects of pulse trawling on cod, shark and ray and other benthic fauna. It is expected that results of the studies will be available in the end of 2009.

5. The cost effectiveness of the pulse trawl in comparison to the beam trawl

The cost effectiveness of the pulse trawl in comparison to the beam trawl on the basis of two periods of commercial trials of the pulse trawl, turns out to be rather positive. The economic performance of the pulse trawl can compete with comparable beam trawls. This is especially due to a decrease in oil consumption, which is a high cost for beam trawlers. Fuel consumption of the pulse trawl is some 45-50% lower than the beam trawl.
Environmental costs are also lower. When it concerns discards, in the pulse trawl, the catch rates of undersized (discard) sole were significantly lower in 2006 than in the conventional beam trawl, and also catch rates of benthic fauna (nrs/hr Astropecten irregularis, Asterias rubens, and Liocarcinus holsatus) were significantly lower. However, in 2009 with the pulse trawl more sole in number and weights per unit of time was discarded and less plaice was discarded. There are indications that undersized plaice are damaged to a lesser degree in the pulse trawl and will survive better in the pulse trawl. Next to this the use of a pulse trawl generates less emission of CO_2 than the use of a beam trawl.

The pulse trawl seems to be an alternative for beam trawlers that are mainly directed towards sole, even sole catches are better, catches of plaice lack behind. Some concern exists on the effects of pulse trawling on certain non target species.

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Partner 11

The empirical assessment of a modified beam trawl that utilizes the measures developed within WP4 was undertaken by partner 11 (UoP). The observed performance of a vessel using the modified beam trawl was compared to that of comparable vessels, employing the conventional beam trawl, operating in the Belgian large beam trawl fleet.

Productivity Effects of a Modified Beam Trawl

1.0 Introduction

This section investigates the effects gear based technical modifications have on the productivity of commercial fishing vessels. Typically these are considered *ex ante* via sea trials that examine the degree to which target species catchability is observed to differ between ‘conventional’ and modified gears. This can be undertaken on board either research or commercial fishing vessels and such trials tend to be relatively short in nature (both in time and number of tows) making the results somewhat indicative in nature. In the case of research vessels, the vessel configuration is not necessarily optimal for commercial fishing, so extrapolating the results to a commercial fleet is difficult. Basing productivity change estimates upon gear trials at sea is also a potentially artificial exercise as it assumes the behaviour of fishers will not change as a result of the using the modified gear. Fishers can be expected to modify their behaviour in a way to reduce the impact of the new gear on their profitability. As a result, adverse productivity changes may ultimately be less than estimated through sea trials. Conversely, productivity changes could also be greater than estimated in the sea trials if fishers do not use the new gear effectively due to their unfamiliarity with it. Thus, the impact on the commercial fishery is largely an empirical question, which can only be resolved by examining productivity changes that actually occur in the fleet when modified gears are applied over time. Examples of assessments that consider the use of technical measures *ex post* operating in truly commercial conditions are far less common. Assessing the performance of vessels in this manner allows any impacts on performance to be more realistically determined.

Here, impact reducing technical measures are considered empirically at the vessel level in an *ex post* assessment. The implications of changes in productivity and costs are then considered with regard to the average vessels profitability.

1.1 Gear/Fleet Characteristics

The conventional gear used by Belgian large beam trawlers is the chain mat beam trawl where a lattice work of chains is towed from the back of the beam sloping down to the footrope of the net. This is heavier than the alternative ‘tickler’ chain beam trawl but more robust and suitable for fishing harder grounds. The mesh size in the net is 150mm polyester (PE), double braided in the belly, single in the top panel. The cod-end is 80mm double braided PE, twine diameter 4mm. The cod-end is 80 open meshes round and 50 meshes deep. The heavy chain mat drags on the ground, ahead of the ground rope, and encourage demersal fish to rise into the following net. In 2007, the average engine power of a large Belgian beam trawler was 1009kW with a gross tonnage (GT) of 315 (VlaamseOverheid, 2007a).

These vessels can land up to 40 different commercial species but specialise in the capture of benthic fin fish such as sole and plaice. The top three most important species landed by Belgian vessels in terms of total value are typically sole, plaice, and lemon sole. They primarily operate in; the North Sea (IVa-c), Irish Sea (VIIa), Celtic Sea (VIIg,h), Bristol Channel (VIIf) and English Channel (VIId,e) and account for approximately two thirds of sole landings from the Celtic Sea and Bristol Channel (VIIf & g) (ICES, 2008b). The latest ICES advice indicates that both sole and plaice are currently considered overfished in terms of potential yield in almost all these areas. The only exceptions being in area VIIh where the status of both species is unknown and VIIa where plaice are considered to be underfished (ICES, 2008a, b). The most recent Belgian annual fleet report indicates return on investment (ROI) figures for the large beam trawl fleet (TBB) (vessels 24m to 40m) have declined steadily over the period 2003 to 2006, and that they have been negative since 2005 (European Commission, 2007).

1.2 The ‘Alternative Beam Trawl’ - Specification and Anticipated Effects of Uptake

The ‘modified beam trawl’ assessed here combines a number of technical measures trialled in Wp4, it is largely the product of over two decades of Belgian research into the matter (Fonteyne *et al.*, 1997; Polet, 2003; Fonteyne *et al.*, 2005) and partner 08 (ILVO) was closely involved with the development of the setup. It is a modified version of the conventional gear described above and differs by having roller gear, large meshes in the top panel, a square mesh benthos release panel (SMP), and a T90 cod end. Discussions with those involved in the gears development and previous trials of similar technical modifications were utilised to guide *a priori* expectations with respect to their likely significance. The anticipated impacts are considered below.

Roller gear. Wheeled trawl shoes in place of conventional ‘ski’ type shoes**.** These are designed to reduce the gears total resistance on the sea bed whilst maintaining adequate contact to fish effectively. They are primarily fuel saving devices as they reduce drag and are not believed to affect the way gears fish.

Large meshes in the top panel (300mm meshes). This modification is designed to reduce the level of finfish bycatch. It is primarily roundfish such as gadoids (e.g. cod, haddock, whiting) that tend to evade capture via this type of modification. Beam trawlers are currently obliged to use short large mesh sections in the front part of the top panel, the section of large meshes applied here extend further into the net. The large meshes of 300mm in the top panel coved the full area between the headline and the bobbins, i.e. somewhat more than the area of the chain mat.

This modification was initially shown to be effective in otter trawls (Thomsen, 1993; Madsen *et al.*, 2006). In sea trials aboard large beam trawls similar modifications (such as square mesh panels and cutaway covers) have been seen to perform well for whiting and haddock (Fonteyne, 1997) and whiting and cod (van Marlen, 2003). Reduced drag, and consequently fuel consumption, may also be achieved through the twofold effects of more open netting and less bycatch in the cod end. If present, any such fuel saving was, however, anticipated to be small.

A Benthos release panel (120mm square mesh). A square mesh panel placed in the belly of the trawl ahead of the cod end, this is designed to reduce the gears impact on benthic communities generally. The meshes in the belly were identical to the traditional gear except for a benthos release panel that was 120mm double braided polyethylene (PE). The panel was 20 meshes wide and 30 meshes long and attached to 30 and 16 diamond meshes in the belly, respectively.

Trials aboard research vessels have reported statistically significant reductions in the number of whiting retained (23%) when using 200mm mesh (based on 6 hauls), the number of whiting retained when using 150mm mesh also fell but was not statistically significant (16 hauls) (Fonteyne and Polet, 2002). However, the 200mm square mesh was also seen to result in large and significant reductions in the number of sole retained (45%) (Fonteyne and Polet, 2002). The same trials noted large but non significant reductions in the number of plaice and dab being retained, respectively, at that size mesh. 150mm SMPs were also seen to result in non statistically significant reductions in the numbers of sole and dab retained. These figures are generally based on very low numbers of hauls so should be interpreted with some caution.

Sea trials aboard commercial vessels have shown benthos release panels to perform well at reducing invertebrate and non-commercial finfish bycatch (e.g. Revill and Jennings, 2005). Furthermore, a recent *ex-post* analysis of catch and discard information indicated a significant reduction in the level of bycatch for otter trawl vessels in the North Sea when using square mesh panels (Enever *et al.*, 2009). SMPs have also been observed to result in reducing the number of undersize whiting and haddock retained whilst having no significant effect on the retention of sole and plaice (Depestele *et al.*, 2008). A later study based upon commercial trials using observers showed decreases in the total numbers of invertebrates in the discards, yet the overall weight of discarded fish and total discards did not change (Depestele *et al.*, 2009). This last study also reported a 6.9% (statistically significant) reduction in the total weight of the commercial fraction of catch retained when fished against gear without a SMP (Depestele *et al.*, 2009).

A T90 cod-end. Traditional 80mm diamond mesh cod end net turned through 90 degrees to prevent it closing up when weight loaded. This is another bycatch reducing modification aimed at reducing the level of juvenile finfish bycatch. The T90 is also referred to as the 'gentle' cod end as it does not pull tight when under load so can be less damaging to the retained fish. The T90 cod-end considered here had 54 open meshes round and was 70 meshes deep. The aft end was made of 5 rows of traditional diamond meshes.

T90 trials aboard demersal trawlers have shown they can be an effective bycatch reducing measure for juvenile fish (Moderhak, 1997). Subsequent trials on large beam trawls aboard research vessels have indicated the T90 can be effective at releasing increased numbers of non-commercial fish, undersize flatfish (such as dab, lemon sole, and sole) and undersize commercial roundfish (Depestele *et al.*, 2008). Similarly, trials aboard commercial vessels indicated significant reductions in juvenile haddock and commercial size hake retention (59% and 10%, respectively) but also worryingly large increases in the number of undersize sole retained (226%) (Depestele *et al.*, 2008). However, a larger scale assessment of T90 cod ends being used aboard commercially active vessels, reported in Depestele *et al*. (2009) (177 tows), indicated no significant difference in the weight of sole caught and a significant reduction in the number of <MLS sole retained (i.e. increase in the number of >MLS sole retained). Yet, in this instance more undersize plaice were reported as being retained. Should this also be the case when using the modified beam trawl, the long term effect of discard related mortality on plaice stocks and consequentially landings may actually be even more detrimental.

Lastly, less bycatch results in less time being needed to sort each haul. The magnitude of these savings and the fact most vessels are now working with the minimum crew required to operate safely mean this alone would not allow savings be achieved by reducing crew numbers. In this case, and assuming it is not re-allocated to other maintenance or operating duties, individual crew members will accrue the non-monetary benefit of less time spent sorting per shift. Further, whilst a number of modifications have been applied they primarily relate the specification (i.e. size, shape and position) of netting. Any differences between the costs of purchasing, fitting or maintaining the modified and conventional gears were believed to be negligible (Hans Polet, ILVO, personal communication, March 2008). Due to the nature of the modifications, additional costs of adjustment such as the re-training of crew in order to work the gear were also not expected.

As indicated above all the modifications applied to the alternative beam trawl have separately undergone at least some level of performance testing aboard either research (RV) or fishing vessels (FV). The combined effect of employing all simultaneously is less well researched and unknown interaction effects prevent the assumption that any expected benefits/costs associated with employing gear modifications are additive. The findings of these trials are somewhat mixed and if anything serve to indicate that the application of technical measures should be considered on a case by case basis.

2.0 Methodology

The approach adopted to examine these productivity changes was the use of stochastic production frontiers. These estimate the relationship between catch and the use of inputs, and take into account differing levels of efficiency of the fishers. Changes in productivity as a result of the use of modified gear are estimated as a shift in the production frontier. The estimation of production frontiers also allows the estimation of the technical efficiency of the vessels. The gears impact is assessed though its impact on the production function rather than efficiency *per se*. However, it is still appropriate to use a stochastic production frontier model rather than a traditional production function to allow for underlying efficiency differences in the vessels using the modified gear. Ignoring these underlying efficiency differences may confound the estimate of the effects of the alternative gears.

2.1 Stochastic Production Frontiers and Efficiency Estimation

Production functions use observed values to define the relationship between levels of input and the resultant levels of output (Schmidt, 1986). They indicate the average level of output as a function of a given level of input on the assumption that all producers are equally as efficient. Stochastic production frontiers differ in that they estimate the maximum level of output that can be produced from a given set of inputs, and consider deviations from this maximum level a result of inefficiency of the producers (as well as random error).

The basic stochastic production frontier is:

$$\ln Y_{it} = f(\ln x) + v_{it} - u_{it}, \quad i = 1...N, t = 1...T \qquad (5.1.1)$$

where $\ln Y_{it}$ is the production of firm *i* in time period *t*, *x* is a vector of explanatory variables, v_{it} the stochastic error term and u_{it} is the estimate of technical inefficiency of firm *i*. Both v_{it} and u_{it} are assumed to be independent and identically distributed (iid) with variance of σ^2_v and σ^2_u respectively.

In order to separate the stochastic and inefficiency effects in the model, a distributional assumption has to be made for u_i. Two main distributional assumptions that have been proposed are a normal distribution truncated at zero, $u_j \sim \left[N(\mu, \sigma_u^2)\right]$ (Aigner *et al.*, 1977), and a half-normal distribution truncated at zero, $u_j \sim \left[N(0, \sigma_u^2)\right]$ (Jondrow *et al.*, 1982). In addition, the inefficiency can also be considered to have a time variant component, so that $u_{i,t} = u_i \exp[\eta(T-t)]$ (Battese and Coelli, 1992), where *T* is the terminal time period (i.e., $u_{i,t} = u_i$ when $t = T$). A further alternative is to define the inefficiency as a function of the firm specific factors such that $u = z\delta + w$, where *z* is the vector of firm-specific variables which may influence the firms efficiency, δ is the associated matrix of coefficients and *w* is a matrix of iid random error terms. The parameters of the inefficiency model are estimated in a one-step procedure (Battese and Coelli, 1995) along with the parameters of the production frontier. Little information on factors that may affect efficiency other than the use (or otherwise) of the alternative gears was available, so this approach was not pursued.

Stochastic production frontiers have been estimated for a wide variety of fisheries (Kirkley *et al.*, 1995; Kirkley *et al.*, 1998; Sharma and Leung, 1998; Pascoe *et al.*, 2001; Pascoe and Coglan, 2002; Herrero and Pascoe, 2003; Tingley *et al.*, 2005). These studies have tended to estimate the translog functional form of the model. The translog functional form is generally preferred over other functional forms as it is conceptually simple and imposes no *a priori* restrictions on elasticities of substitution, production elasticities and returns to scale. The general translog functional form can be expressed as;

$$\ln Y_{j,t} = \beta_0 + \sum_i \beta_i \ln X_{j,i,t} + \frac{1}{2}\sum_i \sum_k \beta_{i,k} \ln X_{j,i,t} \ln X_{j,k,t} - u_{j,t} + v_{j,t} \qquad (5.1.2)$$

where *Y* is the revenue of vessel *j* in period *t* and $X_{j,i,t}$ are the vessel inputs (*i*,*k*) to the production process.

The Cobb-Douglas production function (Zellner *et al.*, 1966) is an alternate functional form and is effectively a special case of the translog where all $\beta_{i,k} = 0$. Typically the translog form is estimated first and then its validity tested against that of the Cobb-Douglas specification. Implicit in the Cobb-Douglas production function is an elasticity of substitution of 1. Further, production elasticities are constant and identical for all producers.

3.0 Data

3. 1 Catch and Effort Data

Data relating to 9 large commercially active Belgian beam trawlers were obtained from the Flemish Institute for Agriculture and Fisheries Research (ILVO) for the period January 2004 to December 2007. This included information on each vessels' physical characteristics (e.g. length, kW, GT), trip level effort (hours fishing, ICES rectangle) and landings (species, ICES rectangle).

Initially (i.e. from January 2004) all 9 vessels were operating with conventional beam trawl gear. However, as of August 2005 one vessel (MT1) changed gears and began to operate with the previously described modified beam trawl. The other 8 vessels (BT1-8) continued to utilise their conventional beam gear for the remainder of the observed period, serving as points of reference.

The vessels in the data set ranged from 32.5 to 38.2m in length and 750 to 957kW in engine power. MT1 was 33.5 meters in length, was built in 1982 and had a 850kW engine that had last been replaced in 1998. The individual vessels characteristics are presented in Table 5.1.1 and the average reference vessel compared with MT1.

Table 5.1.1**.** Vessel characteristics

Vessel	Length (m)	kW	GRT (t)	Hull Vintage
			Experimental vessel	
MT1	33.53	850	233	1982
			Reference vessels	
BT1	34.80	882	236	1975
BT2	32.50	750	247	1982
BT3	32.23	882	259	1985
BT4	36.01	875	329	1985
BT5	37.80	957	385	2000
BT6	38.20	957	384	1997
BT7	37.80	957	384	1998
BT8	37.80	937	389	2001
Average of BT	35.89	900	327	1990
Difference between MT1 & Average BT	-2.36	-50	-94	8 years older

Over the period observed, MT1 primarily fished the Irish Sea (VIIa), the Celtic Sea North (VIIg), the Bristol Channel (VIIf), and the Central North Sea (IVb). Of these areas the majority of effort was exerted in the Irish Sea and Celtic Sea North. A number of the reference vessels had also spent some time fishing other areas so observations relating to these landings were excluded from the analysis to ensure the productivity being assessed was as directly comparable as possible. Furthermore, any period in which MT1 was not recorded as operating were also excluded from the analysis. This resulted in a final data set of 737 fortnightly observations relating to 9 vessels. Descriptive statistics are presented in Table 5.1.2.

Table 5.1.2. Descriptive statistics for vessels MT1 and BT1 to 8 over the period January 2004 to December 2007.

	Min.	Max.	Mean	SD
All data (737 obs.)				
Landings (kg)	24.00	58,517.00	8,471.66	7,323.06
Revenue (€)	60.17	160,100.30	34,256.54	25,323.49
Power (kW)	750.00	1176.00	884.66	84.25
Length (metres)	32.23	38.20	35.02	2.33
Effort (hours)	1.00	480	117.90	75.06
Experimental vessel only (127 obs.)				
Landings (kg)	359.20	24,898.50	8,225.97	5,102.96
Revenue (€)	1,146.89	89,590.44	33,429.23	19,095.09
Power (kW)	850.00	850.00	850.00	0.00
Length (metres)	33.53	33.53	33.53	0.00
Effort (hours)	6.00	480.00	157.04	84.90
Reference vessels only (610 obs.)				
Landings (kg)	24.00	58,517.00	7,707.64	7,707.64
Revenue (€)	60.17	160,100.30	34,428.78	26,446.15
Power (kW)	750.00	1176.00	891.89	90.97
Length (metres)	32.23	38.20	35.33	2.44
Effort (hours)	1.00	372.00	109.76	70.23

3.2 Treatment of Stock

As annual spawning stock biomass (SSB) estimates were available for the most important species by ICES rectangle, a composite index variable was derived to account for temporal and spatial variations in the level of stocks. This included species specific annual SSB based indices for sole, plaice and cod; species specific annual CPUE indices for the 8 species that (individually) accounted for more than 1% of revenue but for which SSB estimates did not exist; and an aggregate (annual) RPUE for the remaining 24 minor commercial species landed that account for less than 1% of revenue (and together less than 5%). The CPUE was a 'fleet' level measure derived from the aggregate landings of all vessels from the 9 present in that time period. The 8 species were Brill, haddock lemon sole, megrim, monkfish nsp, ray nsp, turbot, and other demersal fish. All these indices were constructed at the annual level and specific to the ICES area a vessel was operating in at the time. The SSB index may be represented as:

$$SSBindex_{i,j,t} = \frac{SSB_{j,i,t}}{SSB_{j,i,t_1}}, \quad j = 1...N, i = 1...N, t = 1...T \tag{5.1.3}$$

where; $SSB_{j,i,t}$, represents the estimated spawning stock biomass of species j in ICES rectangle i, in year t. The species level CPUE index can be written as:

$$CPUEindex_{i,j,t} = \left(\frac{\sum q_{j,i,t}}{\sum e_{i,t}}\right) \Big/ \left(\frac{\sum q_{j,i,t_1}}{\sum e_{i,t_1}}\right), \quad j = 1...N, i = 1...N, t = 1...T \tag{5.1.4}$$

where $q_{j,i,t}$ is the quantity (kg) of species j landed from ICES rectangle i in year t, and $e_{i,t}$ is the effort applied in ICES rectangle i in the year t.

Lastly, the aggregate RPUE index for the remaining 29 less valuable species may be written as:

$$RPUEindex_{i,t} = \left(\frac{\sum_{j=1}^{N} \left(p_{j,t} \times q_{i,j,t} \right)}{\sum e_{i,t}} \right) \Bigg/ \left(\frac{\sum_{j=1}^{N} \left(p_{j,t_1} \times q_{i,j,t_1} \right)}{\sum e_{i,t_1}} \right), \qquad (5.1.5)$$

$$j = 1...N, i = 1...N, t = 1...T$$

where; $p_{j,t}$ is the average price of species j in year t (all prices were inflated to 2007 equivalent values).

All indices were constructed from species level data relating to each individual landing within the dataset. The relevant index number was then attached to each individual observation (i.e. by species, area, and year) and weighted by the share that particular species contributed towards a vessels revenue over that 2 week period. When the species level landings data were aggregated to total landings by vessel/area/period the indices were likewise aggregated providing a composite stock index value for each observation;

$$Composite\ index_{v.i,p} = \sum_j index_{i,j} \times revenueshare_{v,i,j,p}$$

$$where\ index_{i,j} \begin{cases} SSBindex\ \ for\ \ j = sole, plaice, cod \\ CPUEindex\ \ for\ \ j = 8\ \ other\ key\ \ species \\ RPUEindex\ \ for\ other\ species \end{cases} \qquad (5.1.6)$$

where v represents the specific vessel and p represents the 2 week periods (roughly akin to typical trip length) the data was finally aggregated into.

On average, and over all years and areas, the three species for which SSB estimates were available (sole, plaice and cod) jointly accounted for 59.5% of total observed landings by value (just over 15 million Euros). The remaining (non-SSB) stocks, incorporated using individual CPUE and an aggregate RPUE indices, accounted for 36.1% and 4.4% of landings by value, respectively. Figure 5.1.1 illustrates the relative contribution of these ‘SSB’ and ‘non-SSB’ stocks to the total value of landings by ICES rectangle.

As such the derived composite index should be a reasonably robust measure. However, considering that proxy stock measure indices such as CPUE (and therefore also RPUE) have the potential to be biased (Alvarez, 2003) stock effects were also investigated using sets of annual and area specific dummies.

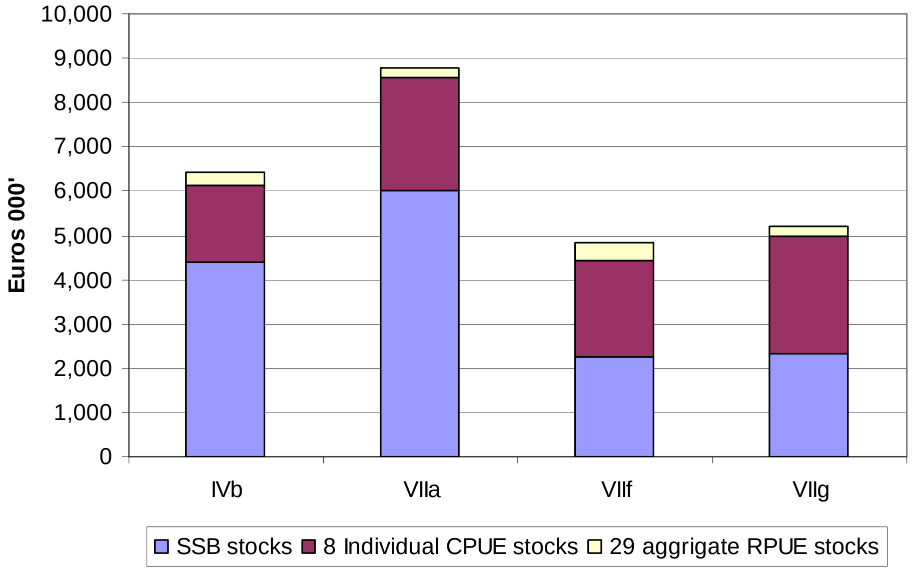

Figure 5.1.1. Value of landings (000' Euros, 2007 equivalent) total for all vessels in data set 2004-2007.

3.3 Additional Cost Data

Whilst data relating to the costs of production were not a part of the productivity analysis, attempts were made to collect information on any costs likely to change as a result of using the modified beam trawl. All costs other than those of fuel were indicated as remaining constant across gears (Polet H, personal communication, March 6, 2008).

Exact records of the fuel consumption associated with the landings and effort values were not available for any of the vessels being considered. However, fuel consumption rates for all vessels were initially believed to be at least 4000 litres/24 hours. The trial vessel was reported to have reduced its fuel consumption by 15% to approximately 3400 litres/24 hours (Polet H, personal communication, March 6, 2008) As fuel costs can account for between 30% and 50% of a beam trawlers gross revenue (Depestele *et al.*, 2007) such a reduction represents a significant saving. However this reduction was achieved through a combination of fishing with the modified gear (believed to take less by catch and therefore create less drag, it also has less drag due to larger meshes in certain places) and more responsible use of the engine due to an econometer being installed around the same time. An econometer is a fuel consumption meter. These provide skippers real time assessments of fuel consumption and help them modify engine use behaviour to reduce unnecessary fuel consumption wherever possible. Consequentially, the extent to which using modified gear, in itself, reduced fuel consumption was difficult to accurately quantify but was indicated to be in the region of 5% or less (Polet, 2008).

4.0 Model Estimation and Results

The models were estimated in FRONTIER 4.1 (Coelli, 1996) using a single (aggregate) dependent variable of landings weighted by revenue share. These were assessed at the fortnightly level, a period roughly comparable with average trip lengths. Revenue share weights were derived by applying annual average Belgian prices (inflated to 2007 equivalent values) to the observed, species level, landings. As species level information was available for each individual landing a multiple output approach was considered (such as those undertaken by Fousekis, 2002; Kirkley *et al.*, 2004; Pascoe *et al.*, 2007). However, even if the number of individual species considered had been restricted to only the main target species accounting for these by area would have required a prohibitive number of explanatory variables relative to the number of observations available. This is because when using a translog functional form the number of square and cross terms required can become problematic. For example the primal multi-output distance function constructed by Pascoe *et al.* (2007) considered only 3 species and 1 ‘other’ category for beam trawlers in the North Sea (one sea area) yet required 27 explanatory variables.

Implicit in the use of a single aggregate output is the assumption that outputs are separable from inputs and production effectively forced to be joint in input quantities (implying that inputs are used in relatively fixed proportions relative to output). Joining in production is believed to be a reasonable assumption for these vessels as the relatively non-selective nature of their gear limits, to a certain extent (vessels can attempt to target certain species by altering areas fished), the ability of these fishers to influence the composition of their catch. Furthermore, Pascoe *et al*. (2007) recently found production in the UK North Sea beam trawl fleet to be joint in inputs, however the same study also found production to be non-separable from inputs. Jensen (2002) demonstrated that separability between input and outputs is commonly rejected in fisheries production studies (see also Fousekis, 2002; Orea *et al.*, 2005) indicating that the majority of fishing technologies should be modelled in a disaggregated context. However, as discussed above, the necessary number of explanatory variable in relation to the number of observations meant doing so was not possible in this instance.

Economic measures of capital (e.g. value of hull and/or engine) were not available and whilst these are possibly more theoretically appropriate than physical measures (e.g. length, kW) in practice it has been demonstrated that both provide similar estimates of efficiency (Pascoe *et al.*, 2003). Boat length (m) and engine power (kW) are typically key determinants of productivity in trawl fisheries (Tingley *et al.*, 2005; Coglan and Pascoe, 2007; Pascoe *et al.*, 2007). The rationale is that a vessel with a larger engine can haul larger nets allowing it to fish a greater area of ground in a given period of time. Additionally, vessels with larger engines should also be faster allowing them to cover greater distances when not fishing, increasing their range and flexibility in terms of areas exploited. The extent to which this applies may rest on quota held and other spatially relevant regulations. Vessel size, often accounted for through length, is typically highly correlated with hold size and consequentially the quantity of fish a vessel can retain (and subsequently land) over the period of one trip. In this respect the extent to which vessel size influences productivity will also vary with stock level; not being relevant when stock levels are below a certain threshold but becoming increasingly important once it is exceeded.

It is common for the key measures to be highly correlated so the simultaneous inclusion of both risks problems of multicollinearity. On testing the data this was confirmed to be the case for kW and length (Pearsons coef. 0.84). A very similar level of correlation (0.881) between kW and length has been observed in the UK beam trawl fleet (Pascoe and Robinson, 1998). With this in mind both inputs were considered in the analysis but separately and in alternative models. Information on crew size was not available however this has also been shown to be highly correlated with boat size in similar trawl fisheries (Pascoe and Coglan, 2002).

The final set of inputs consisted of either engine power (kW) or length (m) as a physical measure of capital, effort (hours fishing) as a measure of capital utilisation, and stock. All variables were normalised to a mean of zero (i.e. $\ln \bar{x}, \ln \bar{y} = 0$) and all monetary values inflated to 2007 equivalents. The more general time variant ($\eta \neq 0$) specification with a truncated normal distribution ($\mu \neq 0$) is a common starting point when estimating the frontier. However, as the MT vessel did not appear in every period, the data were discontinuous. As a result the assumption that efficiency did not vary with time ($\eta = 0$) had to be imposed from the outset. Alternative forms were then estimated and the best models selected following the likelihood ratio (LR) method advocated by Coelli (1996). The LR test results are presented in Table 5.1.3.

Despite being only partially reliant on CPUE based stock indices, a further set of models were subsequently estimated using sets of area and year specific dummy variables in place of the composite stock index. These cannot be considered a direct stock measure substitute due to the fact they will also pick up any other spatially or temporally associated changes.

The impact of using modified gear on productivity was estimated through the use of dummy variables. For MT1 these were specified to have a value of zero (0) for landings associated with fishing operations prior to August 2005 and one (1) after that point. For the reference vessels (BT1-8) the dummy was set to zero (0) for all periods. The production frontier including the dummy variable can again be given by;

$$\ln Y_{j,t} = \beta_0 + \sum_i \beta_i \ln X_{j,i,t} + \frac{1}{2}\sum_i \sum_k \beta_{i,k} \ln X_{j,i,t} \ln X_{j,k,t} + \gamma D_{i,t} - u_{j,t} + v_{j,t} \quad (5.1.7)$$

where $D_{i,t}$ has a value of 1 if the vessel j was using the modified beam gear in period t, or 0 otherwise. The dummy variable effectively shifts the production frontier up or down.
The translog production frontiers were thus initially specified as;

$$\begin{aligned} \ln Y_{jt} = {} & \beta_0 + \beta_1 \ln x_{j,kW,t} + \beta_2 \ln x_{j,EFFORT,t} + \beta_3 \ln x_{STOCK,t} + \beta_4 \ln^2 x_{j,kW,t} + \\ & \beta_5 \ln^2 x_{j,EFFORT,t} + \beta_6 \ln^2 x_{STOCK,t} + \beta_7 \ln x_{j,kW,t} \ln x_{j,EFFORT,t} + \\ & \beta_8 \ln x_{j,kW,t} \ln x_{STOCK,t} + \beta_9 \ln x_{j,EFFORT,t} \ln x_{STOCK,t} + \gamma D_{j,t} + (V_{j,t} - U_{j,t}) \end{aligned} \quad (5.1.8)$$

for the stock-based model, and

$$\begin{aligned} \ln Y_{jt} = {} & \beta_0 + \beta_1 \ln xk_{j,kW,t} + \beta_2 \ln x_{j,EFFORT,t} + \beta_3 \ln^2 x_{j,kW,t} + \\ & \beta_4 \ln^2 x_{j,EFFORT,t} + \beta_5 \ln x_{j,kW,t} \ln x_{j,EFFORT,t} + \\ & \sum_{i=2}^{4} \mu I_i + \sum_{y=2}^{4} \omega A_y + \gamma D_{j,t} + (V_{j,t} - U_{j,t}) \end{aligned} \quad (5.1.9)$$

for the dummy variable based model, where $Y_{j,t}$ is the landings weighted by revenue share for vessel j in time period t, $x_{kW,j,t}$ engine power in kW, $x_{EFFORT,j,t}$ is effort (hours fishing), $x_{STOCK,t}$ the constructed composite stock index variable, I_i is a set of dummy variables each representing one of the ICES rectangles fished (IVa, VIIa, VIIf, VIIg), A_y is a set of dummy variables representing each year (2004-07) and D the previously described dummy variable included to pick up the effect of using the modified beam trawl gear. When using dummy variables to represent seasonal patterns or changes over time, one month or year must be excluded as the base to avoid problems of collinearity. This is implicitly captured in the constant term of the model. In this case, ICES rectangle IVa was the base area and 2005 the base year.

Table 5.1.3. Specification tests.

Null Hypothesis H_0:	$L(H_0)$	$L(H_1)$	λ[a]	Deg. freedom	p-value	Decision
Composite stock index						
			Model 1- engine power (kW)			
$\beta_{i,k} = 0$	-641.32	-619.14	44.36	6	0.00%	reject H_0
$\gamma = 0$	-630.32	-619.14	22.36	2	0.00%[b]	reject H_0
$\mu = 0$	-620.36	-619.14	2.44	1	11.82%	accept H_0
			Model 2 - length (m)			
$\beta_{i,k} = 0$	-640.60	-619.47	42.25	6	0.00%	reject H_0
$\gamma = 0$	-628.26	-619.47	17.58	2	0.00%[b]	reject H_0
$\mu = 0$	-619.52	-619.47	0.11	1	74.56%	accept H_0
Dummy stock variables						
			Model 3 - engine power (kW)			
$\beta_{i,k} = 0$	-530.49	-527.17	6.64	3	8.42%	accept H_0
$\gamma = 0$	-541.03	-530.49	21.08	2	0.00%[b]	reject H_0
$\mu = 0$	-531.75	-530.49	2.52	1	11.22%	accept H_0
			Model 4 - length (m)			
$\beta_{i,k} = 0$	-530.49	-524.86	11.26	3	1.04%	reject H_0
$\gamma = 0$	-534.22	-524.86	18.72	2	0.00%[b]	reject H_0
$\mu = 0$	-524.92	-524.86	0.12	1	73.21%	accept H_0

[a] $\lambda = -2[\ln\{L(H_0)\}-\ln\{L(H_1)\}]$, [b] Using critical value of Kodde and Palm (1986)

The restricted Cobb-Douglass functional form was tested against the translog (H_0: $\beta_{i.k} = 0$) and rejected for all but the dummy kW model (model 3). The presence of technical inefficiency was confirmed for all models with the null hypothesis (H_0: $\gamma = 0$) being rejected at the 1% level of significance in all cases (using the one sided χ^2 table of Kodde and Palm (1986)). Rejection of the null indicating that production could not be just as well described through the specification of a standard production function. Finally, the assumption of a truncated normal distributional ($\mu \neq 0$) was tested and rejected for all models in favour of the half-normal distribution ($\mu = 0$). The specification test results are presented in Table 5.1.3 and coefficients for the preferred stock-based and dummy models are presented in Tables 5.1.4 and 5.1.5, respectively.

As all variables were normalised to a mean of zero (i.e. $\ln\bar{x}, \ln\bar{y} = 0$) the coefficients of non-squared or cross term variables can be directly interpreted as production elasticities. The elasticities relating to capital utilisation (hours fished) were all close to the value expected (approx. 1), highly significant, and demonstrated a greater level of stability across models. The effort elasticities in models 1 and 2 were not significantly different from one suggesting constant returns to hours fished, whereas in models 3 and 4, they indicate decreasing returns. That is, a 10% increase in hours fished, for example, would increase output only by 7.5% and 8.1%, respectively. Constant returns with respect to time fished has previously been observed in other beam trawl fisheries (e.g. Pascoe *et al.*, 2007).

Table 5.1.4. Production frontier results when using a composite stock index.

Model 1 - engine power (kW)			Model 2 - length (m)		
	coefficient	t-ratio		coefficient	t-ratio
Constant	0.19	1.84 *	constant	0.299	2.830 ***
ln kW	2.39	1.85 *	ln length	2.993	3.663 ***
ln effort	1.01	26.57 ***	ln effort	1.006	26.766 ***
ln stock	1.25	4.62 ***	ln stock	1.160	4.286 ***
ln kW^2	-10.02	-2.38 **	ln $length^2$	-62.660	-3.652 ***
ln $effort^2$	0.10	5.02 ***	ln $effort^2$	0.087	4.381 ***
ln $stock^2$	4.02	3.32 ***	ln $stock^2$	4.222	3.496 ***
ln kW * ln effort	0.43	1.45	ln length * ln effort	0.127	0.272
ln kW * ln stock	2.37	0.91	ln length * ln stock	-0.011	-0.003
ln effort * ln stock	-0.63	-2.76 ***	ln effort * ln stock	-0.540	-2.459 **
Gear dummy	-0.21	-1.68 *	Gear dummy	-0.235	-1.873 *
σ^2	0.45	4.63 ***	σ^2	0.393	7.192 ***
Γ	0.31	2.08 **	Γ	0.217	2.058 **
log likelihood	-620.36		log likelihood	-619.525	

Significance at *10%, **5%, ***1%

Table 5.1.5. Production frontier results when using dummy variables to account for spatial and temporal variation.

Model 3 - Engine power (kW)			Model 4 - Length (m)		
	coefficient	t-ratio		coefficient	t-ratio
Constant	0.84	8.64 ***	Constant	0.92	8.55 ***
ln kW	0.01	0.01	ln length	1.31	1.80 *
ln effort	0.75	27.37 ***	ln effort	0.81	21.91 ***
ln kW^2	-	-	ln $length^2$	-43.37	-2.61 ***
ln $effort^2$	-	-	ln $effort^2$	0.03	1.84 *
ln kW * ln effort	-	-	ln length * ln effort	-0.53	-1.33
VIIa	-0.54	-6.04 ***	VIIa	-0.57	-6.17 ***
VIIf	-0.81	-10.38 ***	VIIf	-0.80	-10.30 ***
VIIg	-1.10	-17.10 ***	VIIg	-1.08	-16.97 ***
2004	0.11	1.79 *	2004	0.10	1.64
2006	0.19	2.93 ***	2006	0.18	2.75 ***
2007	0.27	4.10 ***	2007	0.26	4.01 ***
Gear dummy	-0.19	-1.62 *	Gear dummy	-0.20	-1.77 *
σ^2	0.35	4.78 ***	Σ^2	0.31	6.57 ***
Γ	0.32	2.22 **	Γ	0.23	2.05 **
Log likelihood	-531.75		Log likelihood	-524.92	

Significance at *10%, **5%, ***1%

The fixed capital input elasticities (i.e. those associated with engine power (kW) or length (m)) were considerably larger than expected in models 1 and 2, was high in model 4, and was low and not significant in model 3. Elasticities greater than one imply increasing returns to scale, so that an increase in kW or length would result in a greater than proportional increase in output. However, the unrealistic size of elasticities estimated and high level of instability across the various model forms clearly indicates the existence of problems within all models for this variable.

Within models 3 and 4, all coefficients relating to ICES rectangle fished were found to be strongly significant at the <1% level and result in lower vessel productivity when compared to the reference area IVb.

Across all models the coefficients relating to the modified gear dummy variable estimate the impact of using the modified beam trawl to be between -17.3% and -21.0% $\left(i.e.(e^{\beta_{ModifiedGear}}-1)*100\right)$ (Table 5.1.6). Whilst these coefficients are significant at only the 10% level the estimate gives a consistent result across all the models.

Table 5.1.6. Estimated gear effect by model.

	Fixed input used	
Stock assumption used	kW	Length
Composite index	-18.93%*	-20.98%*
Dummy variables	-17.34%*	-18.33%*

Significance at *10%, **5%, ***1%

4.1 Theoretical Consistency

Whilst the most appropriate models were selected using likelihood ratio tests each frontiers' theoretically consistency still requires *a posteriori* validation. For theoretically consistency to be satisfied a frontier should demonstrate both monotonicity and quasi-concavity. It has been shown that a number of flexible form stochastic efficiency assessments in the literature fail to satisfy at least one of these requirements (Sauer *et al.*, 2006). Hence, the regularity of the estimated frontiers were checked for every observation following the method of Sauer *et al.* (2006). Monotonicity implies that at no point can an additional unit of input (x) result in a decrease in output (y) and means all marginal productivities are non-negative. Quasi-concavity implies the diminishing marginal rate of technical substitution law holds.

Due to the number of hours fished (effort) being a measure of capital utilisation, and stock being a non-discretionary input, the only factor inputs considered for assessment were those representing capital (either kW or length). Therefore, only one input variable was assessed for each model and further meant the sign of the associated squared term was sufficient to confirm the curvature (When more than one input variable must be considered the bordered Hessian matrix as the Jacobian of the derivatives $\delta y/\delta x_i$ with respect to x_i must be confirmed as negative semi-definite.). These were negative in all cases implying the existence of quasi-concavity. The monotonicity test results for each model are presented in Table 5.1.7. Only model 2 demonstrated positive marginal products (i.e. $\delta y/\delta x_i > 0$) that were decreasing in inputs ($\delta^2 y/\delta x_i^2 < 0$). Models 1 and 3 were positive in marginal products and neither increasing or decreasing in inputs. For model 1 $\delta^2 y/\delta x_i^2$ was very small, mixed, and on average equal to 0.01 so, given the previously acknowledged likelihood for uncertainty in the parameter estimates, considered not significantly different to zero. Model 3 was of a Cobb-Douglass functional form so $\delta^2 y/\delta x_i^2$ is effectively restricted to zero. Lastly, model 4 violated the requirement for monotonicity by demonstrating typically negative marginal products (i.e. $\delta y/\delta x_i < 0$) that were decreasing in inputs. As such, with the exception of model 4 the requirements for theoretical consistency were generally met.

Table 5.1.7. Monotonicity tests.

	Theoretical requirement $\delta y/\delta x_i > 0$	$\delta^2 y/\delta x_i^2 < 0$
Model 1	>0	0[a]
Model 2	>0	<0
Model 3 (C-D)	>0	N.A.
Model 4	<0	<0

[a]average 0.01

Where theoretical consistency is not satisfied Sauer *et al.* (2006) recommend the imposition of global regularity *a priori*. This was not undertaken in this instance as; all but model 4 essentially satisfied the tests of theoretical consistency; imposing such regularity results in a significant loss of functional flexibility, and; the coefficient of primary concern was reasonably stable across all of the models presented.

5.0 Implications for Profitability

The overall negative effect of using the modified beam trawl indicates that uptake has imposed an additional cost on the vessel utilising this gear (MT1) by reducing its level of productivity in the order of 17 to 21%. The quantification of any reductions in fuel consumption directly attributable to use of the modified gear have been somewhat confounded by the simultaneous uptake of an econometer aboard MT1. Of the estimated reduction in overall fuel consumption (15%) it was believed that 5% (or less) could be attributed to the modified gear effect and 10% to the econometer (Polet H, personal communication, March 6, 2008).

The implications of these changes in productivity and fuel consumption were considered with regard to the profitability of an average vessel (Table 5.1.8). All estimations were based on the average reported costs and earnings for large Belgian beam trawlers in 2007 (from VlaamseOverheid, 2007b). To account for the full range of productivity effects, estimated reductions of 17.34% and 20.98% were considered, these representing minimum and maximum estimated effects. Fuel costs were reduced by 5%, 0% and then 15% for each level of productivity effect considered. This allowed the estimated effects on profitability of using just the modified gear (5% and 0%) and then both modified gear and an econometer (15%) to be considered. The reported figures indicated total crew costs accounted for just under 30% of revenue and were adjusted accordingly for each scenario considered. Following the belief that gear purchase and maintenance costs were consistent with conventional gear, no change in these costs was assumed. Furthermore, no changes in fisher behaviour or other factors were anticipated so all other costs were assumed to remain constant.

Table 5.1.8. Estimated effects of gear uptake and econometer use for an average large Belgian beam trawler in 2007.

Beam trawl vessels >662kW

Average days at sea: 248
Average PK: 1232
Average BT: 324
Average kW: 907

	Average beam trawl 2007			Effects of changes in productivity and fuel consumption					
		Per day at sea	Per kW	Revenue: -17.34%			-20.98%		
				Fuel: -5%	-15%	0%	-5%	-15%	0%
A. REVENUE	**1,536,600**	6,195		**1,270,154**			**1,214,221**		
COSTS									
Remuneration costs	454,985	1,834	502	376,091	376,091	376,091	359,529	359,529	359,529
Fuel	480,803	1,938	530	456,763	408,683	480,803	456,763	408,683	480,803
Other costs*	379,667	1,531	419	379,667	379,667	379,667	379,667	379,667	379,667
B. Total costs	1,316,455	5,304	1,451	1,212,520	1,164,440	1,236,561	1,195,959	1,147,879	1,219,999
C. Gross company result (A-B)	**221,145**	892	180	**57,633**	**105,713**	**33,593**	**18,262**	**66,343**	**-5,778**
D. Depreciation	180,379	727	146	180,379	180,379	180,379	180,379	180,379	180,379
E. Nett company result (C-D)	**40,767**			**-122,746**	**-74,666**	**-146,786**	**-162,117**	**-114,036**	**-186,157**
F. Financial costs	48,028	194	39	48,028	48,028	48,028	48,028	48,028	48,028
G. Financial operating subsidies	21,506			21,506	21,506	21,506	21,506	21,506	21,506
H. Nett gains/losses for tax purposes (E-F+G)	**14,245**			**-149,268**	**-101,188**	**-173,308**	**-188,639**	**-140,558**	**-212,679**

* ‘Other costs’ includes: insurance, maintenance, ice, gas, salt, hire of equipment, and other costs.

It is immediately apparent that both levels of reduced productivity would result in vessels becoming unprofitable under current conditions. For the ‘best case’ scenario in which a 5% reduction in fuel consumption (the maximum believed likely for gear alone) and the lowest effect on productivity (-17.34%) annual profit fell from €14,245 to €-149,268, a total loss of €163,513. When the assumptions were changed to reflect the ‘worst case’ scenario, so there was no reduction in fuel consumption and productivity was reduced by the largest level estimated (-20.98%), annual profit fell by at total of €226,924 (from €14,245 to €-212,679). Whilst the use of an econometer (Fuel -15%) did help by partially offsetting the financial effects of reduced productivity, this was not sufficient to maintain financial profitability (Figure 5.1.2).

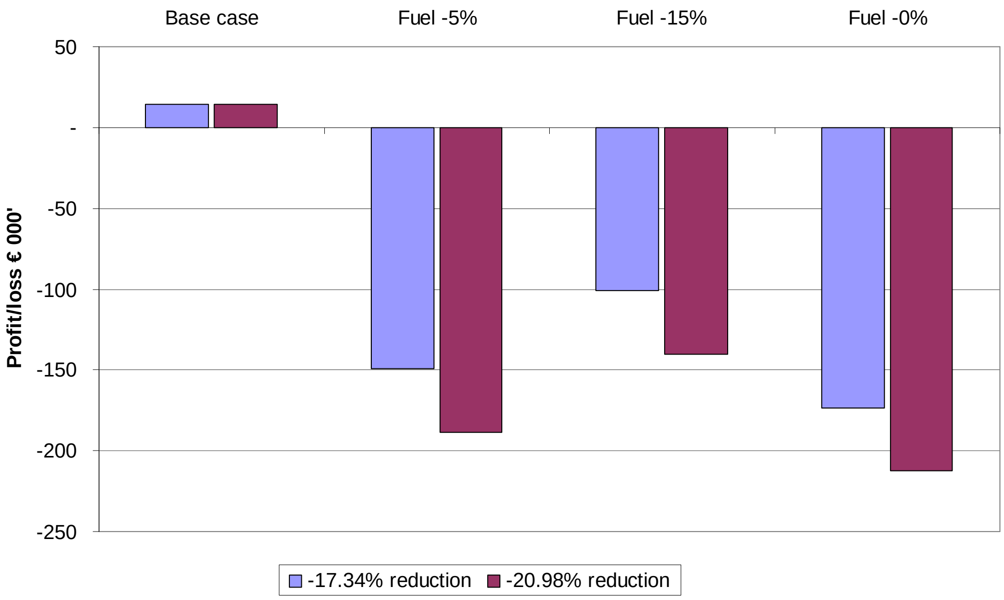

Figure 5.1.2. Profitability implications for an average Belgian large beam trawler under alternative productivity and fuel consumption assumptions.

This is a static analysis and as such cannot account for the possibility of increased (decreased) landings over the long term if the condition of stocks were to improve (deteriorate) or fishers behaviour was to change.

6.0 Discussion and Conclusions

As all the data considered in this assessment relates to vessels from the large beam trawl sector (i.e. vessels >662kW) its findings are only applicable within that context. Whilst a number of the modified beam trawls adaptations have also been separately trialled aboard smaller eurocutter vessels (Depestele *et al.*, 2008, 2009) underlying differences in behaviour and typical fishing grounds prevent these results from being considered as anything more than indicative for the smaller segment.

The relatively small data sample (i.e. a total of 9 vessels and 737 observations) is believed responsible for observed instability in the coefficient associated with capital input. The coefficients accounting for uptake of the alternative beam trawl, however, proved to be relatively stable and consistently negative across all models suggesting a higher level of robustness in the estimates. As the objective of this assessment was to estimate how using the modified gear in place of conventional gear affected productivity, the potential unreliability of other coefficients was of less concern in this instance.

The findings of this study indicate that utilising the 'modified beam trawl' has had a negative effect on the productivity of MT1 when compared to other vessels in the same fleet (circa -20%). A finding that differs to that of similar trials simultaneously testing a T90 cod end and SMP aboard a commercial vessels (Section 7, Depestele *et al.*, 2008). It has also been shown that even when reductions in associated variable costs and fuel consumption are accounted for, the average Belgian large beam trawl vessel would become unprofitable. A fact perhaps worthy of note is that, in 2007, the average Belgian large beam trawl vessel could not afford for revenue to fall by anything greater than 1.32% before registering a loss (assuming all other costs except for crew remained constant). The magnitude of this figure gives some indication of the difficulty involved with applying technical measures if they are likely to negatively influence productivity. It also suggests that internalising the externalities of these beam trawl vessels in this manner is, under current conditions, likely to render most (if not all) unviable.

The indicated negative profitability is the product of a static analysis and assumes no compensatory price effects arising due to reduced productivity and consequentially landings. Neither does it account for the possibility of changes in stock levels of important species. As the analysis was restricted to using average prices any short run price effect would not have been picked up by the analysis. However, estimates of own-price elasticities for the most important species indicate they are highly elastic (i.e. inflexible), and as such any compensatory price effects are thought unlikely. For example, Jaffry *et al.* (1999) estimated the long run ex-vessel own-price elasticity of sole in the UK (Belgian vessels also land into the UK) to be -4 and Barten and Bettendorf (1989) found the ex-vessel own-price elasticities for sole and plaice in the Belgian market to be -9.09 and -5.26, respectively.

A further assumption implicit in the profitability assessment was that crew would be willing to accept a circa 20% reduction in wages, something that will be influenced by the current level of supply and demand for labour within the industry. Should crew not be willing to accept such a reduction vessels may have to increase the crew share of revenue in order to retain crew, operate with generally less experienced crew whom could be paid at a reduced rate, or in the worst case cease operating. However, the second of these options may have additional detrimental safety and productivity implications.

These findings represent more extensive and realistic trials of technical measures than the simulated sea trials often performed by gear technicians. The modified gear was fished on a day to day basis and under true commercial conditions. *Ex-post* assessments such as this are far more representative of the gears true effects than comparative trials as they measure observed changes and account for adaptations in fishers behaviour over time or other unforeseen effects that can alter the way a measure performs.

The empirical assessments confirm that attempting to reduce the impacts of fisheries via the application of technical measures can also negatively affect vessels levels of productivity. Furthermore, the magnitudes of the estimated effects are broadly comparable with the findings of a number of previous *ex ante* gear trials, arguably lending weight to both sets of results. Yet, this only serves to confirm the fact that technical measures can generate; disincentives for rational forward-looking fishers to voluntarily develop or take up such gears (Abbott and Wilen, 2009), and; the incentive for them to attempt impact minimisation or circumvention should the measures be mandated. From the intended management outcome perspective this is a failure, as these undesirable drivers ultimately result in below potential reductions in the levels of bycatch and restrictions in the rate of technological development (Abbott and Wilen, 2009).

Task 5.2 To estimate the cost effectiveness of alternative gears.

Partner 11

1.0 Introduction

Modifying gear to reduce environmental impacts comes at a cost to the industry, usually in the form of reduced catch of the targeted species. Consequently, determining an optimal gear combination to minimise both habitat damage and bycatch at least cost to the industry requires some common measure of environmental damage. Further, tradeoffs between bycatch and habitat damage reduction are not explicit. Is a gear that results in a substantial reduction in habitat damage but little effect on bycatch better or worse than a gear that has the opposite impacts, and if these gears have different impacts on the profitability of the industry which is the most cost effective? To answer these questions, the perceived value of a reduction in one impact over another needs to be formally determined. Calculating the potential future economic value of commercial organisms saved by a reduction in discarding has been done in a number of studies (Hendrickson and Griffin, 1993; Revill *et al.*, 1999; Pascoe and Revill, 2004; Macher *et al.*, 2008). However, determining the value of non-market benefits such as reductions in the level of habitat change or the mortality of infauna due to gear passage across the seabed is not straightforward. Whilst directly measuring nonmarket benefits is difficult and subjective, the analytic hierarchy process (AHP) (Saaty, 1977, 1980) can indirectly measure nonmarket value to stakeholder groups by ranking the importance of attributes. As these values are likely to be highly subjective and hence may differ by stakeholder group these variations also need to be accounted for when developing mitigating measures.

This section develops a means of comparing the relative value of a change in habitat damage with a change in the level of bycatch. Such measures are essential if alternative fishing gears are to be directly compared as it allows not only the overall level of environmental benefit to be derived but also their relative cost effectiveness. The analytic hierarchy process (AHP), a formal decision analysis framework used to clarify and prioritise considerations in achieving a goal, is applied to determine the relative significance stakeholder groups attach to differing impact reductions. These sets of group specific weights allow the value of any changes in impacts to be accounted for and aggregated to reflect the total level of environmental benefit derived from a gear modification. Further, by determining relative priorities at the stakeholder group level it is possible to gain an insight into likely areas of similarity and disagreement with respect to the perceived effectiveness of alternatives.

2.0 Method - The Analytic Hierarchy Process (AHP)

The AHP (Saaty, 1977, 1980) is a method that allows individual preferences to be measured and converted into ratio-scale weights (Forman and Gass, 2001). It is one of several multi-criteria decision making techniques (MCDM) available and provides a relatively simple yet powerful means of deriving individuals' preferences for one attribute over another (for reviews and further information within the context of fisheries see Leung (2006) and Mardle and Pascoe (1999)). It is able to incorporate qualitative/value judgements and allows the inclusion of any non-commercial benefits modified gears may achieve. It is a flexible methodology that enables either an individual or groups of individuals to define a specific problem based on their own experience of that problem. Additionally, as the AHP is not a statistical exercise it does not require probabilistic assumptions about the decision alternatives.

AHP has been widely used in fisheries where studies have largely determined the relative importance of different management objectives (e.g. Mardle *et al.*, 2004; Nielsen and Mathiesen, 2006) or preferences for different management options (e.g. Leung *et al.*, 1998; Soma, 2003). It has also been used to compare the sustainability of alternative fishing fleets (Utne, 2008). In Task 5.2, the aim was to quantify the relative importance different groups attach to reducing certain fishing related impacts through deriving a set of relative weights that these groups place on reducing in-situ impacts and reducing discards.

The AHP has three basic principals (Saaty, 1994); decomposition, comparative judgement, and hierarchic composition/synthesis of priorities. Following previous studies (Leung *et al.*, 1998; Mardle *et al.*, 2004; Himes, 2007) the process was undertaken in four main steps;

1. develop a hierarchy of the factors important in that decision;
2. survey the associated participants to elicit judgements based on pairwise comparisons of the identified criteria;
3. calculate the individuals relative weights of the factors under consideration;
4. determine homogeneous group weights

2.1 Hierarchy of key objectives (step one)

The hierarchy of impacts (Figure 5.2.1) was developed in consultation with DEGREE participants (primarily Wp2) by identifying the potential problem areas which problem areas gear modifications were attempting to improve. The two main areas of consideration were in-situ impacts and bycatch. For the bycatch and discarding impacts, it was considered appropriate to treat commercial and non commercial species separately as each has a different value to the different stakeholder groups. Similarly, fish and invertebrates (which include key crustacean species) were considered separately. As these groups occupy overlapping habitats and positioning in the water column, an improvement (i.e. reduction) in the bycatch of one group could have a positive or negative impact on the bycatch of the other.

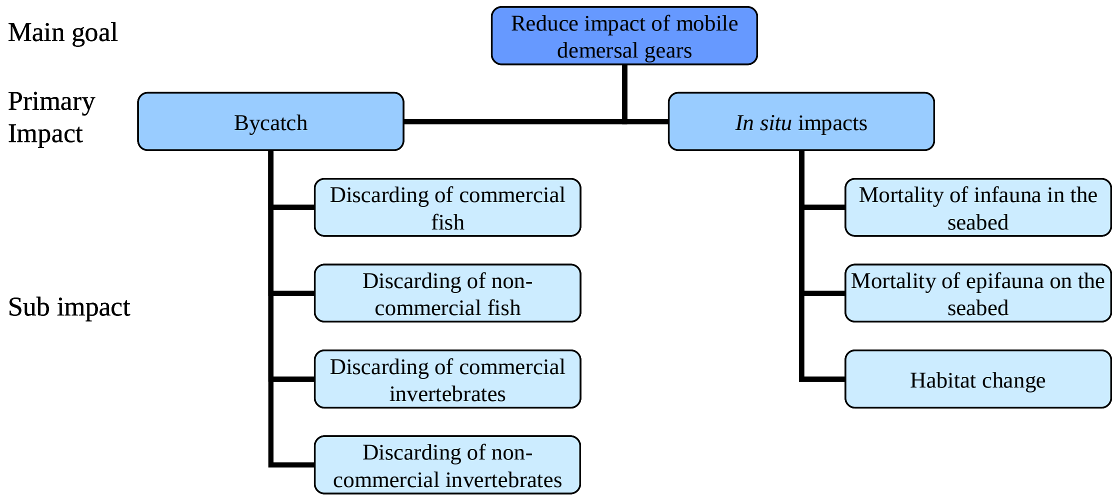

Figure 5.2.1. Key impacts related to the use of mobile benthic gears.

Although infauna (which live within the seabed) and epifauna (which live on the seabed) could potentially be considered non-commercial bycatch, they have an important linking role between the physical habitat and productivity of the accessible biomass. Further, unlike other species that are caught and subsequently discarded, infauna and epifauna are generally not caught *per se*, but are killed as a result of gear contact with the seabed. Consequently, they were considered *in situ* impacts, along with other habitat damage for the purposes of the study.

2.2 Survey of preferences (step two)

The database of ecologists, biologists, economists, gear technologists, industry representatives and fisheries managers (compiled with the assistance of all other project partners, following a request at M2) was completed. Participant suitability was determined by knowledge of issues surrounding environmental impacts associated with demersal trawl fisheries. The database was also developed on a referral basis, with known suitable potential participants being asked to suggest other potential participants. As part of the survey, respondents were asked to make a self assessment of their knowledge with regard to their understanding of the issues using a 10 point scale. The survey was primarily conducted via e-mail, although in a number of instances the surveys were either conducted or completed by telephone.

The scale of importance against which preferences are compared must be consistent for each pairwise choice. The most commonly applied scale is a nine point scale (Figure 5.2.2), which has been validated for effectiveness through theoretical comparisons with a number of other scales (Saaty, 1990). A value of 1 (middle of range) indicates the respondent considers the elements to be of equal importance (i.e. is indifferent). Choosing a higher value, from 2 to 9, indicates that one element was believed to be more important than the other and indicates the strength of that belief.

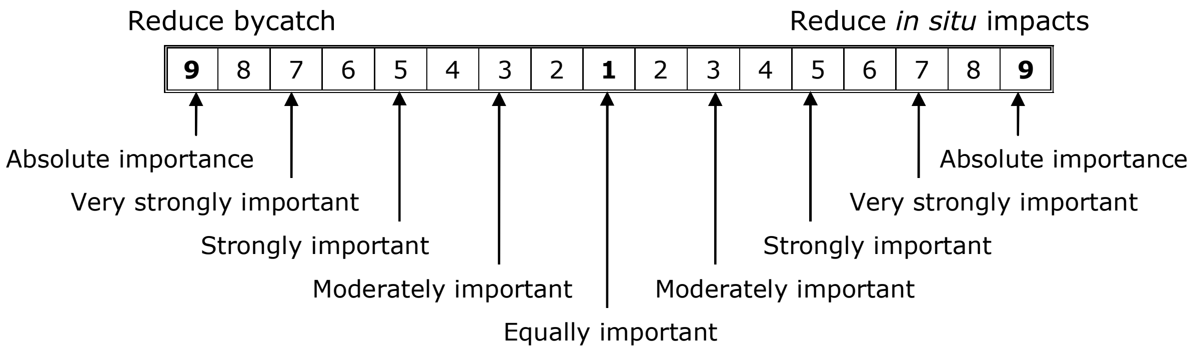

Figure 5.2.2. Pair-wise comparison of objectives.

The hierarchy tree illustrated in Figure 5.2.1 resulted in three sets of pairwise comparisons; one between the two primary objectives, then; a further two sets comparing the sub-objectives within each objective. The number of pairwise comparisons is dependent on the number of elements (say *n*) to be compared on each occasion. The total number of comparisons is then (*n*/2) (Mardle and Pascoe, 2003). This resulted in a total of ten pairwise comparisons.

Calculating the relative weights (steps three and four)

Three pairwise comparison matrices [A] were constructed for each participant's responses; one 2x2 in dimension, one 3x3, and one 4x4. The scores derived from the pairwise comparisons (i.e. 1-9) form the elements in the matrix ratios and are considered reciprocal. That is, if the score for impact B compared to impact A is a_{BA}, then the score for impact A compared with B is $a_{AB}=1/a_{BA}$. The resultant matrix of scores can be given by:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \tag{5.2.1}$$

The scores are normalised by dividing through each element of the matrix by the sum of the column *j* (i.e. summed over *i*, such that $\bar{a}_{ij} = a_{ij} / \sum_i a_{ij}$), and the weight associated with each objective can be estimated as the average of the normalised scores across the row *i*. That is, $w_i = \sum_j \bar{a}_{ij} / n$, where *n* is the number of objectives being compared. The weights were derived for each respondent using the widely applied Expert Choice software (v11) that utilises the right eigenvalue method of Saaty (1977, 1980).

The subjectivity of making pairwise choices means there will naturally tend to be a certain degree of inconsistency in respondents' choices. For example; if a respondent indicates that B is twice as important as A and C is three times as important as B then, in order to be consistent, C should be six times as important as A. Yet, in practice it is common that responses do not display such exact preferences and demonstrate inconsistency in the relative scale of importance between objectives, their rank order or both. Such intransitive relationships are not permissible in alternative MCDM methods (such as Multi-Attribute Utility Theory). However, within AHP, the inconsistency within a set of comparisons can be measured through a consistency index (CI), given by

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad (5.2.2)$$

where $\lambda_{\max}$ is the maximum eigenvalue of the matrix A, given by $\lambda_{\max} = \sum_i \sum_j a_{ij} w_i$. This is compared to a random index, *RI*, to derive a consistency ratio, *CR*, where *CR=CI/RI.* The *RI* values were obtained from Saaty (1980, p.56) and denote the consistency index shown in equation (2) for a randomly generated *n* x *n* reciprocal matrix from the scale 1 to 9 where the reciprocals have been forced.

A consistency ratio (CR) (*CR* = *CI*/table value) of no more than 10% is generally considered satisfactory. However, it has been observed that higher levels of inconsistency are not uncommon within fisheries studies and in such cases maximum ratios of 10% (Leung *et al.*, 1998), 20% (Mardle and Pascoe, 1999) or more (Himes, 2007) have previously been accepted. In this analysis if a ratio was determined to exceed 10% the areas of highest inconsistency in a response were identified and the respondent asked to confirm these choices. In cases where the consistency ratio was not reduced to 10% or below were subsequently excluded from the later analysis. The very small number of cases in which a respondent marked 1 for every pairwise comparison (i.e. all impacts are equally important to one another) were also omitted.

Within group coherence was assessed following the method of Zahir (1999a, b) where the angle of difference between individual group members' overall preference vectors are calculated and averaged for each group. The coherence *p* of a group (that must have more than one member in it) is:

$$p = \left\langle V^i \cdot V^j \right\rangle = \left\langle \left(V^i\right)^T V^j \right\rangle \ (i, j = 1,\ldots, N,\ i \neq j) \qquad (5.2.3)$$

where V^i, V^j are the preference vectors of individuals *i* and *j*, and $\langle \ \rangle$ implies average. The more coherent a group is the closer *p* will be to 1 and only when all preference vectors for a group are equal, indicating perfect coherence, can *p* equal 1. Conversely, when the vectors are orthogonal, *p* equals 0. However, with a limited range for the comparisons (i.e. a nine point scale), purely orthogonal vectors cannot exist (Zahir, 1999b). From Zahir (1999b) a non-parametric equivalent measure of significant differences between vectors can be derived for the nine point scale so that if $p_{ij} < (n + 4)/(n + 8)$, where *n* is the number of objectives examined, opinions may be considered as equivocal to orthogonal. For seven alternative (four bycatch and three habitat impacts), a value of p=0.733 can be effectively considered significantly different.

Respondents were grouped by area of expertise (as indicated in the survey response i.e. ecology, biology, economics, gear technology, industry and fisheries management) and the arithmetic mean of the individual priorities within each group was used to determined group level priorities. Group level priorities can be established as either the mean of the individual priorities (as was done in this case), or derived from the mean of the individual judgements (i.e. derive and average 1-9 score for each comparison and derive the priority weightings from these average judgments). Each approach has different underlying assumptions (Mardle *et al.*, 2004). Aggregating judgements implies the group essentially 'thinks as one'; whereas, aggregating priorities assumes increased autonomy at the individual level allowing for within group differences of opinion (Forman and Peniwati, 1998). As opinions relating to fisheries management tend to demonstrate heterogeneity at both the group and individual level we follow Mardle *et al.* (2004) in applying the latter method. When aggregating priorities either the arithmetic or geometric mean can be used as both have been shown to satisfy the AHPs reciprocal property requirement (Forman and Peniwati, 1998).

2.0 Results

The survey was undertaken during the last quarter of 2007. A total of 150 survey forms were distributed with 48 ultimately being considered usable. Due to the non statistical nature of the method it is not uncommon for AHP surveys to solicit the opinions of relatively small groups of experts or stakeholders. For example 18 respondents in Mawapanga and Debertin (1996), 12 in Nielsen and Mathiesen (2006), 9 in Utne (2008), 39 in Himes (2007), 31 in Mardle et al. (2004). A response rate of 30% is considered reasonable for an unsolicited mail survey Sekaran (2000), and rates as low as 17% have been seen in previous mail based AHP surveys soliciting opinions on environmental impacts (Whitmarsh and Wattage, 2006). The usable response rate of 32% achieved in this survey was therefore considered acceptable for a study of this kind.

As the aim of this survey was to solicit informed preferences with regard to the reduction of mobile benthic gear impact, the groups targeted represent the main disciplines that participate directly in these fisheries or that are closely associated in some way. Of the 48 usable responses 29% were ecologists, 8% biologists, 19% economists, 17% gear technologists, 17% industry, and 10% management. Surveying the opinions of a wide range of stakeholder groups allows any areas of similarity or disagreement relating to impact reduction to be formally identified. As expected the consistency ratios for a number of responses exceeded 10%. However the majority of these were not far in excess of the desired threshold and were easily reduced by identifying the most inconsistent choice/s and requesting respondents check their responses.

The derived ratio-scale measures can be interpreted as final ranking priorities (weights). Group priorities and the associated standard deviation at every level are presented in Table 5.2.1, and illustrated in Figure 5.2.3. The impacts indicated to be of greatest concern overall were commercial fish discards, habitat change, and commercial invertebrate discards. From Figure 1, it is clear that, in general, the groups tend to follow two main patterns: one that demonstrates significant concern for the reduction of commercial fish discards above all else (industry, gear technologists), and the other where priorities are more evenly distributed (all others). The main points of disagreement between the sets of groups are those of commercial fish discards and habitat change. However, reducing commercial fish discards ranked in the top three of all groups and reducing habitat change in the top three for all but industry and gear technologists.

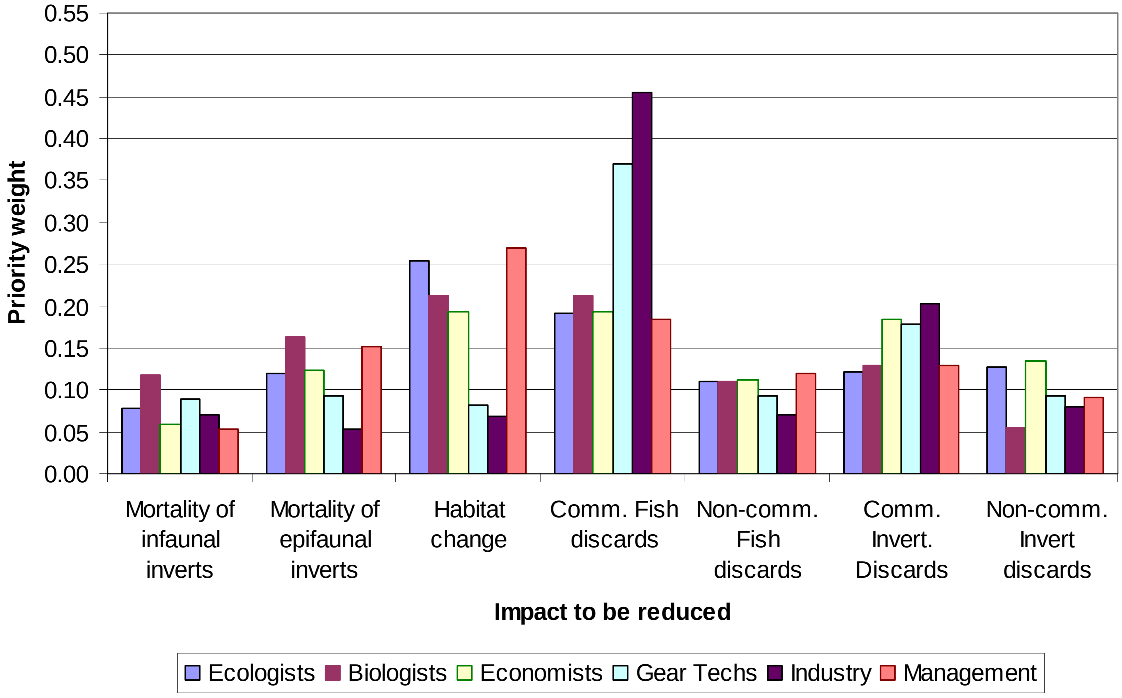

Figure 3. Stakeholder group priorities for reductions in impacts.

2.1 Group level priorities

Two groups (industry and gear technologists) considered the reduction of commercial fish discards to be of highest priority while most of the remainder indicated a reduction in the level of habitat change was of greatest importance and reducing commercial fish discards was then the next greatest priority. Economists maintained a mid-ground position, with the reduction of both commercial fish discards and habitat change being of equal and highest importance (both 0.193), closely followed by commercial invertebrate discards (0.184).

Table 5.2.1. Group level priority scores.

		Ecologists			Biologists			Economists			Gear Technologists			Industry			Management		
		Obj.	Sub obj.	Overall	Obj.	Sub obj.	Overall	Obj.	Sub obj.	Overall	Obj.	Sub obj.	Overall	Obj.	Sub obj.	Overall	Obj.	Sub obj.	Overall
Obj.	Sub obj.																		
In situ impacts		0.452			0.495			0.376			0.266			0.192			0.474		
	Std. dev.	*0.229*			*0.397*			*0.269*			*0.192*			*0.035*			*0.318*		
	Mortality of infaunal inverts		0.182	**0.082**		0.209	**0.103**		0.195	**0.073**		0.259	**0.069**		0.363	**0.070**		0.154	**0.073**
	Std. dev.		*0.191*			*0.179*			*0.114*			*0.178*			*0.072*			*0.088*	
	Mortality of epifaunal inverts		0.294	**0.133**		0.371	**0.183**		0.296	**0.111**		0.440	**0.117**		0.287	**0.055**		0.285	**0.135**
	Std. dev.		*0.171*			*0.189*			*0.132*			*0.244*			*0.057*			*0.095*	
	Habitat change		0.524	**0.237**		0.421	**0.208**		0.510	**0.192**		0.301	**0.080**		0.350	**0.067**		0.560	**0.266**
	Std. dev.		*0.215*			*0.342*			*0.205*			*0.202*			*0.061*			*0.104*	
Bycatch		0.548			0.505			0.624			0.734			0.808			0.526		
	Std. dev.	*0.229*			*0.397*			*0.269*			*0.192*			*0.035*			*0.318*		
	Comm. fish discards		0.337	**0.185**		0.395	**0.200**		0.315	**0.196**		0.503	**0.369**		0.561	**0.453**		0.261	**0.137**
	Std. dev.		*0.189*			*0.211*			*0.165*			*0.138*			*0.064*			*0.202*	
	Non-comm. Fish discards		0.196	**0.107**		0.258	**0.130**		0.164	**0.102**		0.135	**0.099**		0.088	**0.071**		0.224	**0.118**
	Std. dev.		*0.080*			*0.086*			*0.088*			*0.074*			*0.015*			*0.115*	
	Comm. invert. Discards		0.231	**0.127**		0.223	**0.113**		0.312	**0.194**		0.231	**0.170**		0.251	**0.203**		0.259	**0.136**
	Std. dev.		*0.086*			*0.111*			*0.146*			*0.116*			*0.028*			*0.158*	
	Non-comm. invert discards		0.236	**0.130**		0.124	**0.063**		0.210	**0.131**		0.131	**0.096**		0.100	**0.081**		0.256	**0.134**
	Std. dev.		*0.170*			*0.078*			*0.183*			*0.104*			*0.033*			*0.183*	
	No. of respondents:	14			4			9			8			8			5		

The fishing industry indicated a very strong preference for the overall objective of reducing bycatch (0.808) over that of reducing *in situ* impacts (0.192). At the sub-impact level, industry had specific preferences for reducing the discards of commercial fish and invertebrates (with weights of 0.455 and 0.202 respectively). In fact, the reduction of commercial fish discards was indicated to be over twice as important to industry when compared to any group other than technologists. Gear technologists ranked all the abovementioned impacts in the same relative positions and order but the absolute priority values they attached were more moderate; indicating a preference for reducing bycatch (0.734) over *in situ* impacts (0.266). Economists also erred more towards reducing bycatch (0.624) and within this reducing commercial discards, the main impacts on revenue.

At the sub-impact level, the top two preferences of gear technologists were reducing commercial fish (0.369) and then invertebrate (0.178) discards. Biologists, ecologists and management attached more even priority to the main objectives of reducing bycatch and reducing *in situ* impacts. Overall, habitat change and commercial fish discards were most important for biologists, ecologists, economists and management and the absolute size of these priorities were not nearly as large as those observed for industry and gear technologists. The priorities as indicated by the first four groups were much more evenly spread over the seven impacts than seen with industry and gear technologists (Figure 5.2.3)

2.2 Within group coherence

Following Zahir (Zahir, 1999a, b) Group coherence was assessed in order to gauge the diversity of opinion within groups. Additionally, over one hundred additional groups were randomly composed from the pooled survey data and their levels of coherence tested (following Himes, 2007). The distribution of these random group coherence scores indicated a measure of <0.85 signified relatively low coherence, between 0.85 and 0.88 relatively good coherence, and >0.88 high coherence for this data set. The coherence thresholds were determined based on the coherence score distribution for the randomly generated groups. Following this, most group level scores demonstrated relatively low coherence, one had good coherence (ecologists), and the remaining two high coherence (industry and gear technologists) (Table 5.2.2).

Table 5.2.2. Group means for coherence and perceived level of understanding as indicated by respondents.

Group	No.	Coherence	Perceived Understanding
Ecologists	14	0.86	7.8
Biologists	4	0.73	7.5
Economists	9	0.84	6.7
Gear Techs	8	0.95	7.9
Industry	8	0.98	9.1
Management	5	0.82	8.2
All	48	0.85	7.8

The high priority industry and gear technologists attach to a reduction in the level of commercial fish discards will have influenced the measures of their coherence (Table 5.2.2). In placing so much weight on only one of the seven impacts the possibility for relatively large differences between the remaining six is greatly reduced. Low coherence is symptomatic of diverse within group opinion and somewhat typical of fisheries, having been observed in a number of previous studies (Mardle *et al.*, 2004; Wattage and Mardle, 2005; Whitmarsh and Wattage, 2006; Himes, 2007). When respondents preferences were treated as being from one large group (Table 5.2.2) half the groups demonstrated a higher level of coherence whilst half had lower within group coherence.

In addition to the pairwise choices respondents were asked to indicate on a scale of one to ten (where 10 was very familiar/full understanding and 1 was unfamiliar/poor understanding) how well they thought they understood the impacts associated with towed fishing gears. All groups generally felt that they had a relatively high level of understanding/familiarity with the subject (Table 5.2.2). Industry believed that they had the highest level of understanding with an average score of 9.1. In contrast, economists believed that they had the lowest level of understanding with an average score of 6.7. There was a weak but positive correlation between the self assessment of understanding and coherence (r=0.58), with the groups with higher coherence also having a higher understanding score on average.

Further analysis was undertaken in which respondents scores were weighted by their indicated level of understanding prior to the group scores being calculated. This resulted in some small changes in the absolute values of individual and, consequentially, group level scores for all groups. The relative ranking of impacts was also seen to change a certain amount for all groups other than the industry and gear technologists. This was primarily due to the preference scores for ecologists, biologists, economists and fisheries managers having lower levels of within group variability to begin with (as illustrated in Figure 5.2.3) so often only small changes in the absolute values were required to result in reversals. This illustrates the fact that when preferences are relatively evenly distributed over a number of impacts and do not focus strongly on one or two (as is the case with industry and gear technologists here) the overall rankings can be very sensitive to small changes. However, whilst something to be aware of, this was not considered to be a significant issue as the priority values were seen to change very little in absolute terms.

3.3 Overall coherence

When all respondents were treated as belonging to one large group the overall level of coherence was 0.85. The distribution of individual coherence scores between these respondents' choices (Figure 5.2.4) is skewed to the right with 83% falling above the value estimated as equivocal to orthogonal (i.e. 0.73). Furthermore, 50% of comparisons had coherence scores equal to or above 0.88 indicating a generally good level of commonality between individual respondents' choices irrespective of stakeholder group.

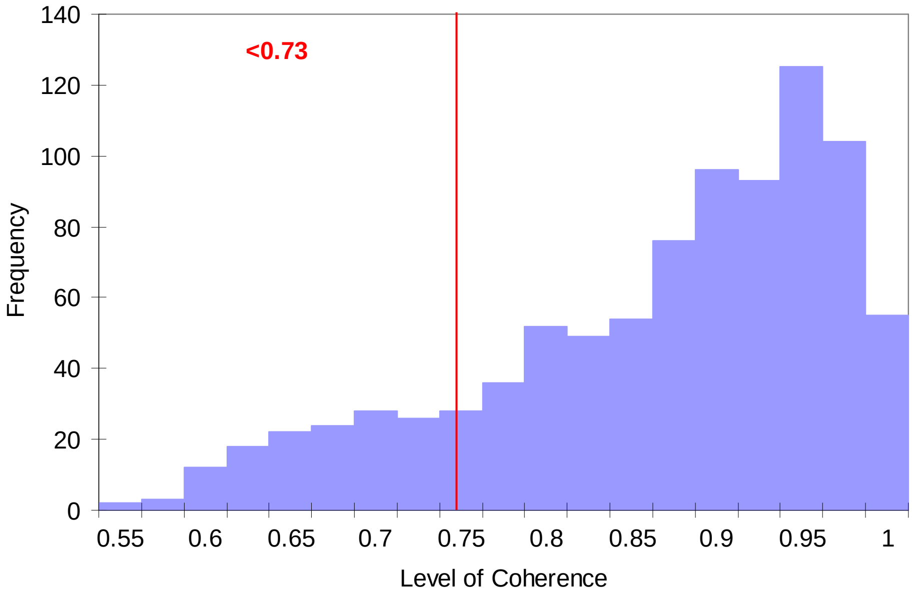

Figure 5.2.4. Distribution of coherence scores for all responses as a whole.

3.0 Discussion and conclusions

This work demonstrates that measures of importance for marine environmental damage vary considerably depending on the motivations of the stakeholders. As preferences are subjective by nature it is reasonable to expect respondents familiarity with the specific issues under consideration or personal perspectives to come through in their responses (e.g. as seen in Piet *et al.*, 2008). The fact fishers are primarily concerned by, and consequently attach high priority to, reducing the level of commercial discards is as such understandable. This is not necessarily to say the industry is unconcerned by the other impacts but, as financially orientated operations, aspiring to maximise profits by reducing any loss of potential revenue is a natural priority. The level of discard related mortality varies by species and fishery but can be high and is often significant (Alverson *et al.*, 1994; Jennings and Kaiser, 1998; Lindeboom and de Groot, 1998). When vessels bring aboard commercial species that they cannot land, the subsequent discarding can impose negatively on the resource upon which they (or other fishers) depend without also contributing to their income. Furthermore, one fisher surveyed expressed a belief that the seabed was somewhat akin to a field, benefiting from regular disturbance. Whether representative of the group as a whole or not this statement goes some way towards highlighting how potentially significant differences in viewpoint may influence impact reduction priorities.

The similarity of opinion observed between the industry and gear technologists is a possible artefact of the way Europe has concentrated on reducing bycatch through the development of technical measures. As a result, gear technologists (and economists) tend to be very familiar with the issues of bycatch whereas attempts to reduce other environmental impacts are a more recent development. Furthermore, gear technologists commonly operate in close connection with the industry so a certain similarity between perspectives can be expected. The more moderate priorities of ecologists, biologists and managers are believed to result from viewing the fishery in a more holistic manner. Ecologists and biologists are likely to take more of an ecosystem perspective where everything is interlinked and changes to both habitat and organism mortality considered significant. Managers are typically required to consider the demands of all involved in the fishery and results in them also having a somewhat more moderate and balanced set of preferences. Managers are also cognisant of policy initiatives – potentially even more draconian than current fisheries policies – that may develop if steps to reduce the broader environmental damage are not undertaken.

Time preferences were not explicitly accounted for in the survey but will also influence preferences, i.e. the industry may be less concerned by impacts such as habitat change because the immediate benefits are less well understood, smaller or harder to observe. Confidence that investing in the long term health of the environment offers a good chance of financial returns is necessary if the benefits will not be felt in the relatively short term. The situation currently facing many trawler fisheries is at best uncertain as if not limited by stock constraints, sustained rises in fuel prices have the potential to make these fisheries economically unviable long before any of the environmental impacts they may be generating will. Also, if impacts such as habitat change do not (or at least are not perceived to) directly affect the species they target the mere existence value is likely to be low when compared to potential revenue further discounting benefits of BRD action.

The level of importance industry placed on bycatch relative to habitat damage has implications for their incentives to voluntarily adopt environmentally friendly technologies. While voluntary adoption of environmentally friendly gears has generally been low (Hall and Mainprize, 2005), there are numerous examples where fishers have voluntarily adopted gears to reduce bycatch of commercial species, particularly in prawn and shrimp fisheries where bycatch rates are high (e.g. Robins *et al.*, 1999; Suuronen and Sarda, 2007; Innes and Pascoe, 2008). While this may be in expectation of a subsequent mandatory regulation, it also reflects recognition of the significance of the impacts by the industry. Indeed, fishers could wait for a mandatory regulation to be introduced before incurring the costs associated with changing gears (including the forgone catch). Conversely, little incentive or motivation exists to adopt gears to reduce habitat impacts, so mandatory regulations will be essential if such gears are considered desirable from a broader social perspective.

As each stakeholder group attaches different levels of importance to the individual impacts, the benefit of any modifications (each resulting in differing bundles of benefits) will be judged accordingly. Furthermore, in instances where the industry is having a significant impact on the environment such differences, and therefore the perceived effectiveness of any management measures tend to be all the more pronounced. From the management perspective the derived measures of importance allow changes in the levels at which the impacts are imposed to be weighted and therefore appropriately accounted for. It also allows them to be aggregated to one weighted benefit measure for each option and considered against the expected costs of application, deriving a ratio of costs incurred to benefit obtained (i.e. effectiveness). In doing so, alternative options may then be ranked in terms of their perceived environmental cost effectiveness. This all serves to aid the management process and allow more transparency with regard to the tradeoffs associated with each management option.

When stakeholder groups believe measures are legitimate and tackle issues they deem to be of importance there are likely to be higher levels of acceptance, or compliance in the case of legislation (Kuperan and Sutinen, 1998; Hatcher *et al.*, 2000). An additional issue associated with some technical measures is the ease with which they can be circumvented without a significant risk of detection (Catchpole *et al.*, 2008). If the likely level of acceptability can be determined prior to final policy decisions being made it is possible greater levels of compliance may be achieved whilst also reducing the often non-trivial burden of enforcement.

Cost-Effectiveness (*CE*) of Alternative Gears

In order to determine the relative cost-effectiveness of alternative gear configurations or alternative management measures the total estimated cost of uptake for each, as determined in Task 5.1, must be set against their expected benefits. In this instance the benefits, in terms of changes in impact, are those expected to derive from each configuration of modified gear (as determined by outputs of Wp2) or management measure. The individual changes (for each gear /measure) are weighted using the priority measures derived in Task 5.2. This allows the relative importance of the changes to be accounted for and facilitates the aggregation of changes in impact to one measure of overall benefit. The perceived cost-effectiveness of a gear/measure, *k*, at the stakeholder group, *g*, level ($CE_{k,g}$) may therefore be represented as;

$$CE_{k,g} = \frac{\sum_j \Delta c_{j,k}}{\sum_i \left(\Delta o_{i,k} \cdot p_{i,g}\right)} \qquad (5.2.4)$$

where $\Delta c_{j,k}$ is the change in cost *j* associated with gear k, $\Delta o_{i,k}$ is the change in outcome *i* that comes about as a result of using gear *k*, and $p_{i,g}$ is the priority (AHP) score associated with output *i* for each group, *g.* The cost effectiveness score represents the cost of 1% reduction in overall impact and allows alternatives to be ranked. Wp2 outputs needed for this.

Task 5.3 To assess the wider economic implications of adoption of these gears

Partner 08
The comparison of the Belgian beam trawl fishery (split up into three sub-fleets) with the Belgian set net fishery has been carried out and a report has been added to interim report 1. A summary of the updated results is presented hereafter.

The objective of this economic study is to compare performance among Belgian sub fleets. Although performance consists of many ‘dimensions’ (i.e. financial, operational and overall effectiveness) (Venkatraman *et al.*, 1986), this study will only look at financial and operational measures. Financial performance measures are in this study based on the average gross operating profit of a vessel (=revenues-operating costs, not taking into account capital costs), starting with its absolute value (i.e. GOP) followed by two relative measures: (i) the average gross operating profit of a vessel per fishing hour (GOP/fishing hour), and (ii) the average gross operating profit of a vessel per kilogram mixed fish landed (GOP/kg fish). The operational dimension of performance is measured through (i) the average landings of a vessel (kg fish), and (ii) the average landings of a vessel per fishing hour (kg fish/fishing hour). Significant differences among sub fleets on these performance measurements are tested through Kruskall Wallis tests (Cool *et al.*, 1988) in combination with Mann-Whitney tests as post-hoc test both with Bonferroni adjustment ($\alpha' = 0.005$ since k=5 where k equals the number of strategic groups).

Table 5.3.1 presents the averages of the different performance measures between the years 1997-2006 for each strategic group. In addition, it also summarizes which averages are significantly different from each other through Kruskal-Wallis tests and Mann-Whitney post hoc tests all Bonferroni adjusted. When looking at the absolute values of GOP and landings these results show that shrimp beam trawlers and set netters both have performed equally weak between 1997-2006. As a result, these two specialized fisheries have limited landings (respectively a mean yearly landings of 76244 and 44558 kilograms mixed fish) which results in low absolute financial profit (respectively on average 55642 euro and 61469 euro). Otter trawlers and eurocutters have equally high GOP's and perform in absolute terms better then shrimp beam trawlers and set netters. They have average yearly landings of approximately 150 tons mixed fish and GOP of roughly 100000 euro which both are roughly twice that high compared to shrimp beam trawlers and set netters. Finally, large beam trawlers have on average the highest GOP's of all strategic groups which is twice that high compared to eurocutters and otter trawlers and almost four times that of shrimp beam trawlers and set netters. When looking at the relative landings per fishing hour approximately the same rank order emerges though the ratios between the strategic groups change. Shrimp beam trawlers land the lowest amount of mixed fish in a fishing hour (only 32.1 kilograms). Eurocutters, otter trawlers and set netters land slightly more (i.e. approximately 40 kg/fishing hour). Finally, large beam trawlers land the most fish per fishing hour namely 75.36 kilograms.

In contrast, the relative measures of financial performance tell a different story in which set netters play an interesting role. Although set netters perform low in absolute values, its gross operating profit per fishing hour is as high as that of the large beam trawlers (i.e. around 50 euro per fishing hour) whereas its profit per landed kilogram mixed fish even outperforms every other strategic groups (i.e. respectively 1.28 euro versus approximately 70 eurocent per kilogram mixed fish). As a result, the financial attractiveness of the large beam trawler fleet should be nuanced because their GOP per fishing hour and certainly their GOP per kilogram landed mixed fish does not deviate strongly from other strategic groups.

Table 5.3.1. Performance indicators among the strategic groups of the Belgian fishing fleet

		Large beam trawler	Eurocutter	Shrimp beam trawler	Otter trawler	Set netter	Sig.
Financial	GOP	218243^{c}	109782.3^{b}	55641.71^{a}	101849.9^{b}	61468.95^{a}	.000
	GOP/fishing hour	52.60^{c}	30.65^{b}	22.08^{a}	$29.63^{a,b}$	$51.41^{b,c}$	.000
	GOP/kg fish	0.69^{a}	0.74^{a}	0.67^{a}	0.66^{a}	1.28^{b}	.000
Operational	Landings (kg fish)	329716.75^{c}	143281.15^{b}	76244.34^{a}	158703.38^{b}	44558.63^{a}	.000
	Landings /fishing hour (kg fish/h)	75.36^{c}	42.10^{b}	32.10^{a}	45.24^{b}	40.04^{b}	.000

Different superscripts (a–b–c) indicate significantly different average means using Kruskal-Wallis and Mann-Whitney as post hoc test both with Bonferroni adjustment ($\alpha' = 0.005$ since k=5).

CONCLUSION

This study illustrates that the financial attractiveness of the beam trawlers and more specific the large beam trawlers during the period 1997-2006 should be nuanced by the results on the relative performance indicators which clearly illustrates that the large beam trawler do not have the best "profit-effort"-ratio. Moreover, this study only looked at gross operating profit not taking into account capital costs. Furthermore, conclusions on which sub fleet performs best is determined by the stakeholder perspective and personal interest. For instance if you are a fishermen who wants to maximize his profits then the large beam trawler fleet stand out as best sub fleet (given a stable fishing environment). However, if you are a fisherman looking for a good "profit-effort"-relation you should look more toward (i) set netting and (ii) large beam trawling. Finally, if you are a policy maker and are aiming for sustainable fisheries, one should start comparing the relative financial and operational performance indicators which are more in favor of (i) set netting and (ii) shrimp beam trawling.

For more details on this analysis see the doctoral dissertation of Hendrik Stouten which is forthcoming. For more descriptive details on the Belgian fleet see the interim report.

8.1 Major findings of this study

8.1.1 General:

The project brought together the expertise of technology, biology and economy. A number of alternative fishing gears and gear modifications were developed with the potential to lower mortality of benthic invertebrates and non-target demersal fish. Attempts were made to determine the bottom impact of the new fishing gear designs and practices by modelling effects on sediments, comparative fishing experiments, and observing tracks made on the sea bed. The economic consequences of using the new gear were analysed for some cases.

8.1.2 Work package 2:

The development and validation of a Finite Element model of the of the physical impact that different gear components make on soft sediments. The validation of the model used experimental data from small scale trials in the laboratory and full-scale trials at sea.

The development of a sand channel with a trolley and drag mechanism that allows for the alteration of the weight of the different components. Comprehensive testing of a model door and a roller clump have been undertaken.

The use of a computational fluid dynamic model (Cosmo FLOWorks) to obtain the values of the hydrodynamic drag coefficients of different gear components. The estimates obtained are similar to those found in the literature but without the bottom drag effects.

The development of a simplified dynamic model of a trawl system integrating the results of the FE model to incorporate correctly contact forces, penetration and drag on soft sediments. This model has successfully replicated the spread of the doors and drag found in the trials and a number of case studies on rippled sea beds or on vessels with surge are very promising.

The use of laser stripe technology to measure surface profiles both underwater on the seabed and in the laboratory sand channel. This approach permits the accurate measurement of the seabed after a gear component has passed.

The development of high resolution trawl force instrumentation that can be used to accurately describe dynamic processes and to validate dynamic model predictions.

The development of techniques to measure the sediment concentration behind fishing gear elements. The resulting data has demonstrated that the concentration of suspended sediment depends on the gear element in question and the sediment type and that there is a relationship between the hydrodynamic drag of the gear element and the quantity of sediment put into suspension.

The development of a simple model of benthic mortality to predict broad changes in abundance, species richness and biomass of soft sediment habitats following trawling, based on the outputs of the physical models of the gear/sediment interaction and tested with measurements taken in the field. In all cases effects were more pronounced in the muddy sediment than in the sandy sediment sampled.

The further development of this model to take into account the living range of the different benthic species found in the area of interest, and then to predict what proportion of all individuals would be encountered by the different gear components (otter doors, groundgear etc.). No more than 30% of all individuals would be encountered by any component of the gear in the sandy habitat surveyed, whereas encounter rates greater than 90% were found for some species in the path of the otter trawl in the muddy habitat surveyed.

The further development of a fish mortality model to predict landings and discards of a wide range of fish species (target and non-target) to the major beam and otter trawl gears. The predictions were validated with real landings and discards data, and found to perform reasonably well, although some suggestions are made for improvement of these. Sensitivity analysis of the fish mortality model revealed catch efficiency to be very important in determining overall outcomes of the model and there is thus potential for this to be further developed to predict the differences in landings and discards of fish assemblages for modified versus standard trawl gears.

8.1.3 Work package 3:

Alternative fishing gear developed range from simple solutions such as changes in the rigging of doors or using new doors designed to reduce both hydrodynamic drag and down-force coefficients, replacing rockhopper ground gears by plate ground gears in otter trawls.

By properly rigging the downward force of trawl doors on the sea bed and thus the extent of the furrows made in the bottom can be substantially reduced. This would also lower fuel costs, often a strong driver in the industry.

Another solution to reach this objective is to change the design of the trawl door with a smaller lower plate in contact with the sea floor. Successful designs were tested in France.

The plate gear showed potential in reducing bottom impact compared to the conventional rockhopper gear. Due to limitations in the sea trials it was found difficult to quantify this effect.

The low impact oyster dredge (the box dredge) developed in Denmark showed improved selective properties and an indication for lower sea bed impact. Sea bed impact and fuel consumption can be reduced by replacing the ‘rapido’ trawl in Italy by a light beam trawl.

8.1.4 Work package 4:

For beam trawls a suit of alternatives was studied among which inserting T90 sections, benthic release panels in the net or enlarging mesh size. These simple modifications can all significantly reduce the catches of benthos and other unwanted material, such as non-commercial fish species, but in some cases there may be a noticeable loss in commercial catches.

A more complex alternative to reduce impact on benthos is the pulse trawl in which tickler chains are replaced by electrodes. Research into the effect of pulse stimulation on various marine biota (dogfish, cod, benthic invertebrates) showed that for some species (e.g. cod) the effects are not marginal, and more studies are needed. On the other hand it was shown that catches and direct mortality of benthic invertebrates can be significantly reduced, and an economically viable operation is possible using pulse beam trawls.

The acceptance in the fishing industry depends very much on maintaining the catch levels of target fish, and many moves toward reducing impact are driven by the wish to save fuel and lower operational costs. Creating proper incentives, e.g. by ‘social marketing’ is needed to ensure uptake.

The Italian “Rapido” trawl can be replaced by a light beam trawl causing lower impact whilst maintaining commercial catch levels.

8.1.5 Work package 5:

When attempting to mitigate the environmental impacts of a fishery there are typically multiple criteria against which the performance of any measures can be assessed. If the gains are non-commercial (i.e. non-market) in nature, formally determining how well measures perform becomes more difficult. A method called the “analytic hierarchy process (AHP)” was applied to quantify the relative preferences of stakeholder groups for one impact reduction objective over another in the context of European mobile demersal fisheries. The advantage of this methodology is that it allows for the inclusion of non-commercial benefits. Preferences are quantified and allow ranked group-specific weights relating to the reduction of discarding and other in situ impacts to be derived. The relative weights placed on the sub-objectives within each of the two objectives are also determined. Establishing a measured order of preference for individual criteria allows the significance of changes in non-market impacts to be determined and alternative measures that result in differing combinations of change to be directly compared. This should facilitate a more targeted and efficient approach to the process of forming impact alleviation policies within these fisheries.

Economic analyses showed the earning potential of new techniques such as pulse trawling. A range of actors in fisheries were addressed and their opinions on various issues concerning ecosystem effects of fisheries and the development of sustainable fishing practices were inventoried. Quantitative measures of preferences for the reduction of mobile benthic gear impacts indicated those of greatest overall concern were commercial fish discards, habitat change, and commercial invertebrate discards. In general, the stakeholder groups tend to follow two main patterns: one that demonstrates significant concern for the reduction of commercial fish discards above all else (industry, gear technologists), and another where priorities are more evenly distributed (biologists, ecologists, economists, fisheries managers). The main points of disagreement between the sets of groups are those of commercial fish discards and habitat change.

When comparing four Belgian trawl fleets (large beam, euro-cutter, shrimp beam and otter) with the set net fishery it was shown that the large beam trawl fleet generated the highest level of gross operating profit (GOP) in absolute terms, whilst the set net fleet had the second from lowest. But it was also found that the set net fleet outperforms every other fleet in terms of profit per landed kilogram mixed fish. Measures of relative financial performance clearly illustrate that the large beam trawlers do not have the best “profit-effort”-ratio (not taking into account capital costs).

8.2 Recommendations

It is recommended to further work along the lines of this project on tools to evaluate the likely ecosystem effects and economy of novel fishing gears designed to decrease the impact on marine ecosystems and contribute to sustainable fisheries. In particular there is a need to subject these new gears to the mathematical-physical models developed, continue on the work to link this physical information to effects on marine biota, and improve the models to predict likely effects of new gears on the marine ecosystem based on their characteristics and prior to their actual introduction into fishing fleets at a larger scale.

More specifically as a result of the work carried out in workpackage 2 we recommend that:

- The soil models be further developed to tackle the particulate nature of the soil and potentially inclusion of water. The present models assume that the soil behaves as a continuum and as a result has difficulty modelling the displacement of the soil particles that can be transported along the front or the edges of the gear components.

- Water is added to the sand channel to allow conditions that better reflect those close to the seabed to be tested in the laboratory. Work has already begun on this and a water proof channel has been built. It has a metal frame, is 4.8 m long, 80 cm wide and 30cm deep.

- An extended range of gear components including discs (ground gear), ropes and chains should be tested in the sand channel.

- The full dynamic model should be completed – this will allow the overall behaviour of the trawl system to be predicted and the governing parameters that influence the physical impact on the seabed to be determined.

- The computational fluid dynamic approach be used to investigate the suspension of sediment in the wake behind different gear components.

- Independent field experiments should take place to truly validate the predictions made by the benthic mortality models developed here. These models are based on the physical modelling work and on an understanding of the ecology and morphology of the animals affected, and any experiments should be carried out with the same level of precision in sampling as was undertaken in the survey work of Task 2.3.

- A more sophisticated analysis (perhaps a generalised linear mixed model) of the benthic mortality model be carried out. Following this, it will be possible to further refine the predictions based on information on important ecological and morphological traits of species encountered.

- The benthic mortality model be used to compare the likely impact levels of different components of trawl gears in any area where information on the species found there is available. This would be a real advance on previous approaches to predict trawling impacts (such as the MAFCONS model) and this sort of model would be essential in being able to provide advice on the overall pros or cons of gear modifications in reducing impacts of trawl gears to benthic habitats and species.

- The fish mortality model should be applied to explore predictions about differences in catch mortality of whole fish assemblages for some of the modified gears from Work Packages 3 and 4. Where good survey catch data is available, this will allow validation of the model's predictions.

- The modified gears developed in the case studies of work packages 3 and 4 should be compared with the original standard gears. This comparison should take into account the results of the physical model and the models of benthic and fish mortality and compare predictions with suitable experimental data where it is available.

Dissemination and communication

6.1 Project website

A website was made available at: http://www.rivo.dlo.nl/degree/

In addition an **eRoom** was set up by SINTEF on https://project.sintef.no/eRoom/fish/DEGREE
This **eRoom** is used more and more for communications and email contacts, as well as storage for project documents. It functions well.

6.2 Consultations with and dissemination to fishing industry

Activities are listed below.

Meeting held or planned	**Venue**	**Date(s)**
Paper presented at Nor Fishing Technology Conference (NFTC) by UNIABDN	Trondheim, Norway	7-8 August 2006
Talk presented at ICES FTFBWG by FRS	Dublin, Ireland	23-27 April 2007
CEFAS (UK) is to hold a meeting with representatives of the South west beam trawls industry in May 2007. The purpose of the meeting is to review the results of the extended (six-month) commercial fishing trials undertaken using modified beam trawls (*i.e.* trawls fitted with benthos release panels).	CEFAS Laboratory (Weymouth), United Kingdom	30-31 May 2007
Contacts with the industry about opinions and gear costs by CEMARE and LEI	UK, Netherlands	
Contacts with the industry by CNR and collaborative tests of a light beam trawl	Ancona, Italy	27/06/2007
Inventory of doors and groundgears used in the industry	Ireland	
Meeting in the Boulogne flume tank (Task 3.6) to discuss gear designs	France	
Workshop with industry in the SINTEF flume tank	Hirtshals, Denmark	Feb 2009
Presentations at fisheries organizations on pulse trawl /beam trawl	Netherlands	February 2007
Seminary “Technological innovations, energy saving and environmental sustainability in professional fisheries, implementations and applications”. A. Sala (P12) was invited as keynote speaker by the Italian National Association of the Fishing Cooperatives “Lega Pesca”.	Mazara Del Vallo (Sicily, TP)	02/07/2009
Seminary “Energy savings: results and perspective for the professional fisheries”. A. Sala (P12) was invited as keynote speaker by the Consorzio Mediterraneo s.c.a r.l. (Mediterranean Consortium), which is the technical and scientific structure of the Lega Pesca (Fishing Association).	Rome	11/03/2009
Multi-disciplinary training course for managers and senior staff of fisheries and aquaculture of Venezuela “Realizacion de una planta fileteadora de pescado en la isla Margarita – Edo. Nueva Esparta” organised by Frigo Tecnica Internazionale spa (MC) held at the “Campus Margarita della Fundacion La Salle de Ciencias Naturales” (Venezuela)	Venezuela	06/07/2007 - 10/08/2007

The project is summarised in a DVD containing information of the work in the various areas.

Where appropriate project results were published in ‘peer reviewed’ scientific journals.

Summary of major conclusions

8.3 WP2 Modelling

- A finite element model of the physical interaction of different gear components and different soft sediments has been developed and successfully validated in a series of small scale laboratory experiments and full scale sea trials. The soil model relating drag force, penetration and velocity, derived from the FE model shows that the drag force is relatively linear with penetration and an increase of the weight of a trawl element results in an increase in contact and drag forces. The models need to be further developed to fully account for particulate nature of, in particular, the sandier sediments.

- A dynamic model of a trawl system that integrates the contact force, penetration and drag estimates of the gear components in contact with the seabed (using the FE model) has been developed. This model has successfully replicated the door spread and warp tension measured in the experimental trials. Furthermore, a number of case studies on rippled sea beds or on vessels with surge are very promising.

- Experiments to investigate the sediment put into suspension in the wake of the elements of a demersal trawl that are in contact with the sea bed have demonstrated that the concentration of sediment suspended depends on the gear element in question and the sediment type. Furthermore there is a relationship between the hydrodynamic drag of the gear element and the quantity of sediment put into suspension.

- Using the above physical models of the interaction of gear components with the seabed sediments, and knowledge of the ecology of the animals living in the area affected, it is possible to predict broad changes in numbers, biomass and species richness in the path of trawl gears. An assumption that any decrease in numbers or biomass post-trawling equates directly with actual impact in the form of mortality, should however be questioned. Further field testing of our predictions about displacement of individuals and damage levels in individuals affected will help to clarify the actual extent of any impacts caused by particular gear designs in different habitats.

- The combined physical and biological modelling approach developed in this work package shows great potential in being able to explore the different impacts of trawl gears for specific species and habitats. Due to the need to finalise development of these it has not yet been possible to fully quantify any differences in ecological disturbance of standard versus modified gears from work packages 3 and 4. Good data are available to do this for the beam trawl net modification work and the oyster dredge work. The fish mortality model has already been published and analysis of the predictions of the benthic mortality model is currently being refined with a plan to submit the findings of this work for publication in a peer-reviewed journal in the next six months.

8.4 *WP3 Otter trawls*

8.4.1 General Conclusions

- Given the differences in the design of trawls, trawl doors, sweep arrangements and actual fishing operations and the characteristics of the target species there is no universal solution to reducing bottom impact of towed gears but in many cases simple rigging changes can limit impacts.

- It remains difficult to assess the physical and biological impacts of all components of towed gears accurately. Biological impacts are particularly hard to measure.

- Acceptance by fishermen of gear modifications to reduce bottom impact will be dependent on the modified gears maintaining catch rates at economically viable levels.

- Even though there is a greater awareness amongst fishermen of the need to reduce bottom impact, the main driver for using lighter or less impacting gears is potential reductions in fuel consumption.

8.4.2 Trawl Doors

- Most existing trawl door designs can be modified to fish with light bottom contact but better results are theoretically obtained with high ratio (height/width) doors and centre of gravity at a higher position. Such doors are commercially available.

- Working doors lighter on the bottom requires clear instruction on how to get a door to work in a stable way. The main faults include using overweight doors, not monitoring door spread and poor adjustment of the warp attachment points on the door itself.

- Bottom impact of trawl doors can be controlled by altering the warp/depth ratio and/or towing speed.

- Using pure pelagic trawl doors instead of traditional bottom doors may be an option for trawlers targeting specific species but may not necessarily be an option for targeting species that are herded by the sand clouds developed by the doors on the seabed.

- The prototype doors designed by Partner 05 and Partner 12 have shown that is feasible to construct low impact doors that have minimal bottom contact but can maintain gear efficiency in terms of door spread.

- The main driver for adopting low impact trawl door designs will be reduced fuel costs rather than solely a need to reduce bottom impact for environmental reasons.

8.4.3 Groundgears

- Standard rockhopper groundgears have been shown to have a major physical impact on soft sediments. It has been shown that the impact is across the whole cross-sectional area of the footrope, while the rockhopper footrope also created higher sediment displacement.

- The biological impact of rockhopper footropes on such sediments is unclear as it has been found difficult to assess biological impacts accurately but the observations made during this project strongly suggest that impact on benthic organisms can be severe.

- With the plate gear, it was observed that mainly the seven bobbins that made visible tracks on the seabed, while tracks from only a few of the plates could be observed. On average about 50% of the cross sectional area of the plate gear could be seen impacting the seabed, and the depth of the plate tracks was small (less than 1 cm as measured).

- The prototype plate groundgear developed has proven technically feasible and does not appear to reduce catches of commercial species although it can be sensitive to small changes in rigging.

- The rigging arrangement used on the final cruise on the “GO Sars” with the groundgear connected to a wire attached directly to the fishing line makes the plate gear less sensitive to changes.

- Further work is needed to design an alternative Danleno arrangement as the rolling bobbin concept tested on the “GO Sars” did not work.

- The physical impact of sweep arrangements on the seabed depends very much on their construction. Observations from the “GO Sars” cruise suggest that sections of chain seem to have more impact than wire.

8.5 *WP4 Beam trawls and dredges*

8.5.1 Flatfish beam trawl modifications to reduce discards of benthos and unwanted fish

BELGIUM

- The T90 cod-end has interesting selective properties for the most important commercial species for the beam trawl, i.e. sole. It allows more undersized fish to escape and more marketable fish to be caught. Round-fish species and non-commercial fish and invertebrates escape much more easily from a T90 mesh than from a diamond mesh in a typical beam trawl cod-end. It can thus be expected that the application of a T90 cod-end will result in less discards and cleaner catches.

- RV trials and commercial trials have shown that the application of a benthos release panel in front of the cod-end can drastically reduce by-catch of inert material and benthic invertebrates. This may improve fish quality and reduce catch handling time. The reduction of benthic invertebrates appears to be strongly species specific, with relatively heavy and small species and individuals yielding the best results.

- The observations for commercial species give a mixed picture. On euro-beamers, there appears to be an unacceptable loss of commercial sole (similar observations were made on board the research vessel that is rigged with trawls of comparable size), whereas the benthos release panel performs better on large beam trawlers. This may be due to the length of the trawl which is needed for the catch to settle after the chain matrix or the tickler chains or it may be due to the length of the panel in comparison to the length of the trawl.

UNITED KINGDOM

- Throughout this project, it has been very evident that simple modifications to beam trawls, such as square mesh benthos release panels and alterations to the cod ends (i.e. larger mesh, square mesh, T90 mesh, etc.) can all significantly reduce the catches of benthos and other unwanted material, such as non-commercial fish species.

- By collaborating with industry in a meaningful manner, several commercially acceptable trawl modifications were jointly developed and evaluated. These were demonstrated to be effective in reducing benthos and other discards.

- However, much of the industry appeared to be reluctant to use these designs on a commercial basis, even though some had been engaged in their development. What appears to be crucial to facilitate commercial take up by industry of these tools, is that a correct incentive framework is formally established. We have found that the use of 'Social Marketing' principles appears to be an appropriate method to identifying and establishing such a framework to facilitate desirable behavioural change in this respect.

NETHERLANDS

- The preparatory studies carried out under DEGREE showed that replacing small-spotted cat sharks (*Scyliorhinus canicula* L.) caused reactions to offering food overruling the effects of the pulse stimulation. As a result the experimental protocol was changed to treating individuals separately under known stimuli. Later tests on this species showed muscle contractions during the stimulation, but no lasting effects. X-rays taken on cod (*Gadus morhua* L.) landed by a commercial boat fishing with pulse trawls showed that the occurrence of spinal damage could not be ruled out. This result led to further study which showed that the pulse stimulation could indeed cause spinal damage when cod was tested close to the electrodes.

- The data collected during four week trips on a commercial boat fishing with the pulse beam trawls in June-August 2009 showed that with the pulse trawl more sole was caught and less plaice than with conventional beam trawls. It also seemed that with the pulse trawl more sole in number and weights per unit of time was discarded and less plaice was discarded. However, the average discard percentages of as well plaice as sole for the pulse trawl of this study were within range with the average discard percentages of conventional beam trawls in 2005, 2006 and 2007. It should be noted, however, that the comparison could not exclude effects of time and area of fishing. To achieve more precision it was recommended to conduct a comparative study on performance of a beam trawl and a pulse trawl, where the two vessels of similar size fish simultaneously, like was done in 2006.

8.5.2 Low impact oyster dredge

DENMARK

- The developed low impact oyster dredge (the box dredge) showed improved selective properties. The box dredge caught more large oysters (>10 cm) and less small oysters when compared to a standard dredge. Track profile analyses indicated a lower impact of the box dredge compared to the standard dredge in terms of removing and compressing sediment, but the drag force measurements showed slightly higher values for hauls with the box dredge. Although the catch comparison experiments indicated that the box dredge catches less megafauna, stones and shells, these catch differences were not significant.

- The developmental and experimental work with the box dredge had a high degree of industry involvement from both oyster fishermen and oyster gear manufacturers, which should ease the implementation of the box dredge on a commercial basis.

8.5.3 Rapido and light beam trawl

ITALY

- The results of the trawling trials (both with Rapido and beam trawl) carried out off Ancona showed that a considerable fraction of the catch was composed of species of no commercial value, either because they were undersized or because they were unmarketable. Beam and Rapido trawl catches reflected the multispecies nature of the fishery in this area. Between 55-80% of the Rapido trawl catch was discarded at sea while for the beam trawl the catch discarded at sea was around 50%.

- The Rapido trawl seemed to exert a strong selective pressure on the macrobenthic community, being able to modify the epibenthic fauna structure which, in heavily exploited fishing grounds, was dominated by bivalves, gastropods, crabs, starfish and brittlestars. Rapido trawl catch was characterised by species living strictly associated to or within the substratum whilst beam trawl hauls were characterised by a wider array of species inhabiting very different realms of the ecosystem (from benthic to demersal to pelagic). These differences were dependant both upon differences in species behaviour and differences in selectivity with respect to different species.

- The Rapido trawl was more efficient also for commercial species even if the performances of the light beam trawl improved during the last trials. In 2009 some fishermen agreed to use the light tickler chain beam trawl and they improved their performance increasing the vertical opening with the aim of catching demersal and pelagic species. It can be noticed that the mean duration of Rapido hauls is around 50 minutes and this leads to very hard work shifts. Thus a reduction of the time for sorting the catch represented a very good option for fishermen. Moreover we noticed that the reduction of the discarded portion of the catch improved the quality of fish. Finally the physical impact of light beam trawl on the sea bed was lower than that observed with Rapido trawl. In fact Rapido trawl showed the highest values of both total warp drag and net drag resistance (recorded with the electronic load cells). This means that Rapido trawl highly impacted the seabed and it needs the highest power to be towed.

- The main results can be drawn: i) the sea trials conducted so far gave evidence that in the Adriatic Sea the Rapido trawl targeting common sole was characterised by multi-species catches; ii) although about 70% of the commercial catch was discarded, the Rapido did not seem to have a heavy impact on this fraction, as most of the species were alive when returned to the sea; iii) both in the Rapido and beam trawl, the catch rates of non-target benthic invertebrates in the modified square-mesh codend were consistently lower; iv) the towing speed of the beam trawls were always lower than Rapido as well as the towing forces. A reasonable amount of fuel was saved by switching to beam trawl; v) the first prototype of chain matrix beam trawl was inefficient and replaced by a tickler chain beam trawl.

- In light of the results obtained in the current study the Italian door manufacture “Grilli” SAS and the CNR-ISMAR patented the experimental beam trawl which is now used by several fishing boats in the Adriatic Sea.

8.6 *WP5 Economy*

UNITED KINGDOM

- Productivity analysis indicated that the effect of using a modified beam trawl (see above for specification) is overall negative and that uptake imposed additional costs on the vessel utilising this gear. All else constant, productivity was determined to have fallen in the region of 20% after uptake and when considered against the performance of comparable vessels in the same fleet. Even when fuel savings were assumed (as a result of reduced drag and then also due to the use of an econometer) it was determined that this would result in an average vessel becoming unprofitable under current conditions. It is worth noting that, on 2007 figures, the average Belgian large beam trawl vessel could not afford for revenue to fall by anything greater than 1.32% before registering a loss (assuming all other costs except for crew remained constant). This gives some indication of the difficulty involved with applying technical measures if they are likely to negatively influence productivity. It also suggests that internalising the externalities of these beam trawl vessels in this manner is, under current conditions, likely to render many vessels unviable. Further, as the own-price elasticities for the main target species of these vessels are highly elastic, the likelihood of any compensatory price effect due to reductions in landings is low.

- Quantitative measures of preferences for the reduction of mobile benthic gear impacts indicated those of greatest overall concern were commercial fish discards, habitat change, and commercial invertebrate discards. In general, the stakeholder groups tend to follow two main patterns: one that demonstrates significant concern for the reduction of commercial fish discards above all else (industry, gear technologists), and another where priorities are more evenly distributed (biologists, ecologists, economists, fisheries managers). The main points of disagreement between the sets of groups are those of commercial fish discards and habitat change. However, reducing commercial fish discards still ranked in the top three of all groups and reducing habitat change in the top three for all but industry and gear technologists. Stakeholder group level preference scores generally demonstrated relatively low coherence, a factor indicative of diverse within group opinion and somewhat typical within fisheries.

- As each stakeholder group attaches different levels of importance to the individual impacts, the benefit of any modifications (each resulting in differing bundles of benefits) will be judged accordingly. From the management perspective the derived measures of importance allow changes in the levels at which the impacts are imposed to be weighted and therefore appropriately accounted for in the decision making process. The level of importance industry placed on bycatch relative to habitat damage has implications for their incentives to voluntarily adopt environmentally friendly technologies. As little incentive or motivation exists to adopt gears to reduce habitat impacts mandatory regulations will be essential if such gears are considered desirable from a broader social perspective. If measures are considered legitimate and tackle issues stakeholders deem to be of importance (something made explicit by the preference weights) there are likely to be higher levels of acceptance, or compliance in the case of legislation. If the likely level of acceptability can be determined prior to final policy decisions being made it is possible greater levels of compliance may be achieved whilst also reducing the often non-trivial burden of enforcement.

NETHERLANDS

- The cost effectiveness of the pulse trawl in comparison to the beam trawl on the basis of two periods of commercial trials of the pulse trawl, turns out to be rather positive. The economic performance of the pulse trawl can compete with comparable beam trawls. This is especially due to a decrease in oil consumption, which is a high cost for beam trawlers. Fuel consumption of the pulse trawl is some 45-50% lower than the beam trawl.

- Environmental costs are also lower. When it concerns discards, in the pulse trawl, the catch rates of undersized (discard) sole were significantly lower than in the conventional beam trawl, and also catch rates of benthic fauna (nrs/hr Astropecten irregularis, Asterias rubens, and Liocarcinus holsatus) were significantly lower. There are indications that undersized plaice are damaged to a lesser degree in the pulse trawl and will survive better in the pulse trawl. Next to this the use of a pulse trawl generates less emission of CO2 than the use of a beam trawl.

- The pulse trawl seems to be an alternative for beam trawlers that are mainly directed towards sole, even sole catches are better, catches of plaice lack behind. Some concern exists on the effects of pulse trawling on certain non target species.

BELGIUM

- When comparing the four Belgian trawl fleets (large beam, eurocutter, shrimp beam and otter) with the set net fishery it was shown that the large beam trawl fleet generated the highest level of gross operating profit (GOP) in absolute terms, whilst the set net fleet had the second from lowest. However when accounting for effort the GOP/hr was almost equal for both sets of vessels and the set net fleet had a significantly higher average GOP/kg fish landed. In fact, the set net fleet outperforms every other fleet in terms of profit per landed kilogram mixed fish. As a result, the financial attractiveness of the large beam trawler fleet should be reconsidered because their GOP per fishing hour and certainly their GOP per kilogram landed mixed fish does not deviate strongly from other strategic groups. Measures of relative financial performance clearly illustrate that the large beam trawlers do not have the best “profit-effort”-ratio (not taking into account capital costs).

- Furthermore, conclusions on which sub fleet performs best are determined by the stakeholders perspective and personal interest. For instance if you are a fisher who wants to maximize his absolute level of profit then the large beam trawler fleet stand out as best sub fleet (given a stable fishing environment). However, if you are a fisher looking for a good “profit-effort”-relation you should look more toward (i) set netting and (ii) large beam trawling. Finally, if you are a policy maker and are aiming for sustainable fisheries, one should start comparing the relative financial and operational performance indicators which are more in favor of (i) set netting and (ii) shrimp beam trawling.

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List of presentations and published papers

8.7 Planned, submitted and published articles

Innes, J., and Pascoe, S., 2010. A multi-criteria assessment of fishing gear impacts in demersal fisheries. Journal of Environmental Management., *Submitted and accepted pending revision.*

Ivanović, A, Neilson, R.D., Chima-Okereke, C., Zhu, J., 2009. Influence of a Roller Clump on the Seabed. 2009 Proceedings of the 28th International Conference on Ocean, Offshore and Arctic Engineering (OMAE 2009) 31May – 5 June 2009, Honolulu, Hawaii, USA.

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8.8 Divulgative publications in Bulletins and specialised magazines

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Other articles

8.9 Reports to Government Agencies

Marlen, B. van, Vis, H. v.d., Haan, D. de, Burggraaf, D., Heul, J. van der, Terlouw, A., 2007. The effect of pulse stimulation on biota – Research in relation to ICES advice – Progress report with preliminary results. IMARES-report Nr. C098/07, 24 pp

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8.10 Poster presentations

8.11 Internal reports and cruise reports

Gear Specifications used on the research cruise on the “GO Sars” – November –December 2009.

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