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Report of the ICES-FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB)

20-23 April 2004
Gdynia, Poland

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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1 Executive summary

The ICES-FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB) met in Gdynia, Poland from 20-23 April 2004. The Group considered four specific Topics (TORs) with a fifth considered during the joint session with WGFAST on April 22. Following the 2003 meeting, convenors for each TOR were sought and given the responsibility of forming **Theme Groups** comprising of other interested WGFTFB members. These groups worked by correspondence throughout the year to produce a series of review documents, outlining the state of the art, summarising the key issues and providing recommendations for future actions. These working document reports formed the core of the 2004 WGFTFB meeting. The WGFTFB's reviews of each report reflect the consensus opinion within WGFTFB. A number of individual presentations were also given during the meeting.

The **Theme Group on Colour and Contrast in netting materials and twines**, and its relationship with fish behaviour, reviewed nearly 50 years of research, covering a wide range of gears, locations, species and behavioural reactions. To obtain information on whether fishing gear manufacturers considered netting colour important, the group also conducted extensive commercial interviews. These suggested that in a number of cases, this was considered important. In addition, the group collated one of the most extensive bibliographies available on the theme. It was concluded that in fishing conditions where visual stimuli are important, i.e., shallow waters, manipulation of netting colours might provide a simple mechanism to improve selectivity. They should therefore be further investigated for both existing and future development of bycatch reduction devices including the behavioural responses of cetaceans and birds. It is recommended that in order to define fisheries where visual stimuli may be important light measurement methodology should be standardised. Further, light measurements should be a standard feature in routine resource surveys using otter trawls and related these to conditions in commercial fishing operations **(Section 5).**

The **Theme Group on Technological Increase in Commercial Fishing Operations** concluded that technological creep is traditionally viewed from either a biological or economic perspective and that such advances can have positive, negative or neutral effects depending on that perspective. Biologically, increases in efficiency that pertains to increased CPUE, can be of concern to managers, particularly where effort limitation schemes are used. From an economic viewpoint, efficiency increases may affect CPUE, but they can also result in a reduction in operating cost for a given unit of catch, the significance of this is that it is acknowledged that economic forces are amongst the most important drivers of change in the catching sector. The group provided an extensive list of previous studies and noted that a range of methodologies had been used, making it problematic to generalise or transfer methods between fisheries. The group concluded by recommending that a multi-disciplinary workshop be set up, with a view to critically evaluate previous studies, standardise methodologies and data requirements and to identify those fisheries where technological creep is an issue and may be problematic for managers **(Section 6)**.

The **Theme Group on Benthic Impact and Mitigation Measures** acknowledged that bottom-tending gears do impact the benthic community and the general ecosystem. They noted that the effects varied considerably between fisheries, that their determination was problematic and that experimental protocols and interpretation of the results needed to be carefully considered. The group endorsed the further development of gear mitigation measures. They also acknowledged that some established measures offered associated advantages of access to otherwise closed areas and improvements in catch quality – features that had encouraged voluntary uptake by industry. In relation to the session on technological creep, the group acknowledged that in strictly enforced, output-controlled fisheries, measures that improve capture efficiency can be expected to reduce seabed impacts as a result of reduced fishing time. The group identified a number of useful modifications such as drop out panels and semi-pelagic gear, and several novel projects that had focussed on more benign methods of stimulating fish reactions to aid fish capture, for example the use of electric pulses in place of tickler chains. The group also recognised the need for seabed impact indicators to evaluate such devices, and encouraged the WGFTFB to seek advice from other Working Groups such as WGECO to define quantifiable impact indicators **(Section 7)**.

At the 2003 WGFTFB meeting, the use of turned mesh (T90) was considered as an alternative to the Bacoma window, which is mandatory in the Baltic Cod fishery. At that time, the WGFTFB could not provide a specific mesh size in T90 that equated to the Bacoma configuration due to lack of data and concerns over data collected by research vessels in oppose to commercial vessels. The **Theme Group on Baltic Cod Selectivity** collated all available selectivity data on T90 codends and conducted an alternative analysis, which identified the principal components affecting selectivity. However, this could not be directly compared to the Bacoma data due to the differences in methodological approach. It was agreed that a further analysis using the guidelines laid down in the ICES Selectivity Manual for Towed Gears be conducted together with all available Bacoma data. This initiative coincides with an official request from the International Baltic Sea Fishery Commission (IBSFC) received a week prior to the WGFTFB meeting. The analysis and reporting of the data will be made available for the 2004 FTC meeting which occurs at the ICES Statutory Meeting in September. The group endorsed the engineering aspects of the T90, and considered that there may be constructional benefits to the concept **(Section 8)**.

Through recent dialogue between the ACFM, CONC, ICES Secretariat and the FTC it has been acknowledged that the FTC/WGFTFB should be further integrated into the fisheries advisory process. There is a shift from single stock models towards more multi-species, fishery-based models, and the adoption of the *Ecosystem approach to fisheries management* will also demand new data. In recognition of this, the Chair of the FTC set up an FTC/WGFTFB *ad hoc* **Discussion Group on Incorporation of WGFTFB Information into Fisheries Based Advice** in January 2004. The Chair of the ACFM was invited to the WGFTFB meeting and gave a presentation on the type of inputs required for fishery-based advice that could be provided by the WGFTFB. Together, the Chair of the ACFM and the *ad hoc* discussion group met for one day to discuss the details of such advice and possible mechanisms through which it could be provided. The group identified areas where the WGFTB could play an important role, such as the provision of: selectivity data by métier, definition of fleets, monitoring changes in technology and its application, capacity definitions, assessment of discards and bycatch in relation to the ecosystem approach, quantification of benthic impact and the development of survey technology. The group concluded that the WGFTFB should be pro-active in encouraging dialogue between disciplines and needed to be able to respond at short notice to specific requests whilst continuing to encourage longer-term, systematic research. The group considered that the formation of an ICES multi-disciplinary workshop **(see Section 12.1.3)** would be advantageous in order to facilitate open discussion regarding, *inter alia* methodologies, data collection and standardising the means of incorporating WGFTFB information into ACFM's fisheries based advice **(Section 4).**

The **Study Group on Unaccounted Fishing Mortality** (SGUFM) presented a report of their activities in 2003/2004. During this period, the SG has been collating data from a variety of sources, this will continue through 2004 and 2005. SGUFM are seeking contributions from scientists for data gathering, workshop participation, information on discard mortality and illegal and misreported landings, and to inform the group of relevant data in the grey literature, of ongoing projects and of anecdotal evidence. The potential of utilising discard data was well demonstrated for two fisheries in the North Sea, clearly identifying these as having high or acute discard problems. Such information could be used to specifically target gear technology research priorities.

2 Directive

The directive of the WGFTFB is to initiate and review investigations of scientists and technologists concerned with all aspects of the design, planning and testing of fishing gears used in abundance estimation, selective fishing gears used in bycatch and discard reduction; and benign environmentally fishing gears and methods used to reduce impact on bottom habitats and other non-target ecosystem components, including behavioural, statistical and capture topics.

The Working Group's activities shall focus on all measurements and observations pertaining to both scientific and commercial fishing gears, design and statistical methods and operations including benthic impacts, vessels and behaviour of fish in relation to fishing operations. The Working Group shall provide advice on application of these techniques to aquatic ecologists, assessment biologists, fishery managers and industry.

3 Introduction

Chair:	Dr. Norman Graham Institute of Marine Research P.O. Box 1870 Nordnes N-5817 Bergen Norway norman.graham@imr.no
Rapporteur:	Dr. Hans Polet Sea Fisheries Department Ankerstraat 1 B-8400 Oostende Belgium hans.polet@dvz.be
Venue:	Gdynia, Poland
Date:	20-23 April 2004-04-20

3.1 Terms of reference

The **ICES-FAO Working Group on Fishing Technology and Fish Behaviour** [WGFTFB] (Chair: Norman Graham, Norway) will meet in Gdynia, Poland, from 20–23 April 2004 to:

a) review and assess the effects of colour and contrast in netting materials and gear components on fish behaviour and catchability in survey and commercial situations;

b) assess efficiency increases in fish capture operations including:

   i) identification of advances in technology and practices, which increase fishing efficiency,

   ii) quantification of such advances wherever possible,

   iii) review of work undertaken in this field;

c) evaluate the effect of fishing gears on the seabed with special reference to mitigation measures in mobile gears and the effects of stationary gears on sensitive environment;

d) evaluate the recent (last 5 years) codend mesh selection experiments dealing with bottom trawls used in the Baltic Sea for cod which used either turned meshes and/or BACOMA windows. With emphasis on estimating selectivity parameters, experimental design and modelling/statistical analyses;

e) review new technologies or fishing gear research leading to standardization in bottom trawl surveys;

f) in a joint session with the Working Group on Fisheries Acoustics Science and Technology on 22 April 2004, review:

   i) the questions raised at the ICES Symposium on Fish Behaviour in Exploited Ecosystems, held in Bergen in June 2003;

   ii) methods for estimating abundance of semi-demersal species, including combining trawl and acoustic estimates;

   iii) methods to observe fish behaviour in relation to fishing gears.

WGFTFB will report by 15 May 2004 for the attention of the Fisheries Technology Committee and ACE.

Supporting Information

Priority:	The current activities of this Group will lead ICES into issues related to the effectiveness of technical measures to change size selectivity and fishing mortality rates. Consequently these activities are considered to have a very high priority
Scientific justification and relation to Action Plan	Action Item 1.12.5,1.13,1.13.2,3.18 – a Action Item 3.13 - b Action Item 2.3, 3.17 - c Action item 1.12, 3.16 - d Action item 1.12.5,1.13,1.13.1- e Action item 1.12.4, 1.13.1, 1.13.2,1.13.4, 3.18-f Action item 5.8 – FAO **Term of Reference a)** It is widely acknowledged that environmental conditions, such as the underwater light field have a significant effect on fish catchability (e.g. *ICES Cooperative Research Report*, 215, Wileman *et al.* (1996)). Past and current studies have also examined the effect of netting colour and contrast on the behaviour of fish. No synthesis of this work has been made but there are potential implications for both commercial and survey fishing operations. In particular the WG will : (1) review past studies on the use of the colour and contrast of fishing gear to modify fish behaviour and improve size and species selectivity; (2) identify current initiatives in this field and also studies encompassing the effect of varying light conditions on fish reactions to fishing gear; (3) gather information on the range of coloured twine in use commercially and the rationale behind these choices.; and (4) compile a list of recommendations on the use of coloured netting to improve selectivity in commercial nets and also possible techniques for improving the efficiency of survey trawls. **Term of Reference b)** Increases in the technical efficiency of fish capture in commercial operations is not currently accounted for, in estimates of fishing effort. Such efficiency increases may therefore undermine management protocols, which utilize estimates of fishing effort as a management tool. **Term of Reference c)** The effect of bottom tendering towed fishing gears on the seabed has received considerable attention in recent years. While it is important that the effect be quantified, studies to reduce the effect should be encouraged and strengthened. WGFTFB will review and evaluate recent work and discuss current status on the effect of towed gears such as bottom trawls and dredges and will put special emphasis on mitigation measures to reduce the effect through modification of

	gear designs and operational methods. In addition, a review and evaluation of the possible effects of stationary fishing gears including but not limited to gillnets, longlines, traps and pots on sensitive environments such as coral reefs, sea mounts, near shore communities and mollusc beds. **Term of Reference d)** Unintentional mortality of juvenile cod continues despite the recent increase in minimum codend mesh size to 140 mm for commercial bottom trawling in the Baltic sea. Experiments on trawls equipped with turned-mesh codends indicate that size selection is more nearly knife-edged and therefore, like the size selection by the BACOMA window, easier to control to obtain better escapement of sub-legal fish. Considering the current crisis in the management of Baltic cod, review of the selective properties of turned mesh codends is critically important. **Term of Reference e)** Standardization of trawl survey methodology can lead to reduced variability in catchability between sampling sites, between research vessels and over time. Such standardization might be increased through the introduction of new technology, changes in the gear or changes in the methodology for using the gear. Renewed interest in trawl standardization has been motivated by a recent US review of standardization in NMFS trawl surveys and the addition of a similar standardization review as a term of reference for WGIBTS and other ICES trawl survey working groups. **Term of Reference f)** The joint session of WGFTFB and WGFAST permits both groups to review and discuss common areas of research such as fish behaviour and abundance estimation in scientific surveys.
Resource requirements:	The research programmes which provide the main input to this group are already underway, and resources already committed. The additional resource required to undertake additional activities in the framework of this group is negligible. Having overlaps with other meetings of expert groups of FTC increases efficiency and reduces travel costs.
Participants:	The Group is well attended
Secretariat facilities:	N/A
Financial:	None required. Having overlaps with other meetings of expert groups of FTC increases efficiency and reduces travel costs.
Linkages to Advisory Committees:	The questions of bycatch reduction and survey standardization are of direct interest to ACFM and seabed damage is of direct interest to ACE.
Linkages to other Committees or Groups:	This work is of direct relevance to the Working Group on Ecosystem Effects of Fisheries, WG on Fishery Systems, WG on International Bottom Trawl Surveys, Baltic Committee, Marine Habitat Committee, Resource Management Committee and Living Resources Committee
Linkages to other Organisations:	The work of this group is closely aligned with similar work in FAO
Cost share:	ICES: 100%

3.1.1 Participants

A full list of participants is given in Annex 1.

3.2 Explanatory note on meeting and report structure

During the 2003 WGFTFB meeting, the mini-symposium format previously used by the WG for the exchange of technological information was discussed. The WG noted that there were certain limitations to this approach. While providing information on individual pieces of ongoing or recent work, it did not readily facilitate a more in-depth analysis or review of the general theme. The format also made it difficult to provide more holistic recommendations for future actions.

In the run-up to the 2004 meeting an alternative approach to the way specific Terms of Reference (TORs) were considered by the WG was proposed by the Chair. For the TORs (Themes) selected at the 2003 meeting individual convenors were appointed oversee and facilitate work by correspondence throughout the year, based on a Theme Group format. The Chair asked each convenor of each TOR to prepare a working document, reviewing the current state of the art, summarising the principal findings, identifying gaps in the knowledge where consultation with other experts was required and recommending future research needs.

One day was allocated for the conveners and members of the individual Theme Groups to meet, finalise their reports and findings, and produce a presentation. The individual working documents can be found in appendices 3 to 6. This format was followed for four of the five TORs, with the TORs on standardisation of survey gears, being dealt with during the WGFTFB/WGFAST joint session held on April 22 in Gdynia.

The **summaries and recommendations** for the working documents for each TOR were reviewed by WGFTFB and were accepted, rejected or modified accordingly to **reflect the views of the WGFTFB**. However, the contents of these working documents do not necessarily reflect the opinion of the WGFTFB.

In addition to the presentation of the review report, each convener was asked to select a small number (~3) of individual presentations based on specific research programmes. The abstracts are included in this report, together with the authors' names and affiliations. Although discussion relating to the **individual presentations** was encouraged and some of the comments are included in the text of this report, the contents of the individual abstracts were NOT discussed fully by the group, and as such they **do not necessarily reflect the views of the WGFTFB**.

4 *Ad hoc* discussion group on incorporation of WGFTFB information into ACFM's fishery based advice

Conveners: Norman Graham (Chair WGFTFB) and Steve Walsh (Chair ICES Fisheries Technology Committee (FTC)).

In addition to the work identified in Section 3.2, a further item was placed on this years agenda. During the 2003 Annual Science Conference, there was general agreement that the Fishing Technology Committee (FTC) and its working groups should be more involved in the fisheries advisory process within ACFM. It was also recommended that the Chair of the FTC seek appointment as an ex-officio member of the ACFM similar to FTC Chairman's membership within ACE for the last three years. This initiative was well received by the Consultative Committee (CONC), but FTC was asked to consider practical ways in which this could be achieved. In the run up-to the 2004 WGFTFB meeting, the FTC Chair formed a small group of FTC members within the WGFTFB to consider this, and worked by correspondence throughout the year, canvassing opinion from a variety of sources. A meeting was held during the first day of the WGFTFB meeting and a summary of the group's findings is given in Section 4.2. The TORs for the group were to:

a) review ongoing projects relevant to forecasting fishery-based advice from a gear technology perspective; SGDFF, SGIF and projects such as TECTAC, EFIMAS and TEMAS;
b) discuss data needs and methods of collection of data from fleets and fisheries that would be valuable for assessment working groups and ACFM in fishery-based forecasting ;
c) discuss the best way that FTC/WGFTFB can interface with other ICES WG/SG in providing information for fishery-based forecasts;
d) discuss a framework for monitoring development of fishing technology, and
e) outline requirements for the quantitative assessment of the effect of gear technology (prediction of proposed changes or post-hoc analyses of implemented changes).

This group will make its final report at the annual FTC meeting during the ICES Statutory Meeting in Vigo, September 2004.

As part of the consultation process, the Chair of the ACFM, Poul Degnbol, was invited to participate in the *ad hoc* discussion group's deliberations. The co-Chairs of the group recognised that this was central to any future developments in this field and appreciated the effort made by Poul Degnbol to attend this meeting. During the first day of the WGFTFB meeting, Poul Degnbol presented the ACFM perspective on how the FTC/WGFTFB could assist in providing scientific information for ICES advice on fishery based forecasting, before discussion at length with the *ad hoc* group on the issues raised.

Participants:

Co-Chair	Co-Chair
Norman Graham (Norway, Chair WGFTFB)	Steve Walsh (Canada, Chair FTC)
Poul Degnbol (Denmark, Chair ACFM)	Dick Ferro (Scotland)
Dominic Rihan (Ireland)	Hans Polet (Belgium)

4.1 FTC/WGFTFB role in ICES advice - Poul Degnbol, Chair ACFM (presentation summarised by Norman Graham, Chair WGFTFB)

There are a number of changes in the way that fisheries advice is to be provided and structured in the future. Shifts include moving from short to medium term forecasting and advice strategies that follow the principles of the ecosystem approach to fisheries management. These changes also imply a move to area-based information and management advice. Recently it has become apparent that there is a tendency within certain management regimes, particularly the EU, to reduce emphasis on gear based management strategies in favour of effort control and closed areas. It is important to note however, that the ecosystem approach does recognise the need to consider issues such as non-target catch and impacts on habitats. There is a change within management towards a more fisheries based system of advice rather than the existing single species stock-based models. As part of this change there is a need to consider the reactions of fishermen to factors such as regulatory controls, stock and market changes. A likely prerequisite of this is integration of fishermen's knowledge into the management process. In future, advice will be based on catch options by species mix rather than on an individual species basis, and, as a consequence, it is important to have information on the individual fleets exploiting these mixed fisheries, how they interact with each other and their relative dynamics. A possible format for future advice, from a gear technology perspective, might include a number of important elements, such as provision of information on regulations and their effects, changes in technology use within the fishing industry and potential benthic/ecological impacts caused by changes in fishing gears or fishing patterns.

A range of more gear-specific input requirements was subsequently identified. It was felt that the WGFTFB had a strong role to play in the provision of data describing key issues in the new approach. There is a need for parameterised selectivity data from specific fleets and métiers that not only consider the target, but also non-target species. Such information should also consider the ways in which the fishing industry may circumvent or adapt to such regulations, for example possible mechanisms to negate technical measures. A need to assist in the definitions of fleets and métiers using the practical knowledge base of individual members was strongly advocated, for example as a validity check of definitions based on statistical analysis only. Other potential areas to which WGFTFB could contribute related to technological changes within the fleets. Information (qualitative and quantitative) on technological creep is considered necessary, especially when put in the context of effort management systems. Such information should not only monitor technological change but also how the technology is applied. Additionally, assistance is required in defining capacity and the key features that affect it. More general information is also sought in terms of the spatial behaviour of fleets and how they react to changes in regulations, such as effort shift due to closed areas. Finally, the presenter noted that there was an increasing trend towards fishery independent methods for stock evaluation, involving continuous evaluation and review e.g. in relation to the development of new survey trawls and advice on their application. Again in this respect the WGFTFB has an important advisory role to play.

In summary potential future contributions from FTC and especially WGFTFB include:

- 'traditional' FTC inputs
    - Technical measures – selectivity re target and non-target species
    - Evaluate the effect of regulations in force
    - BUT this must include the actual practices in the fisheries.
- Fisheries based advice
    - Identification of fisheries/métiers
    - Monitoring and describing fisheries practices including technological change and changes in use of technology
        - Technical aspects
        - Human aspects – adaptation to changing regulatory, resource and market conditions
    - Spatial fleet behaviour
- New management instruments
    - Adaptation to closed areas – redistribution of effort
    - Advice on catchability (changes and sources of variability) in relation to effort management
    - Technological creeping
    - Capacity definitions in relation to capacity control programmes
- Ecosystem approach
    - Impacts on non-target species (including birds and mammals)
        - Measure impact and advise on means to reduce impact
    - Gear impact on habitats
        - Measure impact and advise on means to reduce impact
- Increased emphasis on fisheries-independent information requires:
    - Survey design and technology development
    - Such information is delivered through science committees but crucial to the advice

4.2 Summary of the ad hoc discussion group findings on incorporation of advice from FTFB into fisheries based forecasts, stock WG' s and ACFM presented to the WGFTFB on 23 April, Norman Graham (Chair WGFTFB)

An overall explanation of the rationale behind the formation of the *ad hoc* group and a summary of the recent dialogue between the FTC, ICES secretariat and ACFM leading up to its formation was presented. The *ad hoc* discussion group had worked by correspondence during the past 3 months. Some extracts from recent communications between ACFM, FTC, ICES Fisheries Advisor and the WGFTFB were presented, outlining some of the areas to which WGFTFB could contribute.

The group reviewed a number of ICES expert groups, national and EU supported RandD projects/initiatives that are focussing on the development of a more multi-disciplinary approach to fisheries management, the provision of tools for the evaluation of such management strategies and the more general fisheries-based management system as opposed to the traditional single species approach. In reviewing the work of SGDFF, SGFI and the Working Group on Methods of Fish Stock Assessment together with such and EU/national projects such as TEMAS, EFIMAS and TECTAC, a number of areas were identified that would clearly have benefited from consultation with gear technologists. These particularly related to the selection of appropriate fisheries data criteria (gear evolution, vessel design, fleet structure and fishermen's own information) for inclusion in fisheries-based models, as per the requirements considered in Section 4.1. It was agreed that WGFTFB should play a pro-active role in contacting appropriate persons in order to facilitate dialogue.

The SGDFF reports had outlined the need for clear definitions of fisheries, fleets and métiers. It was noted that in the first instance these definitions were based on cluster analyses, using landings data as the principal identifier. It was felt that it would be more appropriate, and better reflect commercial activities, if catch as opposed to landings data were used, given the known limitations of official landing statistics. It was recognised that this would require considerable additional data collection from other sources such as gear technologists, on board observers and possibly fishermen themselves. The WGFTFB could play an important role by screening such analytical evaluations, to ensure that these matched the knowledge base of researchers operating in the field. However, it is probably better that these exercises be conducted at a national level, with WGFTFB having a co-ordinating role. WGFTFB could also be used to encourage additional data collection programmes, such as the one implemented by the Marine Laboratory, Aberdeen, where sea-going staff routinely recorded gear attributes used on a vessel-by-vessel basis. Such data sources could be then used for the refinement of fleet definitions.

Another issue considered was the provision of selectivity data for particular gear types competing in specific fisheries and in this respect WGFTFB needs to encourage the use and population of the SELDAT database. However, in order to provide better estimates at a fleet rather than vessel level, the WGFTFB needs to encourage the development of models for estimating fleet selectivity. In light of increasing focus in some regions on effort-based management policies, initiatives such as the 2004 TOR on efficiency increases should be continued (see Section 5). This could also be aided by changes in the National reports to WGFTFB where qualitative information on technical changes within fleets could be reported. This approach, while laudable, needs further consideration, as it may need a considerable increase in resources at a national level, particularly for countries with large geographical coverage and diverse fleets.

Any future development in defining fishing effort and how it relates to fishing mortality should include expertise from within the WGFTFB, given the influence that gear development can have on fishing effort. In this respect individual members have been involved in a number of research initiatives and participated in several technical experts groups, for example within the European framework, but input from WGFTFM members needs to be recognised and built on.

It was also noted that there are a number of initiatives attempting to draw fishermen and scientists together. The group concluded that WGFTFB might act as an interface between these groups recognising that gear technologists often have better skills in communicating with the industry. At an EU level this would require WGFTFB to be involved in the SGFI study group and to contribute to RACs being proposed by the Commission. For such initiatives to be successful however, the perception and focus of these groups would need to be significantly changed so that they could contribute more constructively to the overall management process.

There were a number of concerns that these changes (suggested by the ACFM Chair), might result in substantial changes to the operating procedures of WGFTFB resulting in a shift away from a gear technology research dissemination role to a more fleet monitoring function. However, it should be noted that some North Atlantic countries such as Norway, Iceland and USA, rely heavily on gear-related technical measures as part of their management system. These regimes largely driven by strict bycatch regulations and as such there is still a substantial requirement in terms of expertise in gear technology. Furthermore the co-sponsorship of the working group by FAO has increased the geographic remit considerably. This is reflected in the TOR on shrimp trawling proposed for the 2005 meeting. The ecosystem approach to fisheries management must consider issues such as discards and bycatch, including mammals and sea birds and also consider issues relating to benthic impact of fishing gear, again WGFTFB would have a central role in guiding such research. The *ad hoc* discussion group felt that some of the future data requirements and inputs needed further consideration and concluded that a more integrated approach with other disciplines was needed to progress the concept further. The group proposed that a multi-disciplinary workshop be set up, including other ICES expert groups, stock assessors and external experts in the fields of socio-economics and sociology. The WGFTFB fully approved of such initiatives by the WGFTFB/FTC *ad hoc* discussion.

4.2.1 Conclusions and Recommendations

- The WGFTFB should be pro-active in encouraging dialogue with other WG and project initiatives. The WG supports the formation of a dialogue workshop to encourage an inter-disciplinary approaches and to determine appropriate data needs and tasks to cater for the changing needs of fisheries advice (see page for TOR proposal).
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- WGFTFB needs to be more focused and be able to respond at short notice where issues of relevance arise, while continuing to support and guide longer-term systematic research.
- Seek appointment of FTC or FTFB Chair as an ex-officio member of ACFM.
- There are a number of areas where the WGFTFB can contribute:
    - *Fleet/Métier definitions*
    - *Monitoring technological creep*
    - *Assisting with the development of methodologies for monitoring ing gear impacts on habitats and review/monitor gear related remedial measures*
    - *Facilitating dialogue between industry and scientists*
    - *Providing data on selectivity for fishery-based forecasting*
    - *Formulating of advice on technical regulations relating to gear and evaluate their effectiveness*
    - *Advising to SGFI and RACs on gear development*

5 Topic: Review and assess the effects of colour and contrast in netting materials and gear components on fish behaviour and catchability in survey and commercial situations

Convener: Emma Jones

5.1 General overview and presentation of principal findings

This TOR was introduced by Emma Jones. A review (Annex 2) was presented and showed that a considerable amount of work has been done in the last 50 years demonstrating a global interest in this topic.

5.1.1 Terms of reference

Review and assess the effects of colour and contrast in netting materials and gear components on fish behaviour and catchability in survey and commercial situations

5.1.2 Abstract

Environmental conditions such as the underwater light fields have a significant effect on fish catchability (Wileman *et al.* (1996)). This report represents a review of studies that seek to elucidate the effects of varying light conditions on fish reactions to fishing gears including the use different coloured twine to effect behavioural reactions. It is recognised that the relevance of visual stimuli depends on parameters such as time of day, depth and water clarity. A number of studies found that, where fishing occurs under visual conditions, the opportunity does exist to manipulate visual stimuli in order to improve selectivity, bycatch reduction or catchability. In addition to reviewing the scientific literature, a survey canvassing commercial net manufacturers and net suppliers to understand fishing industry perceptions and preferences produced variable responses, but indicated that in certain instances, this aspect is considered important. A very common theme being to choose a colour of netting that matched the colour of the water, the unstated but implicit inference being that minimal contrast, and therefore minimal visibility was preferred.

5.1.3 Participants

Emma Jones (Aberdeen)

Chris Glass (USA)

5.1.4 Summary

This report represents a synthesis of work carried out, spanning 50 years, and many countries. It is recognised that the relevance of visual stimuli depends on parameters such as time of day, depth and water clarity. However few of the studies encountered have attempted to explore the frequency or extent of such dark conditions or attempted to discuss what proportion of commercial fishing activities are conducted either above or below these absolute visual thresholds for target species. Obviously these conditions occur more often in certain fisheries, such as those in shallow coastal or clear waters. This proportion could be estimated but a pre-requisite of this would be standardized an accurate measurements of light intensity.

The survey canvassing commercial net manufacturers and net suppliers to understand fishing industry perceptions and preferences produced variable responses, but indicated that in certain fisheries, this aspect is considered important.

Where fishing occurs under visual conditions, the opportunity exists to manipulate visual stimuli in order to improve selectivity, bycatch reduction or catchability. These changes are potentially very simple and relatively cheap to make. The same manipulations could also be used in survey trawls to either increase or reduce herding.

5.1.5 Recommendations

- Produce a reference document that establishes a recommended methodology for measurement of light levels and provide guidelines for appropriate instrumentation.
- Assess to what extent visual conditions exist at fishing depth on commercial fishing grounds.
- Given the implications highlighted in this study, the group recommends that appropriate light intensity measurements be incorporated into routine survey operations
- Explore the influence of netting colour (contrast) on reaction behaviour of other animals such as cetaceans and sea birds, which may be caught as bycatch.
- Update the current review to incorporate studies not covered including those pertinent to cetacean, turtles and other threatened or endangered species.
- Examine why colour of twine is still perceived as important in some fisheries and not others.

Discussion

The question is raised whether the way contrast is experienced is similar for humans as it is for fish. This is certainly the case, and if anything, fish vision is more sensitive, especially in low light, low contrast environments. This is species dependent. Most commercial fish, however, have similar visual abilities as humans so it is assumed that contrast, from a physiological point of view, can affect behaviour.

It was stated that a number of studies have shown that colour can affect the catch rates in gillnets. Presently, however, in practice fishermen don’t seem to pay attention to this issue so it is assumed that fishermen assess the effect to be minimal or absent.

This review made clear that a lot of the work is indeed not new but certainly worth revisiting as visual stimuli have proven to be important for the availability as well as the catchability of fish to fishing gear. It was noted that by considering contrast/colour it may be possible in a number of cases to improve the efficiency of existing bycatch reduction devices, for example the square mesh panel.

5.2 Abstracts of Individual Presentations

5.2.1 Use of coloured large mesh panels to reduce flatfish bycatch in the New England silver hake fishery

Henry O. Milliken and Joseph T. Dealteris (USA)
Presented by Chris Glass (USA)

Fishermen must use small-mesh bottom trawls to capture certain species of fish that cannot be retained by standard groundfish mesh sizes. These fisheries are subject to bycatch limits when such trawls are used in areas where regulated species reside. Bycatch of regulated flatfish in the small-mesh bottom trawl fishery for silver hake *Merluccius bilinearis* in the northwestern Atlantic is a concern of management because silver hakes are captured in areas where juvenile regulated flatfish are common. An evaluation of flatfish and silver hake behaviours using low-light underwater cameras suggested that the two species could be separated within the mouth of a bottom trawl. Using the alternate tow method, four different large-mesh panels positioned in the lower belly of the trawl were separately evaluated. One of them proved to be effective in reducing flatfish bycatch while not reducing the catch of silver hakes; a large-mesh panel constructed of 40.6-cm (16-in) stretched mesh that was diamond shaped using orange-coloured nylon twine 1.6 mm (0.06 in) in diameter in the lower belly resulted in a 73% reduction in flatfish catch with no effect on the catch of silver hakes.

Discussion:

These panels are also used as debris excluders. Since the 5% bycatch rule also takes seaweed and non-commercial species into account and these panels exclude these components of the catch, they help fishermen in conforming to the 5% rule.

5.2.2 The influence of colour and contrast of netting on fish escape behaviour from square mesh panels in demersal trawls. Emma Jones, FRS, Scotland

Square mesh panels inserted in trawl nets ahead of the codend can be used to improve selectivity by providing an escape route for under-sized fish. For the purposes of this experiment, different combinations of coloured square mesh escape panel and codend were tested. For observational work, "split" design square mesh panels were fished in combination with 40 mm codends.

Contrary to previous experimental observations, no significant difference was found in the split panel experiment with equal numbers of fish escaping overall from each side of the panel. The earlier experiments were conducted with a design of net that resulted in a much rounder, more open extension shape, allowing fish more freedom to move. The current study used standard commercial rigging of the panel and extension that results in a flatter, more restrictive cross section. The design of the experiment relies on the fish being evenly distributed beneath the panel. It was not possible to ascertain if this was indeed the case. Unobtrusive video observations were found to be difficult to achieve and distortion of the panel was unavoidable.

The issues of altering panel geometry and light restrictions are avoided with selectivity experiments. The data for haddock did suggest that the white panel released more fish below 30cm than the black panel. However the difference was only marginally significant. The square / diamond combination panel appeared to retain less haddock than the black panel but was not as effective as the white panel although neither difference was significant. This reduced proportion of escapes therefore suggests that fish do utilise the entire length of the panel.

Manipulating colour and contrast of twine can produce subtle effects and require more data than was collected in this study to properly elucidate. The prevailing environmental conditions such as depth, time of day and turbidity of the water will clearly influence effectiveness, but there are indications that a simple change of twine colour can improve the performance of escape panels.

Discussion

A remark was made that a similar study in the past did show a significant effect of the panel colour. This study was based on a larger sample size. However, it was noted that the geometry of the extension was very different i.e. larger cross sectional area, which may have influenced the results.

5.2.3 Lumilux exit grid in shrimp fishery. Haraldur Einarsson and Asta Hrönn Björgvinsdottir, MRI, Iceland

On the shrimp fishing grounds where this study was conducted, regulations require the use of a grid with 22 mm bars in the trawl. In October 2003 small trial was conducted to test if fish would swim through a "glowing grid". A four-panel shrimp trawl was used with an additional lumilux exit grid positioned in the trawl in the side panels. The grid was plastic, 1800 x 1000 mm in size, with 98 mm between the bars and painted with lumilux paint to make it glow. A cover bag over the regular grid sampled all fish that entered the trawl but did not swim through the glowing grid. A total of 8 hauls were completed with the lumilux grid used in every second haul. The idea was to see if fish would swim through the glowing grid with relative large bar spacings to avoid eventual mortality as a consequence hitting the grid or meshes. The results showed no fish escaping through the glowing grid. The concept of using lumilux paint on grids or any other trawl components is interesting, but more knowledge about the reaction of fish to light is needed.

Discussion:

In comparison with this glowing grid the example was given of the glownet which aimed to herd the fish in dark conditions. Practice does demonstrate that this works.

5.2.4 General discussion

An introduction to the general discussion was given by Chris Glass summarizing what is known on this topic but also highlighting lacks in knowledge. An extensive bibliography on this topic has been compiled which was welcomed by WGFTFB as a very interesting tool for use within and outside the Working Group. It was stated that a lot of the experimental work carried out in the past (e.g. by Clem Wardle, UK) aimed at indicating principles and was not done with ready to use designs. Even with designs tried in commercial trawls, local fine tuning is often necessary before they can be introduced in the commercial fishery (e.g. square mesh windows). An important conclusion of the review is that colour can have an effect on catchability and selectivity and can be used as an easy to implement technical measure.

The discussion evolved around possible applications in specific cases to solve bycatch problems. One example is the politically sensitive case of incidental bycatch of cetaceans in pelagic trawls that, amongst others, is being dealt with in the EU-Necessity project. This particular topic was not targeted in the review but there may be more information available. The remark was made that marine mammals, however, mainly use echo orientation and colour may not be so important for these animals. Another possible application is the use of a canvas tunnel to induce escape, which has been tried in the Baltic. Although experimental results were promising, implementation in the commercial fishery and enforcement poses practical problems. Colour of netting and knowledge on vision can be an element in reducing the problem of incidental catches of sea birds in static gear. This is already applied in some regulations stating that driftnets can only be set in light conditions. Conclusively it was stated that net colour should be a tool in the gear technologist's tool box.

A comment was expressed on the implications that vision of fish may have for trawl surveys. Variance in catchability of survey trawls may be partly caused by depth depending visibility of the trawl components. A hardly visible non herding survey trawl could reduce this variability.

Light intensity is an important factor for fish behaviour in relation to fishing gear. It was stressed that splitting up experimental data into night-day blocks, though, is considered insufficient. Together with this conclusion comes the problem of measuring light intensity. Many instruments exist to measure light but often these do not provide the necessary level of sensitivity. The question was raised as to whether procedures exist to measure light in fish behaviour studies. A recommendation or a reference document and easy to use and portable equipment would be welcomed by gear technologists and fish behaviourists.

A remark was made that fishermen often do not seem to pay much attention anymore to the colour of netting, although some clear exceptions exist. In the past, colour was deemed important in many fisheries and it is unclear why this commercial attitude has changed.

A lot of Russian literature exists on this topic. A Russian member of FTFB offered to make translations.

6 Topic: Assess efficiency increases in fish capture operations

Conveners: Bjarti Thomsen (Faroes) / Andy Revill (UK)

6.1 General overview and presentation of principal finding

This TOR was introduced by Bjarti Thomsen. A review report (Annex 3) was presented by Andy Revill.

6.1.1 Terms of reference

Assess efficiency increases in fish capture operations including:

a) *identification of advances in technology and practices, which increase fishing efficiency;*

b) *quantification of such advances wherever possible;*

c) *review of work undertaken in this field.*

6.1.2 Abstract

The efficiency of fishing operations process appears to be viewed from two distinct perspectives, namely biological and economic. From a biological perspective, efficiency increases pertains to technologies /practices that result in more fish being caught per unit of fishing effort. The biological perspective of efficiency is of primary current concern to fisheries managers. From an economic perspective, not all efficiency improvements necessarily result in more fish being caught (i.e. new cost reduction technologies, value adding practices etc). The economic perspective is however of primary concern to fishers and largely governs their behaviour.

Many factors affect efficiency, including technology, however not all new technologies increase efficiency. Some technological advances may have positive, negative or neutral effects on efficiency whether viewed from a biological or economic perspective.

Fisheries managers may require assessments of efficiency increases, particularly where effort based management strategies are used.

Previous studies undertaken to assess efficiency of fishing operations have been sporadic, intermittent and are a mixture of biological assessments and/or economic based assessments. The previous studies show that efficiency has increased in many fisheries, but trends cannot be generalised or transferred between fisheries.

6.1.3 Participants

Bjarti Thomsen (Faroe Islands, Chair)
Gérard Bavouzet (France)
Ole Eigård (Denmark)
Arill Engås (Norway)
Hallvard Godøy (Norway)
Andrew Revill (UK)
Ken Weinberg (USA)
Mats Ulmestrand (Sweden)
Alessandro Lucchetti (Italy)
Barry O'Neill (Scotland)
Dominic Rihan (Ireland)
Stan Kotwicki (USA)

6.1.4 Summary Statements and Conclusions

1) In previous studies the efficiency of fishing operations process appears to be viewed from two distinct perspectives, namely biological and economic.
2) From a biological perspective, efficiency increases pertain to technologies /practices that result in more fish being caught per unit of fishing effort or more effort being exerted. The biological perspective of efficiency is the primary current concern to fisheries managers.
3) From an economic perspective, not all efficiency improvements necessarily result in more fish being caught (i.e. new cost reduction technologies, value adding practices etc). The economic perspective is however of primary concern to fishers and largely governs their strategies.
4) Many factors affect efficiency, including technology, however not all new technologies necessarily increase efficiency. Some technological advances may have positive, negative or neutral effects on efficiency whether viewed from a biological or economic perspective. Changes in management regimes may also affect efficiency.
5) Further studies should aim to complement advice to management as to where to set target fishing mortality levels for the future.
6) Fisheries managers require assessments of efficiency increases, particularly where effort based management strategies are used.
7) Methodologies, which usefully incorporate both biological and socio-economic data, may be the most appropriate, particularly for predictive forecasting of efficiency increases. Using biological or economical only based assessments of efficiency may limit the usefulness of such studies.
8) Previous studies undertaken to assess efficiency of fishing operations have been sporadic, intermittent and are a mixture of biological and/or economic based assessments.
9) Previous studies show that efficiency has increased in many fisheries, but trends are difficult to generalise or transfer between fisheries.
10) No simple formula such as the product of tonnage and engine power can be used to predict the fishing efficiency of a replacement new vessel compared to an existing craft.

Further studies and actions required

A workshop should be convened which aims to address the issues detailed below. The participants in the workshop should be a balanced mix of experts in the field of fisheries technology, economics, sociology, biology, fisheries management, and who have an interest in efficiency methodologies. The following issues should be addressed:

- Indicate in which fisheries such studies are required.
- Standardise the data requirements for such studies. Data collection should then be undertaken on a continual basis by appropriate bodies.
- Critically evaluate the methodologies available to undertake such studies with a view to developing a standardised and integrated methodology.

6.2 Individual Presentations

6.2.1 Efficiency increases in the Faroese longline fishery. Ole Eigård, Denmark

The trend in efficiency of the Faroese long line fishery was examined in terms of both the change in fishing effort and the change in catch per unit of effort (CPUE). The basis of the investigation is formed by an analysis of variance in a time series from 1986 – 2002 of catch and effort data from 5 larger long line vessels between 130 and 315 GRT. This set of quantitative data is related to two sets of qualitative interview data on technological innovations covering the same time period. The analysis showed an average annual increase in effort, measured as number of hooks set per day, of app. 1.5% from 1986 to 2002. Scrutinizing of this trend revealed two rather stable periods separated by a third period of marked annual increase of app. 4% from 1991 to 1996 - probably induced by a mixture of new technology, management measures and biological factors. We did not attempt to quantify the overall temporal trends in CPUE for the long line fishery. In this investigation we limited ourselves to exploring the partial contribution to the CPUE trends from three single technological innovations: the global positioning system (GPS), the swivel line SL) in combination with skewed hooks (SH). The results were subject to uncertainty and most likely heavily biased. We therefore hesitate to conclude anything more, than that the analysis indicates that the introduction of the GPS and the SL-SH in the long line fishery have had a significant positive effect on the CPUE of the main target species cod and haddock.

Discussion:

WGFTFB acknowledges that the quantification of technological creep, as has been done in this study, is new and important for fishery management.

The question was raised whether hook style in longlining is important in relation to technological creep. Studies have indeed shown that this is an important factor (e.g. for pacific halibut).

6.2.2 Faroese case study on technological efficiency. Bjarti Thomsen, Faroes

The Faroese management system that is based on effort limitation (fishing days allocated to vessels) raises the question whether the efficiency of a fishing vessel increases over time. From logbook data and additional information from vessel owner and skippers examples of efficiency changes has been demonstrated. The logbook data series includes 45.986 hauls in the period from1985 to 2002 for eight identical trawlers 37.7 m long and with an engine power of 1200 HP. The vessels operated as single trawlers for a couple of years, but were then converted to pair trawlers. The fuel consumption decreased from more than 3000 liter per vessel per day to 2000 liters while the catch per vessels was maintained. An additional 15% saving was on gear expenses. This is an example of efficiency increase without exerting more pressure on fish stocks. When comparing the catch per hour of saithe and cod in relation to the respective stock size it is seen, that the effort has shifted from saithe towards cod and then back again. The pairs that are most efficient on saithe are less efficient on cod and vice versa. From the early 1990'ies there was a systematic increase in tow length for all vessels. For one pair the increase is substantial and maintained, while another pair has decreased the tow length to previous levels. The increase in tow length increases the hours fished per day, but the trade of between tow length and fish quality presumably limits further increases. According to skippers the tow speed has increased over the years from around 3 knots to around 4 knots. This increases the swept area considerably. This information was not reflected in the logbook data. According to the vessel owner the symmetry sensors on the trawl is the single electronic aid that has been most beneficial to the fishing. However, when comparing pairs using index on CPUE and the time for introducing the sensors, no effect could be found. One new pair of trawlers has replaced old ones and has been in operation in 2003. The new vessels have similar size and power (38m, 1305HP) but the bollard pull has increased considerably (12 tons on old vessels, 19 tons on new vessels). Comparison of old vessels to new vessels show a 47-48% increase in catch per day and a 41% increase in number of fishing days, which result in a 100% increase in total catch per vessel in 2003. It is concluded that efficiency changes are difficult to access without going into economics, as effort changes toward species according to availability. In the Faroese case, the efficiency increase is not as much from increase in catch per hour (CPUE) as from increase in hours fished (effort). There is no simple formula to compare the efficiency of old and new vessels.

Discussion:

It was suggested that the increase in towing time could have been a direct response to the management regime (effort restrictions). The data however showed that this event happened earlier. It was also questioned whether fishermen could maintain the same price for the fish if a longer towing time produced a catch with a lower quality. The author stated that there seems to be a trade off: longer towing time, lower quality and lower price. One pair of vessels may have responded to that problem because later in the time series the duration of the hauls is decreasing again.

6.2.3 Irish case study on technological efficiency: A comparison of twin rig trawling and single rig trawling in terms of relative fishing efficiency. Dominic Rihan, BIM, Ireland

Under the Irish Government's Whitefish Renewal Scheme's of 2000 and 2002 a number of new demersal vessels have entered the Irish fleet. The introduction of these vessels has, however, raised a number of questions in that while overall tonnage and horsepower has not increased above permitted EU levels, the overall fishing efficiency and also the effort required to maintain viability has more than doubled. In particular the use of twin-rigs for species such as *nephrops* and demersal species such as monkfish and megrim by these new vessels has attracted many critics, who say it is too effective and indeed a wasteful form of fishing. The "over-efficiency" arguments against the use of multi-rigs are well documented, and in Ireland due to increasing operating and gear costs and also a chronic shortage of qualified crew some of the bigger operators who have been working twin-rigs for mixed whitefish species, have begun to investigate the possibility of returning to fishing with a single trawl to reduce costs.

The findings of this study suggest that, for this sector of the Irish fleet encompassing around 19 vessels, a return to single-rig trawling has some obvious advantages, particularly in terms of fuel and other cost savings but there will be a corresponding loss of earnings, which from the results from these two vessels surveyed averages out at 16%.

Extrapolating from the fuel savings and the indicative reduction in gear and crew costs, showed the reduction in gross earnings to be almost negated on one vessel. On the other vessel due largely to lower fuel costs and higher prices for monkfish at the time of the first part of the study the reduction in earnings was much higher.

The differences in earnings also reflect the different strategies adopted by the vessels when reverting to single-rig trawling, and in this respect there is no doubt that when monkfish are the main target species the twin-rig has a significant advantage over the single rig. The over reliance on this species, however, raises serious questions and it is fully accepted by all of the operators in the twin-rig sector that there is a need to diversify to other species.

In terms of relative fishing efficiency twin-rig gear has an advantage in terms of swept net area but again this is largely counteracted by the fact that much longer bridles can be worked with a single net, giving a larger swept door area. Towing one net also had the added advantage of increasing the effective fishing time by up to 3 hours per day, equivalent to 4 complete tows a trip.

Discussion:

It was mentioned that efficiency is often looked at in terms of amount of fish caught but the reality is economics. More fish does not always reflect a better income and the factor “costs” should be taken into account.

The question was raised whether the earnings mentioned in the report were gross earnings. The author responded that this was indeed the case. The data on profits are available but not analysed yet.

It was noted by the Chair that in a business context, profit is the main economic driver as opposed to gross revenue.

6.2.4 General discussion

It was stated that the issue of technology creep has significant importance to scientists as well as managers. Managers currently use a unit of effort (KW days) that does not include any measure of technological creep and this needs to be addressed.

The report presented is a good first step to addressing this issue from a WGFTFB perspective. It seems to be the first attempt to handle this topic in a comprehensive way, although it was stated by the conveners that it is not a “critical review” by any means.

The TOR and its justification were thought very narrow in their interpretation of efficiency increase and the question was raised as to whether the Group had fulfilled the TOR correctly with the report presented. This was on the basis that it had included economic factors as well as changes in CPUE, not included in the original TOR. It was felt by the conveners that economics are an important consideration in this area as from a fishermen’s perspective they are the major factor and it was impossible to ignore them. One of the conveners remarked that as the review continued it appeared that the issue of efficiency was much broader than the original justification. He felt that the TOR had indeed been addressed correctly, and the WG members endorsed that the review does answer the question if increase in efficiency undermines management goals. Comments were also made on the need for a good definition of fishing efficiency and technological creep and also for a standardised methodology as the studies reviewed used varied models and approaches.

It was felt that this report is highly relevant to the new role that FTFB and FTC are trying to develop within ICES and provides opportunities to spread expertise to other committees and sub-group. The remark was made that this issue was of global concern but there is general uncertainty on how to address and the WGFTFB needs to be pro-active in this respect, using its collective knowledge to fill gaps and encourage dialogue. Again it was stated that the WGFTFB does not have full competency in this area and a group including socio-economists, biologists and modellers needs to be formed to work collaboratively.

There was a recommendation by the Chair that this report be made into a co-operative research report. The majority of the WG supported this, although one of the conveners felt that this report had not really identified anything new in the field; rather provide a review of existing knowledge.

7 Topic: Evaluate the effect of fishing gears on the seabed with special reference to mitigation measures in mobile gears and the effects of stationary gears on sensitive environment

Convener: Pingguo He

7.1 General overview and presentation of principal finding

This TOR was introduced by Pingguo He. An overview was given of recent studies in this field; a summary report has been written and added to this report in (Annex 4)

7.1.1 Terms of reference

Evaluate the effect of fishing gears on the seabed with special reference to mitigation measures in mobile gears and the effects of stationary gears on sensitive environment.

The following work items for this report were proposed and adopted at the WGFTFB meeting in Bergen, Norway, June 2003:

> *The effect of bottom tendering towed fishing gears on the seabed has received considerable attention in recent years. While it is important that the effect be quantified, studies to reduce the effect should be encouraged and strengthened. Members of WGFTFB will summarize and review previous works and discuss current status on the effect of towed gears such as bottom trawls and dredges and will put special emphasis on mitigation measures to reduce the effect through modification of gear designs and operational methods. In addition, the members of WGFTFB will summarize and review possible effects of stationary fishing gears including but not limited to gillnets, longlines, traps and pots on sensitive environments such as coral reefs, sea mounts, near shore communities and mollusc beds and will evaluate current status on the subject.*

7.1.2 Abstract

Bottom-tending mobile fishing gears such as otter trawls, beam trawls and shellfish dredges alter the physical structure of the seabed though their impacts on benthic communities and ecosystems vary with sensitivity and natural disturbance of the seabed, among other factors. While more research is needed to quantify various impacts of different fishing gears used in different fisheries under different fishing ground conditions, technical measures to reduce seabed impact are encouraged. This report summarizes such measures and ongoing research projects with the potential to reduce physical impacts on the seabed as well as negative effects on benthic communities. In general, measures that improve fishing efficiency can reduce fishing time and seabed impact in strictly enforced output-controlled fisheries. Also, alternative gears with less seabed contact may be used instead of traditional bottom-tending gears in some fisheries. Gear modifications which have less seabed effects include measures to reduce the seabed contacting areas/points of trawl footgears, the use of semi-pelagic trawls for shrimp, the provision of dropout aft-belly openings in beam trawls, the adoption of "sweepless" trawls for whiting, and "wheeled" footgears replacing rockhoppers. Electrical stimuli may be employed in beam trawls to replace traditional heavy tickler chains for some species, and the use of electric pulses in scallop dredges has also shown promise. Some novel gears which have potential for reducing seabed impacts include the "Active Trawl System", the "Auto-trawl" system, and the use of kites and depressors in trawls, although some of these gears are in the early stages of development. It should be noted that some technical measures described in the report may have other negative or positive outcomes in additional to potential for reduction of seabed impacts. Caution should therefore be taken in recommending or implementing their use in specific fisheries.

7.1.3 Participants:

Pingguo He (USA, Chair)
Paul Winger (Canada, Rapporteur)
Ronald Fonteyne (Belgium)
Michael Pol (USA)
Phil MacMullen (UK)
Svein Løkkeborg (Norway)
Bob van Marlen (Netherlands)
Thomas Moth-Poulsen (USA)
Kristian Zachariassen (Faroe Islands)
Antonello Sala (Italy)
Wilfried Thiele (FAO/Italy)
Ulrik Hansen (Denmark)
Eduardo Grimaldo (Norway)

The above WGFTFB members participated in discussions on 20 April 2004 at the Working Group meeting held in Gdynia, Poland and drafted the report. The full draft report has been attached as an Annex 6. The following conclusions and recommendations were reviewed and approved by WGFTFB on 23 April 2004.

7.1.4 Conclusions and Recommendations

- Bottom-tending mobile gears have an effect on the seabed. Impacts are poorly understood and documented in many fisheries. Research into fishery-specific impacts on the seabed must continue.
- The group has identified a number of technical measures available or in development, such as semi-pelagic trawls, drop-out windows and electrical stimuli in beam trawls, and ground gear modifications. Many of these offer potentially powerful means of mitigating seabed impact. These research and development efforts should continue with an additional focus on their commercial application.

- The measures identified largely reduce apparent impact but few studies include quantifiable measurements. Seabed impact indicators are needed to help gear technologists to evaluate the effectiveness of mitigating measures. WGFTFB should seek advice and input from other groups such as WGECO to define practical indicators of seabed impact in different fisheries.
- In a strictly-enforced output-controlled management regime, impacts on the seabed can be reduced through the development of methods that improve efficiency, such as detailed mapping and changes in fishing practices.
- Techniques for the mitigation of seabed impacts by mobile fishing gears outlined in this report are intended as a review of the current state of knowledge. Progress in assessment and mitigation of bottom impacts should be evaluated and reported to WGFTFB on a regular basis.

Discussion

The impacts of passive gears were considered. Some comments claimed that passive fishing gears like traps and gill nets had little impact except in very sensitive areas with high ecological importance. If this were the case then for most cases, further studies on passive fishing gear would not be necessary. There was, however, no agreement on this and it was accepted that little relevant and conclusive research had been undertaken.

The question was raised as to whether this topic was concluded or should be continued. It was agreed that the uncertainty relating to the subject area, and the recommendations for consolidating its definition, meant that it should be kept open. It was a topic of potentially great importance and public interest so WGFTFB should both follow and support the changes in the science and the ongoing research. The work area could also be included as a separate header in the national reports of FTFB and it was proposed that the group's report should be worked up to a cooperative research report although the conveners stressed that the report produced is not a final and that any additional comments or studies not included were welcome

7.2 Individual Presentations

7.2.1 Overview of the status of gear impact studies. Svein Løkkeborg, Institute of Marine Research, Bergen, Norway

Concerns about the impacts of towed fishing gears like trawls and dredges on benthic habitats and organisms have increased over the last two decades. The rationale for this concern is that benthic habitats provide refuge for juvenile fish and the associated fauna comprise important food sources for demersal fish. Few general conclusions have been drawn on the responses of benthic communities to impacts from trawling disturbances. This lack of knowledge is due to the complexity and natural variability of these communities, and the fact that it is very difficult and demanding to conduct this type of studies. Here I review the most recent experimental studies on impacts of towed fishing gears on benthic communities. Generally these studies have important caveats due to limitations in the methodologies applied, which have not been taken into account in previous reviews. Thus this review also presents a critical evaluation of the methodological deficiencies of impacts studies, and accordingly interprets the results from these studies with caution.

Trawl impacts are investigated either by conducting experimental trawling and assessing the responses of the benthic community or by using historical effort data and comparing fishing grounds subjected to low and high fishing intensities. The former approach provides exact data on the disturbance regime but do not replicate real fisheries, whereas the latter method seldom provides suitable control sites. The methodology applied in impact studies should ideally fulfil three important requirements: trawling disturbance at a spatial and temporal scale representative of commercial fishing, replicate control sites and quantitative sampling. The most serious shortcoming in impact studies may be confounding effects due to lack of replicate controls.

Otter trawls, beam trawls and scallop dredges are likely to have different physical impacts on the seabed due to their different catching principles. The most noticeable physical effect of otter trawling is the furrows (up to 20 cm deep) created by the doors, whereas other parts of the trawl create only faint marks. Beam trawling and scallop dredging cause a flattening of irregular bottom topography by eliminating natural features such as ripples, bioturbation mounds and faunal tubes.

The most serious effects of otter trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna where erected organisms such as sponges, anthozoans and corals were shown to decrease considerably in abundance in the pass of the ground gear. Experimental trawling on sandy bottoms of high seas fishing grounds caused declines in some taxa. However, the disturbances did not produce large changes in the benthic assemblages as these habitats may be resistant to trawling due to natural disturbances and large natural variability. Studies on impacts of shrimp trawling on clayey-silt bottoms have not demonstrated clear and consistent effects, but potential changes may be masked by the more pronounced temporal variability in these habitats.

Long-term effects of beam trawling and scallop dredging have not been investigated, but several studies provide clear evidence of short-term effects. Intensive disturbance has been shown to cause considerable reductions in abundance of several benthic species. Trawling disturbance caused no effects in areas exposed to natural disturbances, e.g. wave actions and salinity fluctuation.

It can be concluded that our knowledge of impacts of towed fishing is still rather rudimentary. The difficulty of conducting impact studies leading to clear conclusions is mainly due to the complexity and natural variability of benthic communities.

7.2.2 Progress in reducing seabed impact of beam trawling in the North Sea

7.2.2.1 Netherlands - Bob van Marlen, RIVO, Ijmiuden.

A number of comparative fishing trials were carried out in 1999 on research vessels "Isis" and "Tridens" to investigate the effect of cutting large meshes in the lower panel just behind the footrope Such drop-out panels were effective in reducing bycatches (varying from 10% to 26%). Particularly the heavier type of benthic species such as quahogs could be released, but the penalty was a loss in marketable flatfish.

Two different alternative tickler chain configurations were tested, i.e. a <u>parabolic</u> and <u>parallel</u> arrangement. The landings (target fish species above the minimum landing size) were about the same with the <u>parabolic</u> chain configuration. For all three gear tests with the <u>parallel</u> chain configuration the landings ratio was smaller than 100%, ranging from 77%–89%. Most noticeable was the reduction in sole catches for the modified gear, particularly the marketable sized to about half of those of the conventional gear. Parallel chains offered more potential in reducing bycatches (undersized target species, non-target species, benthos, particularly shellfish), but losses in commercial flatfish occurred, and when combined with net ticklers, the system generated a higher direct mortality of invertebrates, i.e. 54%.

A 7 m prototype pulse trawl was tested thoroughly in 1998 and 2000. The gear was scaled up to 12 m and re-designed to ease production and lower investment costs in 2000. The catches of the pulse trawl for all commercial marketable species taken together were about 70% that of the conventional beam trawl. The pulse trawl caught about the same or slightly more sole. About 50% of plaice were caught compared to the conventional gear. The electrified trawl caught significantly less benthic invertebrates per hour than the conventional 7 m tickler chain beam trawl, by 45% for all species added together

7.2.2.2 Belgium - Ronald Fonteyne and Hans Polet, CLO, Oostende

Flatfish beam trawling

In the flatfish beam trawl fisheries the bycatch by weight of invertebrates is several times the amount of marketable fish. In order to reduce the impact of beam trawling on the benthic communities a number of benthos escape modifications to the trawl were tested. A drop-out opening (escape zone without netting) and large diamond and square mesh escape zones just behind the groundrope were not effective in releasing the benthos bycatch and induced an unacceptable decrease in commercial catch. Square mesh windows inserted in the belly just in front of the codend were more promising. With these devices a significant reduction in weight and number of most benthic species could be realized. The penalty is some loss of commercial catch but the results indicate that with an appropriate mesh size in the square mesh window a balance may be found between a significant benthos bycatch reduction and an acceptable loss of marketable fish.

Shrimp (Crangon crangon) beam trawling

Most selectivity enhancing measures concentrate on the net part of the trawl. These aim at catch separation or improved filtering of the catch, the disadvantage being that the animals are exposed to net meshes or other parts of the net before they can escape. Damage incurred by contact, or stress caused during the capture and escape process may lead to mortality amongst escapees. A better approach to improve selectivity, if at all possible, is to try to avoid unwanted sizes and species to enter the net. To attain this goal, it is necessary to find alternative means of stimulation in the net mouth, i.e. a stimulus inducing the desired reaction from the target species without stimulating unwanted animals. The idea in the present project was to use electric pulses to improve the selectivity of the shrimp beam trawl, i.e. reduce the discards while maintaining the target species catches. A suitable design of an electro-trawl reduces bottom contact of the groundrope and thus seafloor disturbance.

In a first phase of the project, detailed observation and survival tests were carried out as a preparation of the sea trials. These gave good basic information on the behaviour and survival of several fish and invertebrate species regularly caught in the brown shrimp fishery.

The sea trials demonstrated that a selective electro-trawl can be designed which shows no losses of commercial shrimps. The experiments indicated that a raised groundrope creates an escape route for most of the species regularly caught in shrimp trawls, and also for brown shrimps if no electric field is present. Future work should pay attention to the design of an electro-trawl with a larger net opening to fit long electrodes and a new type of bobbin rope with less bottom contact. Bearing this in mind, electric fishing should be a feasible alternative to the standard shrimp trawl and could be an acceptable alternative between the economic interests of the fishermen and the ecological demands of the marine ecosystem. On top of the reduction of discards, a reduced seafloor contact can be achieved with an altered bobbin rope.

7.2.2.3 England - Andy Revill, CEFAS, Lowestoft

Studies undertaken in the UK using benthic drop out panels in the English Channel beam fishery have been conducted since 2002. A variety of square mesh drop out panels have been evaluated (n=8). Square mesh panels fixed into the belly of a beam trawl just a few meshes in front of the cod end joining round; have proven to be the most effective (140–150 mm full mesh). Around 80% of unwanted benthic invertebrates are typically released from the beam trawls (fitted with drop out panels) and escapees exhibit a high survival rate. No loss of target species was observed with this simple technology and the panels have been piloted by one vessel for extended periods on a voluntary basis without problems. Fleet trials on a wider scale are to be initiated shortly throughout the UK Channel beam trawl fleet.

7.2.3 Reducing Seabed Contact of Trawling: Semi-pelagic Shrimp Trawling Experiments in the Gulf of Maine and in Newfoundland. Pingguo He, University of New Hampshire, USA

Shrimp trawling is one of the most important fishing methods in Atlantic Canada and the northeastern US. Shrimp trawling may alter physical and biological structure of the seabed as trawl doors and other ground gear components roll over the seabed. While effect of alteration on benthic ecosystem and fish/shellfish population may vary, reducing alteration to the seabed by fishing activities would be viewed positively by all concerned with the marine environment and fishery. This report describes two parallel projects to test feasibility of a semi-pelagic shrimp trawling system in the Gulf of Maine and in Newfoundland. The primarily control of the door height off the seabed was achieved through the shortening of warps. The height of the door was monitored through the use of door height sensors attached to the door. Preliminary results indicated that the semi-pelagic trawling system with trawl doors off bottom had catch rates of shrimp comparable to those of commercial vessels fishing on the same grounds when the trawl system was properly rigged and operated. Further experiments are required to design a more robust trawling system that will stay on the bottom and to establish water depth and warp length relations for various fishing conditions.

7.2.4 Development and use of sweepless trawl in the Gulf of Maine whiting fishery - Michael Pol and Daniel McKiernan, Mass. Div. Of Marine Fisheries, USA.

The goals of this project were to monitor an existing small-mesh fishery for whiting *Merluccius bilinearis* and to improve voluntary adoption of the sweepless raised footrope trawl. The sweepless raised footrope trawl is a semi-pelagic net developed as a modification of a raised footrope trawl. The ground gear of the sweepless net consists only of 1-m long “drop chains” attached at approximately 2.5 m intervals to the fishing line. It is presumed to have limited impact to the sea bed because bottom contact is reduced to the ends of the drop chains. Improved adoption was encouraged through two types of outreach: “changeover” trips; and a video. On changeover trips, an experienced fisherman modified a vessel's net during a fishing trip. Reaction by fishermen was limited and mixed. An edited video, produced in-house, described proper rigging of the net and its improvements over the raised footrope trawl. Reaction to the video was generally positive, although it is too soon to tell whether greater adoption will result. However, the sweepless net has been popular with resource managers and other gear scientists.

7.2.5 General discussion

The report was received by WGFTFB as a good quality report. Some discussion evolved around the question whether this topic should be maintained during the next few years. The public perception of this problem is very strong and fishermen are aware of the problem. WGFTFB seems to be a good forum to collect this information and a multitude of grey literature could get a wider distribution through this report. It was generally accepted that this topic could be continued during the next few years and that the report could each time be completed further. It was also suggested to make a website with relevant information on this issue but no agreement was made to actually go forward with this.

It was stressed that reviews in this field are often not critical as to the methodology of the studies. WGFTFB should be pro-active in this field and present a balanced view on the issue.

8 Topic: Evaluate the recent (last 5 years) codend mesh selection experiments dealing with bottom trawls used in the Baltic Sea for cod which used either turned meshes and/or BACOMA windows. With emphasis on estimating selectivity parameters, experimental design and modelling/statistical analyses

Convener: Erdman Dahm

8.1 General overview and presentation of principal finding

This TOR was introduced by Erdman Dahm. An overview was given of recent studies in this field and the report of the statistical analysis has been added to this report in Annex 5.

8.1.1 Terms of reference

Evaluate the recent (last 5 years) codend mesh selection experiments dealing with bottom trawls used in the Baltic Sea for cod which used either turned meshes and/or BACOMA windows. With emphasis on estimating selectivity parameters, experimental design and modelling/statistical analyses

8.1.2 Abstract

In this contribution a short history of the turned meshes concept was presented and information given about activities during 2003. A database of 161 valid hauls collected on research vessels has been collected in the meantime and provides a good opportunity to compare the selectivity factors obtained for turned meshes codends to others with improved selectivity as the Bacoma codend or other advanced selectivity improving designs. However, due to the unbalanced nature of data collected in the database there is still a large amount of variation in selectivity estimates for turned meshes codends. This was the reason for collaboration with an external statistical adviser from the Faculty of Mathematics of the Hamburg University. With his help it was possible to identify the quantitative role of different factors affecting the relation of mesh size to L50. Prominent factors among others able to be influenced voluntarily are yarn material, construction and size. These analyses are helpful for directing future research on the topic. Reference was made to positive practical results with turned meshes codends with regard to reduction of bycatch of undersized cod and good catches of large cod. Such codends are in use now since three years on two ships of the Polish commercial fishing fleet on a voluntary basis. There are a number of good reasons for continuing research on turned meshes codends in account of the fact that they will be able to cope with some of the problems encountered during the now longer lasting use of Bacoma codends (Unknown long-term behaviour of Ultracross, influence of repairs in the window on selective properties). However, the only partly understood effect of the mentioned factors onto the selective efficiency of turned meshes codends admonishes to caution before their general admission as legal alternative to the Bacoma codend. Though, a limited admission for turned meshes codends of single yarn PE may be possible. Hence, such admission was as well recommended as a repeated evaluation of the augmented database. In addition, a short term program to clarify influence of the mentioned prominent factors was requested.

8.1.3 Participants

Erdmann Dahm (Germany, Chair)
Waldemar Moderhak (Poland)
Daniel Valentinsson (Sweden)
P-O Larsson (Sweden)
Harald Weinbek (Germany)
Andrzej Stepnowski (Poland)
Ulrik Jes Hansen (Denmark)
René Holst (Denmark)
Haraldur Einarsson (Iceland)
Eduardo Grimaldo (Norway)

8.1.4 Conclusions and Recommendations

- Carry out an analysis of all available T90 data that takes into account all identifiable sources of fixed (e.g. gear specific information) and random variation.
- Make a statistical comparison of the selectivity of turned mesh and Bacoma codends.
- The working group acknowledges the potential benefits of turned mesh codends.
- Participation at a short-term research program to clarify remaining questions on influence of yarn material, yarn construction and attachment ratio to diamond meshes is strongly supported

8.2 Individual Presentations

8.2.1 Performance of codend and belly sections in 90 degree mesh. - Ulrik Jes Hansen, SINTEF, Hirtshals, Denmark

This paper describes a series of tests conducted in the SINTEF Flume Tank with different designs and constructions of codends. The principal aim was to disclose the performance of a codend where part of the netting was turned 90^0 (called T90) and compare it with codends made from netting stretched in the normal direction. Measurements of cross section, water flow, and turbulence were taken and the dependency of towing speed and catch size was determined. It is concluded that the T90 codend must be superior to standard codends in many ways: preservation of fish quality, selectivity, survival rate of escapees, efficiency and strength.

Discussion

The questioned was posed what would happen to the mesh shape if catches become larger. According to Ulrik, no additional closing of the meshes occurs.

The comment was also made that a possible difference in survival of escapees and discards from both types of codend cannot be assessed because there are no data. So T90 and Bacoma cannot be compared in these terms.

8.2.2 The engineering aspects of the mesh shape and codends made of turned meshes. - Waldemar Moderhak, MIR, Gdynia, Poland

Selectivity is mainly defined in an empirical way. Finding proper selective codends construction for particular fish species can be supported by theory. On that way it is possible to adopt some engineering theory to determine faster the proper material and twine of codend netting and construction for protection of fish juveniles. In active fishing, e.g. trawl fishing, the meshes of the codend are subjected to the mechanical and hydrodynamic forces and moments from water moving through the meshes. Depending on the positioning of meshes to the water flow, the hydrodynamic forces act on particular mesh bars to either close or open the mesh, thus decreasing or increasing opening of a meshes and selectivity. All technical phenomenon’s taking place during towing of different construction codends with different features bring about their different shape and mesh opening. Those effect in a different selective properties and catch abilities of particular codends construction.

The paper presents technical explanation of different properties of meshes and codends turned 90°.

Discussion

It was commented that T90 codends have better strength properties and that the same conclusion was drawn from the Danish tests by Ulrik Jes Hansen. Also the water flow in a T90 CE is higher compared to a conventional diamond mesh codend but it is unclear whether this would have an influence on the escape opportunities for fish.

8.2.3 A review of recent experimental results with the BACOMA codend. Daniel Valentinsson, Vesa Tschernij and Per-Olov Larsson, IMR, Sweden

In April 2003 the Baltic cod trawl fishery was temporarily closed by the EU commission due to reports on massive discarding in the fishery. The main reason for the high discarding rate was an increase in minimum landing size for cod (35 to 38 cm) without a corresponding change in gear selectivity. Two alternative codends were allowed in the fishery, a traditional 130 mm diamond mesh codend and a 120 mm square mesh window codend (Bacoma model). In theory, the two alternatives shall have similar selective properties. However, all Swedish vessels used the diamond mesh alternative. The objectives of this study were to evaluate why the diamond mesh codend was preferred and what Bacoma window codend mesh size show better correspondence to the new minimum landing size. A total of 77 hauls were performed using two commercial twin-trawlers during March and April 2003.

The results clearly show that the massive discards could be explained by the ease to legally manipulate the selectivity of the traditional diamond mesh codend. Comparative trails between a legally manipulated 140 mm diamond mesh and the 120 mm Bacoma window codend showed that the loss of legally sized cod when using the Bacoma alternative was estimated to around 60% in numbers. The resulting short-term economic loss may explain why the fishermen preferred the diamond mesh codend. Based on the present results together with previous results from the Bacoma project we recommended banning the use of diamond mesh codends due to the susceptibility to manipulations that reduce selectivity. The present results further indicate that the mesh size of the Bacoma designed escape panel should be reduced from the legislated 120 mm to around 110 mm in order to harmonise the selectivity and MLS and thereby reduce the incentives for manipulation of gear selectivity.

Discussion

The author was asked if he knew of any illegal handling of the Bacoma codend. He replied that he has no clear indications but this may be the case.

The comment was made that it is very important to be able to control all variables of the codend. For example, in Scotland, lifting bags are banned. Controlling all variables allows reducing the possibilities of reducing selectivity by fishermen. In relation to this remark, it was said that there is a revolution in yarn development. New yarns can have a detrimental effect on the selective properties of a net.

8.2.4 General discussion

For the statistical analysis, an alternative analytical method has been used. The comment was made that the analysis does not follow the methodology laid out in the ICES Selectivity Manual, it lacks good procedure as concerns the variance component of the data. The Polish theoretical calculations indicated that the 110 mm Bacoma equals a T90 codend of 105 mm for single PE twine. For PA not enough data are available. After a thorough discussion, it was accepted that a new analysis should be carried out along the standardized procedures. This was endorsed by WGFTFB. A further comment was made that selectivity calculations alone are not enough. We should take all problems with the different codends into account because you may end up with a codend with good selective properties but having a lot of practical problems. Restrictions should also be formulated to make T90 meshes perform well (e.g. twine thickness, yarn constructions, meshes on the circumference…). Estimation of the influence of such factors should be taken up in the analysis. From flume tank modelling, the fractional mesh opening of the turned mesh is higher when compared to diamond. Tests indicate that the mechanical strength properties of turned mesh are better when compared to traditional diamond. However, flume tank modelling may be required later to determine the optimum joining rate between normal and turned mesh netting, a number of presenters noted that a straight joining ration of 1:1 was not appropriate, particularly if the extension was constructed from normal netting and the codend from turned mesh, this may also have implications for EU regulations pertaining to codend circumference definitions. It is also important to note that a number of commercial fishing vessels are using turned 90 netting on a voluntary basis. The statement is made that we know that there are constructional benefits to the T90 codends.

Following people will carry out the statistical analysis: Norman Graham, Rene Holst, Waldemar Moderhak and Barry O'Neill. The results will be presented to the Fisheries Technology Committee at the next ASC meeting.

The question was raised how many of the data presented are from research and commercial vessels. The convener replied that the data for the T90 meshes were mainly from research vessels. The comment was raised that advice for the industry cannot be taken from RV data and that this has been proved in the past (e.g. Wileman's Selectivity Data Review). The convener does not share the opinion that there is a systematic problem with RV data. The statement was also made that we need more data on the T90 codends. The Chair concluded that advice should be formulated during this meeting or shortly after and the advice now can only be based on the available data but the problems involved should be clearly mentioned.

The topic group identified and utilised an alternative analytical approach to the assessment of the turned mesh codend data, and identified the primary factors affecting selectivity. However, it is important to determine which mesh size of turned mesh gives similar selection parameters to the current legal configuration (105 mm diamond + 110 mm Bacoma window). This has been concluded by the topic group and has coincidentally been received as a specific request from the International Baltic Sea Fishery Commission (IBSFC), see Section 11.6.

9 Study Group on Unaccounted Mortality (SGUFM)

Mike Pol (USA) and Andy Revill (UK)

A Study Group on Unaccounted Fishing Mortality [SGUFM] (Chair: Mike Breen, UK, m.breen@marlab.ac.uk) has been established to:

a) consider issues relating to the sources of fishing mortality other than those that can be accounted for by the reported catch;

b) report on the current knowledge of unaccounted mortality; and

c) review and make recommendations on methods used to estimate escape mortality from towed fishing gears.

The priority for 2004 is data gathering. The work plan for the next three years includes gathering all available information on each sub-component of unaccounted fishing mortality, conducting workshops in 2005 and 2006 that will review escape mortality (F_e) methodologies and define the relative impact of each component of unaccounted fishing mortality for key fisheries / capture methods. Progress reports will be made to FTFB in 2005 and 2006 with a final report planned for April 2006 on methodologies for escape mortality experiments. The final overall report is planned for December 2006. This report will summarize available data on each sub-component; provide sources and magnitude of unaccounted mortality, estimates of survival, and mitigation measures. An overview of the relative impact of each subcomponent for key fisheries / capture methods will also be included.

The group is currently recruiting volunteers from a variety of disciplines. The expertise of FTFB members is requested for data gathering, workshop participation, information on discard mortality and illegal and misreported landings, and to inform the group of relevant data in the grey literature, of ongoing projects and of anecdotal evidence. The Study Group will report its progress to the 2005 and 2006 WGFTFB meeting. The Chair is requesting volunteers to contribute to the Study Group – experts from different fields but also from the WGFTFB.

Discussion

The importance of this work was stressed in relation to targeting technical fishing gear studies. It helps in identifying where the problems are and what we should focus on with selectivity studies.

The 2004 SGUFM report can be found at: http://www.ices.dk/reports/FTC/2004/SGUFM04.pdf

10 Summary of Posters and other presentations

10.1 Measuring the correct mesh size – The OMEGA project. Ronald Fonteyne, CLO, Oostende, Belgium

The objective of the OMEGA project is to build and test a new objective mesh gauge suitable for fisheries inspection, fisheries research and the fishing industry, netting manufacturers and net makers as well as fishermen. The project is part of a strategy to improve the measurement and control of the minimum mesh size. The achievement of this project will be a new, modern mesh gauge capable of making unambiguous measurements unbiased by the operator and acceptable to courts.

A prototype is now being tested by a large group of future users. These test are being performed in the laboratory as well as at sea. Comparisons with the present wedge gauge and the ICES gauge will be made. The OMEGA gauge will become commercially available in the spring of 2005. The project is co-financed by the 5^{th} Framework Programme of the European Commission.

Discussion:

The comment was made that one of the issues on the standardization of surveys is comparing gear. This instrument can be a handy tool to facilitate this.

10.2 Development of an experimental method for quantifying the resistance to opening of netting panels. A. Sala, F.G. O'Neill, G. Buglioni, G. Cosimi, V. Palumbo and A. Lucchetti, CNR, ISMAR, Ancona, Italy

In recent years, there has been a tendency, in some sectors of the fishing industry, towards the use of thicker and stiffer twines in the manufacture of netting materials. Previous work has shown that the use of such netting increases the mesh resistance to opening and consequently reduces the selective performance of fishing gears. The main twine characteristic that contributes to mesh resistance to opening is the flexural rigidity of the netting twine. This poster presents an experimental method of measuring twine flexural rigidity. Thus it will be possible to use twine flexural rigidity as an explanatory variable in selectivity studies and also include mesh resistance to opening in mathematical models of commercially fished codends.

Discussion:

The question was asked if experiments are planned to investigate the effect of rigidity on selectivity. The author replied positively and stated that different codends with the same mesh size but with different rigidity will be tested. A remark was made that other experiments have already shown that PA is more selective than PE.

The author was asked if the new instrument could be used with T90 meshes to know what material would be best to keep the meshes open? This should be possible.

10.2.1 Recent selectivity research conducted at the University of Tromsø. Eduardo Grimaldo

10.2.1.1 By-catch excluding devices in the Norwegian coastal shrimp fishery

The study assessed to different types of bycatch excluding devices to be used in the Norwegian coastal shrimp fishery. This work was based on determining the shrimp retention capacity, and the fish escapement properties of an aluminium grid and a high density polyethylene (HDPE) grid. Factors like water flow and inclination angle were monitored and later analysed to determine their influence on the grid performance.

10.2.1.2 Combined selective system to reduce fish bycatch in the Norwegian shrimp fishery

This work is part of a research process based on the evaluation of a combined selective system to be used in the Norwegian shrimp fishery. Here, the joined performance of a plastic grid and two exit Windows attached laterally to the selective section has been tested. Measurements of water flow and inclination angle were recorded to establish their influence on the performance of the grid. Moreover, an underwater camera was attached to the grid section to observe the fish behaviour inside it.

10.2.1.3 Comparative selectivity of 55 mm flexi-grid and 130 mm/145 mm Exit Windows.

Experiments were carried out to compare the selective properties of Exit Windows (130 mm and 145 mm) and sorting grids (flexi-grid, 55 mm bar spacing) in the cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) fishery in the Barents sea. The codend configurations tested were: a) 135 diamond mesh, b) two 130 mm exit windows placed laterally, c) one 145 mm exit window placed on the upper panel, d) two 145 mm panel placed longitudinally on the upper panel and e) a 55 mm flexi-grid. The results showed that the L50 for the codends fitted with exit windows were higher than for the codend with the flexi-grid. Underwater observations gave valuable information regarding fish escapement behaviour in relation to the different codends tested.

11 National reports

11.1 Belgium

Agricultural Research Centre Ghent - Sea Fisheries Department
R. Fonteyne and H. Polet

Selectivity and discards reduction of shrimp beam trawls

The study on the development of environment friendly fishing methods for brown shrimp (*Crangon crangon*) in the Belgian coastal waters was concluded. The discarding problem has been quantified, its biological and economical consequences estimated and sorting grids, sieve nets and alternative stimulation (electric pulses) have been tried as technical means to reduce discarding. All results on the shrimp work of the last seven years have been collected in a PhD thesis and has been published.

Reduction of cod bycatches in beam trawls

In the frame of the EU Cod Recovery Plan, the technical measure for beam trawls – a large mesh panel in the front part of the top panel – has been evaluated and found to be not very effective for whiting and poor cod in small beam trawls. For larger beam trawls, having a large mesh panel stretching further back in the net, bycatch reduction is expected to be more pronounced. This was confirmed by experiments in a 4m beam trawl with a complete top panel in large meshes. In this case, the reduction of the whiting catch was doubled to almost 50%. Unfortunately, no sufficient numbers of cod were caught but it can be expected that this panel will not release significant numbers of cod.

The EU-project “Research on effective cod stock recovery measures” (RECOVERY) (Contract Q5RS-2002-00935) has been continued and aims at a reduction of cod bycatches. A series of trials have been carried out on the Dutch RV TRIDENS and on RV BELGICA with a lowered headline and a square mesh panel in the codend. The reduction of cod bycatch is low. Further experiments are planned.

Mesh measurement

The EU RandD and Demonstration Project "Development and testing of an objective mesh gauge" (OMEGA) started in September 2002 with SFD as co-ordinator. Research institutes and fisheries inspection services from Belgium, France, Germany, Italy, the Netherlands, Spain and Scotland are involved as well as a Belgian and a Dutch instrument maker. A test type was built and was evaluated. Subsequently a modified prototype has been built and will now be extensively tested in the lab and at sea by a large international group of future users, including netting manufacturers and fishermen. These tests were prepared at a Workshop held in Bilbao in October 2003. Details on the project can be found on the OMEGA website www.dvz.be/omega.

SFD also co-ordinated the activities in the frame of the ICES Study Group on Mesh Measurement Methodologies. The final SG meeting (Oostende, 19–21 March 2003) was attended by scientists, fisheries inspectors and representatives from the industry (netmakers) and the EU. Based on mesh size measurements made with different measuring forces a new standard measuring force was defined. A recommendation for a new mesh measurement methodology was made. An ICES Cooperative Research Report was written and will be published later this year.

Balancing Impacts of Human Activities in the North Sea

The sustainable management of the North Sea is a very complex theme due to the interaction between the social, economic and ecological dimensions of the use-functions of the Belgian part of the North Sea. A project (Balancing Impacts of Human Activities in the North Sea – BALANS) was started aiming to develop a first conceptual balancing model "Sustainable Management of the North Sea" for the policy makers and the users of the North Sea. The purpose is the correlation and the balancing between the different social, economic and social dimensions, through the elaboration of indicators, via the development of a conceptual policy model. As this type of research concerning the marine environment is still in an embryonic phase, the research boundaries are strictly limited to the use-functions sand- and gravel extraction, fisheries and related shipping.

11.2 Canada

Stephen J. Walsh

11.2.1 Northwest Atlantic Fisheries Centre, Newfoundland

Activities in 2003

Fisheries and Oceans Canada, Fisheries Management Branch, St. John's, Newfoundland and Labrador, Canada.

Reducing Capelin By-Catch in the Northern Gulf of St Lawrence Shrimp Fishery:

The bycatch of Capelin and juvenile groundfish that pass between the bars of the Nordmøre Grate in Shrimp Trawls is high when the fishery begins each year. To reduce the bycatch, experiments were carried out to test the effectiveness of a 1.5 meter x 1.5 meter 80-mm square mesh panel inserted into the top of the lengthening piece directly behind the Nordmøre grate. Also, experiments were carried out to compare the effectiveness of 50-mm square mesh codends mesh to the traditional 40-mm diamond mesh codend.

Assessing Juvenile Turbot By-Catch in Shrimp Trawls:

The bycatch of juvenile Greenland Halibut (Turbot) that pass between the bars of Nordmøre Grates in Shrimp Trawls is high in some areas of the Northeast of Newfoundland and Labrador. Two, 20-meter shrimp vessels carried out two fishing trips, comparing the effectiveness of Rockhopper and Roller footgear to reduce the bycatch of juvenile Turbot. Both vessels completed a third trip comparing shrimp trawls rigged with 120-cm toggle and chains to the standard 71-cm toggle and chains.

Plaice By-Catch in the 3PS Hook and Line Cod Fishery:

The bycatch of American Plaice, a species under moratoria, is high in the Cod hook and line fishery of the south coast of Newfoundland. To reduce the plaice bycatch, an experimental Hook and Line fishery was carried out on Burgeo Bank by two vessels to compare the amount of bycatch using #11, #12 and #14 circle hooks. The gear was set on the bottom in the usual manner and the # 12 hooks were also floated four feet off the bottom with gillnet floats. A second set of experiments were carried out comparing the bycatch levels in different water depths: under 50 fathoms, 50-60 fathoms, 60-70 fathoms, 70-80 fathoms, and greater than 80 fathoms.

Effect of Chaffing Gear on Cod-end Size Selectivity:

The catch of undersized (<30-cm) Yellowtail Flounder in otter trawls on the Grand Banks of Newfoundland is often higher than the 15% acceptable limit. Two fishing trips were carried out by a 30-meter stern trawler to compare the catch in codends without chaffing gear to that of codends with the traditional stranded poly rope chafing gear. During a ten-day fishing trip half the sets were made using chaffing gear while the remaining sets were conducted without chaffing gear on the codend.

Contact person: Gerald Brothers, Chief, Conservation Harvesting Technology, Fisheries Management Branch, Fisheries and Oceans Canada, P. O. Box 5667, St. John's, Newfoundland, Canada, A1C-5X1. Telephone (709) 772-4438, Fax. (709) 772-3628, e-mail: brothersg@dfo-mpo.gc.ca

11.2.2 Centre for Sustainable Aquatic Resources, Marine Institute of Memorial University of Newfoundland

P.O. Box 4920, 155 Ridge Road St. John’s, Newfoundland and Labrador NF A1C 5R3. Telephone: 1 709 778-0430; Fax: 1 709 778-0661

Snow Crab Discard Mortality:

This study investigated whether drop height and air exposure duration negatively influence the survivorship of under-sized male crab discarded at sea. Both instant and delayed mortality were found to increase with increasing drop height and exposure duration, indicating that mishandling of discarded crab can have a substantial effect on the future resource.

Contact Scott Grant (Scott.Grant@mi.mun.ca).

Codpotting:

Sea trials in 2003 revealed promising results on the feasibility of capturing cod using pots. Large rigid pots (5’ x 5’) with circular funnels performed the best, averaging between 12 and 20 fish per set with a maximum of 76 fish harvested in one day from a pot. Preliminary tests on bait placement inside pots have also been conducted.

Contact: Philip Walsh (Philip.Walsh@mi.mun.ca).

Flow Dynamics:

Flow velocity was measured inside full scale 2-seam and 4-seam shrimp trawl sections in the vicinity of the Nordmore grid. The 4-seam design improved the volumetric flow inside the trawl and offered improved flow speed at the outlet of the funnel and the lower portion of the grid. Large reductions in flow speed behind the grid indicates that the use of additional grids for size sorting may not be a viable option. Bar shape and spacing did not appear to have any effect on gross flow.

Contact Carl Harris (Carl.Harris@mi.mun.ca).

Multi – Level Trawl for Northern Shrimp

Sea trials were conducted to identify the vertical distribution of shrimp and capelin using a multi-level trawl. Preliminary results indicated a size related vertical distribution with larger shrimp dominating the catch in the lower band of the trawl. Further sea trials are planned for the summer of 2004.

Contact: Harold DeLouche (Harold.DeLouche@mi.mun.ca).

Semi-Pelagic Shrimp Trawl

The goal of this project was to develop a fishing system that would allow the trawl doors to be fished off the seabed while the trawl maintained light bottom contact. The trawling system was designed and tested in the flume tank and then tested at sea. Using high aspect trawl doors, increased door spread was achieved with fewer warps out than the traditional towing system. Catch rates were comparable between experimental and traditional gears.

Contact: Harold DeLouche (Harold.DeLouche@mi.mun.ca).

Snow Crab Pot Selectivity

Detailed observations of snow crab behaviour were conducted under laboratory conditions to determine the escape behaviour of undersized pre-recruit crab. Preliminary observations indicate that escape diameter as well as the escape location significantly affect escape success. Sea trials are planned for the summer of 2004.

Contact: Paul Winger (Paul.Winger@mi.mun.ca).

Reducing By-catch of Vaquita Porpoise

Alternative harvesting methods are being tested in the commercial shrimp fishery in the Northern Gulf of California in collaboration with the Mexican government and academic institutions in an effort to reduce entanglements of the critically endangered vaquita porpoise. Various trap designs are being considered as an alternative to gillnets.

Contact: Philip Walsh (Philip.Walsh@mi.mun.ca).

Under the Ice Kite Technology

A new kite was developed for spreading turbot longlines under the ice in Cumberland Sound. Scale models were designed and tested in the flume tank and then tested full scale in the field. The final design was found to have a number of improvements over existing gliders.

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Herding behaviour of a survey bottom trawl

In the spring of 2003, the herding efficiency of the NAFC’s survey bottom trawl, Campelen 1800 shrimp trawl, was investigated using a combination of varying bridle lengths: the standard length, ½ of the standard length and twice the standard length. The experiment was carried out on the St. Pierre Bank and represents year 2 of the project. Target species are cod, yellowtail flounder and American plaice.

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Activities in 2004

Fisheries and Oceans Canada, Fisheries Management Branch, St. John's, Newfoundland and Labrador, Canada.

Energy Efficient Shrimp Trawl:

In the last decade the Total Allowable Catch (TAC) of Shrimp off the East Coast of Canada has grown from 40,000 MT. to over 150,000 MT. However, the price paid to fishermen has been reduced by 40%. This has resulted in some of the Shrimp TAC left in the water. Consultations with Shrimp fishermen, Shrimp Trawl Manufactures and government agencies has led to the development of energy efficient Shrimp Trawls to match the Horsepower of three vessels classes under 20-meters. An energy efficient Shrimp trawl with matching trawl doors will be constructed for each of the three vessel classes and tested during the 2004 Shrimp fishing season. The energy efficient trawls will include the use of thinner twines, larger mesh sizes, synthetic ropes instead of steel wire for the fishing lines and head rope, roller footgear instead of rockhopper, etc. The energy efficient shrimp trawls will be compared to the traditional trawls used by the fleet.

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Centre for Sustainable Aquatic Resources Marine Institute of Memorial University of Newfoundland, St. John’s.

In 2004, research initiatives in mobile gear technology are being directed toward:

- The reduction of seabed contact by bottom trawl gears
- The design and testing of a new multi-level shrimp trawl.
- Static gear research will focus on the design and/or improvement of pots and traps targeting snow crab, toad crab, blue shrimp, Atlantic cod, and Greenland halibut.
- Biological and behavioural research will focus on the live release of American plaice, intra-specific competition in snow crab, and the distribution and biology of several finfish species in northern Canada.

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Fisheries and Oceans Canada, All 4 Atlantic Science Institutes

Size selectivity and catchability of survey bottom trawls

In 2004, a series of comparative fishing experiments will be carried out utilizing all three survey bottom trawls currently used for annual resource assessment in Atlantic Canada. These experiments will involve using 2 research vessels towing side by side and will examine the selectivity and efficiency of all three bottom trawls. The goal is to consider the possibility of using one common survey trawl in the Atlantic region. In addition, the suitability of reducing 30 minute tows to 15 minute tows will also be considered. All 4 Atlantic Fisheries and Oceans Institutes will participate.

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11.3 Denmark, DIFRES, Hirtshals

Activities are mainly been embedded in internationally coordinated activities, with particular focus on selectivity in trawls addressed in EU funded projects started in late 2002.

A main objective of the EU funded project RECOVERY is to reduce catches of cod while maintaining catches of other economically important species in the North Sea mixed human consumption fishery. Initial trials were conducted with a Norwegian research vessel using sonar and camera systems to collect information on fish behaviour inside the trawl. Scale models of selective trawls were built and tested in a flume-tank located in Hull (UK) with participation of net makers and fishermen.

The objectives of the EU project SURVIVAL are to describe the escapement process by which undersized cod, haddock and whiting leave escapes from the trawl and to estimate the additional mortality rates for fish that escapes through the meshes. The studies require application of advanced techniques to sample escaping fish during various phases of trawling. The first experiments were conducted during August from the west coast of Scotland.

The EU project PREMECS II aims at developing a stochastic simulation model to assess the selective properties of codends in towed fishing gears. It is expected that these types of simulation tools will be increasingly important as a tool to design cost intensive field and flume tank experiments and verify experimental results. DIFRES will try to develop this area further in 2004.

A national project was conducted in collaboration with the Danish Fishermans organisation to develop selective trawls for the Kattegat and Skagerrak Norway lobster fishery. The at-sea sampling programme of DIFRES indicated a particular high discard rate in this fishery. Several selective devices were tested from a commercial trawler in August and September. The experiments will continue in 2004 where new selective devices will be tested. Furthermore mew series of experiments in Kattegat and Skagerrak area will be conducted within the EU project NECESSITY.

Apart from being directly incorporated into scientific advice on technical management measures, the results of gear selectivity projects were used in research projects that aim to describe and model fishery selectivity, addressing fishermen behaviour relative to gear selectivity, technological development, stock status and distribution as well as to economic and social considerations.

Research was conducted in a series of national and international projects to quantify and reduce the bycatch of marine mammals in Danish fisheries and to limit the impact of marine mammals on fisheries by means of technical gear modifications, the use of deterrent devices and changes in fishing tactics. DIFRES participates in the EU project NECESSITY concerning bycatch reduction of dolphins in pelagic trawl fisheries. A project financed by the Nordic Council of Ministers aiming reducing seal impacting on traps was initiated in 2003.

11.4 Faroe Islands

Ground-gear experiments

Experiments to reduce the impact on the bottom from trawl ground-gear continued in 2003. A new design of a gear was compared with a rock-hopper gear. Under-water video recordings showed that less sediment disturbance came from the new gear. The experiments will continue in 2004 where also the fishing efficiency will be compared.

Cod and Greenland halibut tagging

Since 1997, more than 21000 cod have been tagged on various locations on the Faroe Plateau. More than 6000 cod have been recaptured and stomach content from more than 1000 of these fishes has been analysed. This experiment provides valuable understanding of the migration pattern and feeding behaviour of cod on the Faroe plateau. Preliminary results were reported to the ICES 2003 Symposium in Bergen. A smaller scale tagging experiment on Greenland halibut and halibut was initiated in 2002. Totally 399 Greenland halibut and 53 Halibut have been tagged and of these 19 and 10 respectively have been recaptured.

Salmon and Monkfish tagging

In a Nordic project 112 post smolt and pre adult salmon were tagged in 2002 using data storage tags (DST). The aim was to study vertical and horizontal migration of salmon in the ocean. The salmon was caught and released in the open waters north of the Faroes using a purpose built surface trawl with the codend formed as a fish-cage. No tags so far have been returned from the 2002 tagging.

In 2003 116 post smolts were tagged with DST tags using the same method as in 2002.

In another Nordic project 235 monkfish were tagged with Floy tag around the Faroes. Of these 235 monkfish 10 also were tagged with data storage tags (DST). The aim is to get more knowledge about the distribution and migration of Monkfish.

Selectivity in monkfish Gillnets

The selectivity of different mesh sizes in Monkfish gillnets was tested in 2003. Four different mesh-sizes were tested, 280 mm, 300 mm, 380 mm and 400 mm. As expected the size of monkfish caught increased with mesh-size. The table below shows the medium length and weight for each mesh-size.

Mesh-size:	280 mm	300 mm	380 mm	400 mm
Average length (cm):	79	84	91	94
Average weight (gutted) (kg):	5.69	6.64	8.63	9.26

The selection-range was much longer for monkfish in monkfish gillnet than for example Greenland halibut in Greenland halibut gillnet. The best fishing success in kg/gillnet was achieved in the 380 mm mesh-size although higher number of monkfish was caught in the 280 and 300 mm.

The testing continues in 2004.

Technological Efficiency

For use in stock assessments the Faroese Fisheries Laboratory has scrutinized logbook data for selected fleet segments. This time series, together with information from vessel owners, has been used to reveal efficiency changes in the Faroese fishing fleet. Results are reported in the FTFB special topic session 2004.

Lanternfishes

Lanternfishes (*Myctophids*) have been caught as bycatch in the blue whiting fishery. In cooperation with Russian, Norwegian and Icelandic scientists study on horizontal and vertical distribution of this fish has been initiated. This work will also include studies on suitable fishing gear. The aim is to develop commercial fishery for such species.

More focus on fishing gear research

The Faroese Fisheries Ministry has decided that one of three special focused research kernels will concentrate on fishing gear research. This research is housed by the Fisheries Laboratory and will among other things build on the expertise of the Laboratory on underwater observation technology.

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11.5 Germany

11.5.1 Institute for Fishing Technology and Fishery Economy, Hamburg

Technical- biological investigations:

Selectivity of cod trawls in the Baltic

Work on this subject concentrated in 2003.on the evaluation of possible effects of a change in legal codend mesh opening from 130 to 140 mm. Own experiments demonstrated that the production technology of netting has reached a state where mesh opening becomes negligible as management tool. Underwater observations of the new codends showed that even herring had problems to get out of a codend of 140 mm meshes. Further work done was the collection of data on the selective properties of BACOMA- codends with 110 mm window mesh opening. Predicted selectivity parameters (by the BACOMA- project) could, probably due to higher flatfish bycatches, neither be obtained on research nor on commercial fishing vessels. The data collection on turned-meshes codends was further augmented.

Selectivity of eel in trawls in the Baltic.

Eel trawl fishing is presently a much-debated fishing method in the Baltic because of the large bycatch of other fish species due to the small codend mesh size used. There are strong tendencies to forbid this method completely. Work of the IFF focused on construction details of the trawls used with the aim to improve their species selectivity and, thus, maybe allow for a continuation. A horizontal separating panel gave after some adjustment in the angle of attack very encouraging results (95% of the eels caught in the upper compartment) however, 37% of the other fish are in this compartment, too, which is still thought to be unacceptable. Further behaviour-based experimental designs will be tested.

Optimization of gillnets to avoid unwanted bycatch of porpoises

There are three lines at present followed to suppress the unwanted bycatch of small cetaceans in gillnets. The use of reflectors or inclusion of barium sulphate into the netting yarn has already been tried elsewhere with varying success. The work of the institute was focused on the investigation of deterring panels made of very large meshes and of thick netting as recommended by Dutch scientists. It was detected that gillnets fitted out this way had a significantly reduced catchability compared to nets without deterring panels. The acceptance of such construction by commercial fishermen will be rather low, particularly if the bycatch of porpoises is a very rare event in the German fishery. Additional experiments with deterring meshes in three different colours carried out in 2003 did not improve the catchability. They will be continued, however, to exclude the possible effect of inadequate mounting.

A new theoretical model for the combination of selectivity and optimized yield

A theoretical study issued by a scientist of the institute was continued to combine the Beverton-Holt- model and real selectivity functions to optimize the exploitation of a stock. For the Baltic it shows that the present exploitation regime is far beyond a possible economic optimum. The results indicate a need to lower the fishing effort to 53% of the present and to raise the mesh opening to 240 mm to obtain maximum profit.

Technical investigations:

A remote-controlled cover closing device

A prerequisite of the use of selectivity-improving devices in trawls is that fish having passed through such devices will have a high survival rate. This has been proven for valuable commercial fish escaped at catching depth. No one, however, knows at present which portion of all escapees escapes during the tow and which when the net is hauled up to the surface. For the study of the latter a device was developed which allows closing the cover only when the trawl is at the surface. The intended use of a hydroacoustic releasing device will allow expanding this to the state when the trawl leaves the sea bottom.

A new research ship

Though the keel-laying ceremony for the new FRV “Solea” has happened the institute is still actively involved into details of the fitting out. The completed ship will now be delivered in May 2004 and comparative-fishing tests with the old “Solea” will be carried out in June.

Progress with a cableless video- transmission system

The design of the device has been further improved. It incorporates now an inflatable collar improving the safe handling and giving extra lift. Thus, it is possible to add a further video recorder storing data from a video channel not transmitted. In addition, it enables to fit in a radar transponder improving the safe recovery of the device. The switch from one application to the other is now possible via a handheld transmitter.

A new mesh measuring device

The IFF was actively involved into laboratory and field tests of a prototype of the new OMEGA mesh gauge.

11.5.2 Rostock University

Technical means for the underwater observation at an artificial reef

In the period 2003 to 2006 the project of an artificial reef is tended scientifically in the Federal State of Mecklenburg-Vorpommern. Available financial means amount to ca 2.5 Million Euros provided by the EU (Program FIAF) with a share of 75% and with a share of 25% by the state government. Work in 2003 was focused on the construction of the reef in a depth of 11 to 12 m close to the Baltic resort Nienhagen (approximately 10 km west of Warnemünde) The rigid elements of the reef consist of ca 1300 components in total (tetrapods, rings, cones of different sizes from 2 to 6 tons). Flexible structures, partly a kind of netting are added, thought to encourage the settlement of water-filtrating organisms as e.g. mussels. The University of Rostock is involved interdisciplinary with several research departments. At the Chair for Maritime Technologies several technical projects are coordinated thought to provide long-term and continuous underwater observation at several locations within the reef area (200 x 200 m). One of the main observation targets is fish behaviour in and close to passive fishing gear under the protected conditions of the reef elements, partly of 3 m height. The project coordinator, the state owned Research Centre for Agriculture and Fisheries Mecklenburg-Vorpommern with its Institute for Fisheries intends to prove by this fishery and in comparison with data obtained in a reference area the enhancement of the fishing conditions within the experimental area. First observations and catch results indicate the acceptance of the reef as protected area, particularly by juvenile cod. In account of this artificial reefs may provide a meaningful measure for the protection of fish stocks. The project gains particular importance because basic knowledge collected during this project might be applied fruitfully for the fishery during the planned operation of offshore wind parks.

Read more under http://www.uni-rostock.de/riff

Wind channel experiments on ropes with flow-induced transverse forces

During motion through water every rope experiences hydrodynamic resistance and lift forces. Relatively little is known about transverse forces caused by the flow. These transverse forces exist particularly in lines with a helical surface structure. (Towing warps, twisted ropes). These relatively small forces can have practical importance in account of the fact that they may lead to an unsymmetrical load and depending on this also shape of towed fishing gear. Especially in deep-sea trawling with long towing warps and if both warps have the same twist direction this may lead to a considerable transverse offset of the course line of the ship. Recent publications on “self spreading ropes” speak of enormously increased lift coefficients connected with a seriously decreased resistance. Samples of some of these lines were tested in the big wind channel of the Rostock University. Their surface structure resembled Scruton helices. The parameters diameter and slope of the spiral cord were identical to “self spreading ropes”. Samples rigidly fixed were blown at under different angles of attack. The results could not confirm the statements given by the producers. However, a small hydrodynamic-induced transverse force could be proven which may lead to an additional, though weak shearing force. Some of the more important results of this research were presented during the sixth International Workshop DeMaT’03.

Technical problems during a fishery in deep waters

During the DEEP SEA-conference in Queenstown/ New Zealand organized by the New Zealand Ministry of Fishery, by the Australian Department for Aquaculture, Fisheries and Forestry and by the FAO from 1 to 5 December 2003 a contribution on deep water trawling was delivered by Dr. W. Thiele. The Chair for Maritime Technologies cooperated in the preparation of the manuscript, particularly by performing some example calculations concerning shape and load on very long towing warps. The presentation will be published in short in the appropriate proceedings of the FAO.

Calculations of reticular structures (Oil pest control, outdoor bird cage Zoological Garden Rostock).

The calculation of reticular structures aims not always to its use in fishing gear but is also performed fruitfully for other subjects. Mathematical models were developed for two other projects.

Oil pest fighting with dynamically lowered reticular structures with integrated absorbing materials (Presentation by M. Paschen und G. Niedzwiedz during DeMat’03)

Design of lestridge and rope supporters for the protective net over the seabird outdoor cage of the Rostock Zoological Garden. There the netting had to exchanged completely during the winter 2003 to 2004. This offered an opportunity for the inclusion of small corrections.

During both tasks software was applied which was developed at the Rostock University and which is applicable at the Chair for Maritime Technologies.

DeMat ‘03

The Scientific International Workshop DeMat’03 took place in Rostock, now for the 6th time. More than 40 scientists from 10 countries participated. Colleagues from Asia, particularly Korea and Japan, were the strongest foreign fraction. More and more DeMat develops to a forum where engineering aspects of the fishery are presented and discussed without leaving out of sight biological and environmental aspects. Very interesting were new hydrodynamic aspects in the calculation of flexible fishing gear exposed to a flow (use of CFD Methods). The event was focused further on experimental and theoretical methods for the modelling and simulation of fishing gear and on the application of new techniques and technologies in the observation and measurement of parameters from the marine environment. The interaction between maritime structures and the living and physical environment was a further interesting subject. The 2- years- rhythm in the repetition of the event should be maintained. However, particularly the Korean colleagues raised the wish to organize the next

DeMat-Workshop in Pusan/Korea. The traditional particant countries will examine the financial possibilities to comply with this proposal.

11.6 Norway

11.6.1 Institute of Marine Research, Bergen

Instrumentation/Fish behaviour

There is a need for developing techniques to observe fish behaviour in relation to gillnets. The performance of a multibeam echo sounder system with the transducer mounted horizontally on a camera frame has been tested in a preliminary field experiment. The system gave high precision, but the narrow observation volume seemed to be a problem when tracking fish. Other observation and tracking techniques such as multibeam sonar, Echoscope sonar and telemetry will be tested during two cruises in 2004.

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Fish aggregating devices as instrumented observatories of pelagic ecosystems (FADIO)

An international tuna fishing fleet considerably exploits tuna species in the Indian Ocean. Few independent data apart from fisheries statistics exist on abundance, aggregation level and behaviour of tuna in this scarcely studied ecosystem. The EU- project FADIO was initiated to collect data on abundance and behaviour of various species of tuna around fish aggregating devices (FAD’s) and develop prototypes of acoustic buoys.

The first coordination meeting was held in March, where planning of cruises and synopsis of all data collection were discussed. A three weeks cruise was performed onboard “Indian Ocean Explorer”, where acoustic equipment was tested (long-ranging tuna sonar and echosounders) in relation to pelagic fish aggregating around FAD’s. Fishing with handline, acoustic tagging, passive acoustics, some environmental monitoring and visual observations of birds and fish were performed and synthesised.

In 2004 at least 2 cruises will be performed. The main objectives will be to collect as much complementary data as possible on tuna abundance, aggregation and behaviour around FAD’s and develop a prototype instrumented acoustic buoy for future scientific work on tuna species.

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Environmental effects of fishing

Fish scavenging behaviour after otter-trawl disturbance in the Barents Sea

As demersal trawls are towed across the seabed, they dig up, displace, injure or kill a proportion of the epi- and infaunal animals in the path of the gear. Fish stomach analysis revealed that cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), increased their food intake and changed their diet composition by capitalizing on re-suspended animals shortly after otter trawl disturbance in the Barents Sea.

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Unaccounted mortality

Survival

An EU project aimed at estimating the mortality in gadoid fish escaping from towed fishing gears is carried out in co-operation between IMR, Bergen, FRS, Aberdeen and DFU, Hirtshals. The objectives of the project are:

- to develop sampling techniques that overcome current biases in escape mortality estimation;
- to compare codend selectivity and survival of gadoid fish escaping at the surface in side-trawler fishery, with that of fish escaping at depth;
- to study the effect of high intensity fishing on fish survival;
- to study seasonal variation in fish survival;
- to develop models for including escape mortality data in stock assessments and predictive modelling;

During the first field trials carried out in August 2003 on the west coast of Scotland, the new sampling technique was tested, and the first survival figures were estimated. New experiments in February 2004 were hampered due to bad weather conditions. In April/May 2004, experiments will be carried out in northern Norway to see if there is a difference in survival between an area with low and high fishing intensity. Field trials for seasonal variation and surface selectivity and survival will be conducted in Scotland in May and August 2004.

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Some aspects of trawl induced unaccounted mortality

Several studies have been carried out to access the survival rate of escaping fish through codend meshes and other selectivity devices used in trawls. This project aims at investigating three other possible sources of unaccounted mortality of cod associated with bottom trawling; 1) The exposure to mud cloud set up by the trawl doors and bottom gear, 2) The run over of fish by the trawl, 3) The repeated encounter (capture and escape through sorting devices) by juvenile fish at intensively trawled fishing ground.

Tank experiments have been carried out to study the effect of mud clouds on the physiology of cod. The effects of run over and repeated encounter will be studied during field experiments in April and August 2004. Results of these experiments will be reported in 2005.

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Size and species selectivity

EU Recovery Project

This multi-national project that aims to reduce capture of cod is ongoing. Flume tank tests with models were conducted in collaboration with fishing industry representatives. During these consultations, it was concluded that insufficient quantifiable behavioural data was available in relation to towing speed, diurnal effects and trawl size. Trials on the Scottish RV vessel ‘Scotia’ are scheduled for April 2004, in which further behavioural observations will be conducted. In November 2004, trials will be conducted on the Norwegian RV ‘Johan Hjort’ where further tests with the Echoscope and an alternative method for obtaining species id will be conducted in conjunction with species selectivity experiments with exclusion devices. Analysis of the 3D Echoscope data is ongoing, this has proved to be time consuming, but recent software modifications have speeded up the process.

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EU Necessity project

The pan European project Necessity focuses on improving bycatch selectivity in *Nephrops* trawls. The programme has recently begun, with a large number of trials planned across Europe; IMR is coordinating the selectivity work package. IMR, in collaboration with IMR-Sweden and the Danish institute, DIFRES, plan to conduct trials with a bycatch exclusion panel in the *Nephrops* fishery in the Northern North Sea early in 2005.

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Reduce bycatch of red king crab

In 2003 two trials were performed trying to reduce the bycatch of red king crab in the gillnet fishery for cod at the coast of Finnmark. Gillnets were set on norsels of one meter and compared to standard nets. The crab catch was reduced significantly and the cod catches were also reduced to about 20% in numbers.

A pilot study on floated fish pots has also been performed. The pots were lifted about 70 cm above the bottom and the catches were increased compared to bottom set pots.

In 2004 the trials with floated pots will continue together with two trials to reduce the bycatch of king crab in the gillnet fishery for lumpfish. Also here norsel nets will be compared to standard nets.

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Sorting grid in herring trawl

Experiments with grid selection in big pelagic trawl for herring continued in 2003, focusing on the sorting capacity of herring. With 50% increase in grid size compared to earlier years, catch rates up to 100 tonnes herring pr. hour gave a herring loss of 2% or less. Catch rates of 120 tonnes or more in ½ hour (or less) tows indicated that the capacity of grids decreased. Bycatch of saithe was reduced by 83 to 94% (in weight) in single hauls. Grid with 60 mm bar spacing gave a L50 around to 60 cm and a selection range around 10 cm.

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Reduced bycatch of juvenile fish during shrimp trawling

Experiments in the northern Norway showed that nearly 100% of shrimp was entering the extension of a shrimp trawl closer than 10 cm from the lower netting. This finding was utilized testing a modification of the traditional Nordmøre-grid system. The grid was mounted in a square mesh extension without a guiding panel in front of the grid. Extra floats (5 kg) were mounted to the grid such that the lower panel of the square mesh extension was rising towards the grid. This modification gave a 50% higher exclusion of juvenile cod and haddock and less loss of shrimp, compared to the traditional Normøre-grid system. Similar experiments will be carried out in November 2004.

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Fishing gear development

A new shrimp trawl concept

IMR, Bergen, in cooperation with SINTEF Fisheries and Aquaculture, Hirtshals, are working on a shrimp trawl concept where the spreading forces is incorporated in the trawl itself by using a self-spreading ground gear, a divided belly and flexible kites for horizontal “lift”. The idea is that the sweeps/bridles in front of the trawl can be almost parallel and that large trawl doors can be replaced with smaller doors or some kind of roller weights. 1:10 scale testing of this trawl concept has been conducted in the flume tank in Hirtshals, and further development work is in progress.

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Fish trawl development

IMR, Bergen in cooperation with SINTEF Fisheries and Aquaculture, Hirtshals has developed a new design of a commercial fish trawl for the Norwegian cod trawler fleet. The development has included mathematical simulation, testing of 1:10 scale models in Hirtshals and 1:2 scale models of the same trawls (two and four panels) on commercial fishing grounds in northern Norway. A major difference from existing commercial trawls is the replacement of the rockhopper ground gear with squared rubber plates arranged in such a way that they generate spreading forces in the wing section of the groundgear. Flexible kites for lifting are also developed as part of this project. The tests with the 1:2 models were convincing with regard to spreading forces and ground contact performance. Full-scale trawls rigged with 50 cm squared rubber plates are produced and will be tested in commercial bottom trawl fisheries in the Barents Sea in April-May 2004.

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Krill trawl development

IMR has developed a commercial krill trawl with 15 m vertical opening that was tested in the Norwegian Sea in 2003. It was learnt that very small mesh sizes (probably less than 20 mm) in the belly of the trawl is required to retain krill. A multi-trawl design divided into 9 codends has been designed and produced in 1:2 scale model (10 m vertical opening) for performance testing and fishing trials in Norwegian fjords in June 2004.

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Live fish technology

The interest of live fish technology is steadily increasing. A fishing trial including 8 seine net boats gave about 1200 tonnes live cod that were transferred to net pens and stored until periods with low landing rates of cod (summer and autumn). By landing the cod alive, the fishermen increased their income by more than 30% compared to conventional landings.

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11.6.2 Fisheries and Aquaculture, Trondheim, Norway and Hirtshals, Denmark

New Generation Cod Trawl

In cooperation with IMR see description under IMR.

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Gentle codend: 90º turned netting

Despite the fact, that the quality of the catch in trawls often is poor, very little has been done to improve the situation. This project is committed to find solutions to this and two subjects are believed to give results. One is a reduction in the turbulence found in the pear-shaped codend. The turbulence is 'washing' the fish round, and in the 'grinding' process the layer of mucus and scales are removed. The other subject is finding net materials with a more smooth or gentle inner surface. The Flume tank at the North Sea Centre Flume Tank has been used to test several different half-scale codends. The smallest cross-section area and the flow have been measured and the waving action has been recorded. The codends were filled with ½-liter (1 pint!) plastic bags with water, simulating fish, equivalent to a full-scale catch of around 450 kg. The results have so far revealed that the standard codend with two selvedges have a very narrow entrance and are waving from side to side. Inside the codend the 'fish' are being thrown against the net wall, just as can be seen on full-scale underwater video recordings. Several attempts were made to reduce the turbulence, and two solutions were found to give considerable improvements: a full square-mesh codend (netting turned 45º) and a codend with the netting turned 90º. The cross section area is around 12 times larger in the 90º codend, indicating that the large codend will let out more water and thereby reduce the turbulence. This is confirmed by an almost non-moving codend. The codend will be fitted with a lifting bag made from knotless netting, making the inner side gentler to the fish.

SINTEF has applied for a project for testing this cod end design onboard a commercial fishing vesssel. Full-scale codends will be tested and the quality of the catch measured. It must be noted that a gentle codend preserving the quality of the catch, will also improve the survival rate of the small fish escaping from the trawl. The use of the codend therefore also has implications for the exploited resources and for fisheries management.

If a fishing quota is granted this tests will be held during last months of 2004.

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Fine Meshed Pelagic Trawls

The project will establish a theoretical basis for describing and predicting the flow in small-meshed pelagic trawls. The background is the growing interest in exploitation of marine zooplankton and small fish, motivated by the growing demand for feed for the aquaculture industry. Several attempts have been done to exploit for instance krill, but a to a sustainable and economic exploitation of such resources requires improved and new technology. Pelagic trawls are believed to be suitable for harvesting this resource, but a better understanding of the flow is necessary, especially because there will be a strong dependency between efficiency, quality of the catch and the flow through the net. A study of literature has been conducted in 2003. Basic trials in the flumetank in Hirtshals will bee conducted during spring of 2004.

Contact: Svein Helge Gjøsund, Trondheim, svein.h.gjosund@sintef.no, Ulrik Jes Hansen, Hirtshals, ujh@sintef.dk

Active trawl control

The Norwegian company Scanmar AS, in co-operation with SINTEF Fisheries and Aquaculture, has been developing an active trawl control system. A mathematical model and a conceptual solution for control are developed and are planned verified.

As a project spin-off a computer program is developed for calculation of a trawl door's orientation (roll, pitch and yaw), hydrodynamic angle of attack and hydrodynamic slip angle. The calculations are based on the door's force and moment characteristics (hydrodynamic point of attack), and drag and lift coefficients. The inputs are forces acting in the door's body-fixed frame (hatchways, foils and so on) and forces acting in the earth-fixed frame (warp line forces, bridle/backstrop forces, buoyancy and gravity). The computer program is capable of calculating the dynamic response of the trawl door when the forces (or hydrodynamic characteristics) changes, but coefficients for added mass and damping coefficients have not yet been verified against experiments.

Tests of trawl system in the flume tank are scheduled during spring / summer 2004 as a part of the PhD thesis of Vegar Johansen. SINTEF will also initiate new projects for development of the theoretic fundament for trawl doors and nets. This will be of high value during the forthcoming development of the next generation of trawl gears where computer-assisted operation probably will be one of the key advances. New methodologies and measuring systems for flume tank testing are also under development, and will improve the value of such testing.

Contact: Vegar Johansen vegar.johansen@sintef.no

Calanus Trawl

Continued full scale tests have been conducted over the past year. A large trawl was made and tested in Trondheim's Fjord. Some improvements were made, especially for strengthening the net, and it has later been tested in other localities in Norway. The handling of the net has been important and it has therefore been tested against vessel type and size. Small Danish Seiners have been found to be especially suitable for the gear, due to the presence of a power block to retrieve the net. During the summer season of 2003 a large number of tows proved that it was possible to get good catches. During the 2004 season tree vessels will catch calanus in a "commercial" project in Tromsø.

Contact: Håvard Røsvik haavard.rosvik@sintef.no

Distant learning/demonstration/training/instruction from the Flume Tank

The North Sea Centre Flume Tank has equipment for Video Conferences. It is therefore possible to follow demonstrations in the flume tank without being present. This has great implications for classes from schools and universities, research laboratories and vessels, and others, which have difficulties in finding funds for the travel expenses, board and lodging - and justify such in cases where only a few hours of tank hire is required. 3 movable and 3 fixed cameras plus the computer readings are mixed and can be transmitted to the customer sitting in a videoconference studio abroad. The system was tested during the fishing fair in Aalborg in October 2003 and it proved to be a good system for distant demonstration of trawls. The system has also been used for exchange of ideas during project work and meeting between the employees in Denmark and Norway.

Contact: Ulrik Jes Hansen, Hirtshals, ujh@sintef.dk

11.6.3 Norwegian College of Fisheries Science

Activities on fishing gears during 2003/2004:
Fish behaviour in the vicinity of trawls. Special attention to fish escaping below the footrope of conventional fish trawls have been made under various conditions (darkness/natural light/large and small fish).

Selectivity of shrimp trawls. Studies made on coastal shrimp trawl designs with different types of Nordmöregrids combined with selective escape panels.

Selectivity of offshore shrimp trawl designs. Further studies on a PA-plastic grid (Cosmos design) combined with selective escape panels.

Studies on size selective mesh panels (Exit Windows) compared to two versions of compulsory grids.

Further development of a twin body fish trawl (commercial size) for direct comparisons of different selective devices in the aft of the trawls. An option when double trawl systems are not available and to avoid covered codend or alternate haul methods.

Comparisons between gillnets and pots on a local cod fishery. Master thesis.

Development of a commercial size Calanus (zooplankton) trawl.

Development of an "automatic longline system" with the aim of improving quality of fish, reducing loss of fish, etc.

11.7 Scotland

Nephrops Selectivity

A study was made on the Fladen grounds of the North Sea to compare the selectivity of three codend mesh sizes using the twin trawl method. *Nephrops* and roundfish catches were compared using a 4-mm single twine 90-mm diamond mesh codend and 5 mm double twine 100-mm and 120-mm diamond mesh codends. The 90-mm codend and 100-mm codend had 110-mm square mesh panels fitted into their extensions. No lifting bags were fitted over any of the codends. Further Nephrops selectivity work is planned for 2004. Contact person – David Bova.

Project survival

Field work for Project Survival started in July 2003. This project has tested and demonstrated the validity of new sampling protocols for measuring the mortality of fish escaping from towed fishing gears. Work will continue in 2004 and 2005 to collect data at different periods during the year to establish whether there is any seasonal variation in escape mortality. This data will then be incorporated into stock assessment calculation to assess the impact of this source of unaccounted mortality on fisheries management. Contact person – Mike Breen

Project recovery

Behaviour trials were undertaken on a Norwegian research vessel in May/June 2003. An industrial liaison group was established and had its first meeting at the Marine Laboratory during June 2003. Development trials were undertaken at the SFIA's flume tank in Hull during December 2003. Further full scale trials were carried out on a 12 day cruise aboard FRV Scotia in April 2004 to establish fish behaviour in relation to a prototype cod separating trawl at different speeds during day and night. Contact person Dick Ferro/Rob Kynoch

Project PREMECS II

Two cruises were carried out on the Clupea (in April and September) observing fish behaviour in the codend and measuring fish morphology.

The data from experiments carried out by ISMAR, Ancona on the resistance to opening of a netting panel was analysed and demonstrated clearly how twines of the same thickness can have different flexural rigidities.

A model of flow in partially blocked netting has been developed and experimental trials in the wind tunnel of Rostock University are taking place at the moment. Contact person Barry O'Neill

Fishing Effort (Relationship between F and Fishing Effort)

An initial fishing gear survey of the Scottish *Nephrops* fleet targeting North Sea grounds was undertaken by the Marine Laboratory to establish its fleet structure in terms of the number of vessels, main engine power and landings by weight and value. Two cruises were undertaken in early 2004 to compare the gear performance or catching ability of two commercial *Nephrops* twin trawlers with main engine power of 298 Kw and 519 Kw respectively. This project is to continue into 2004 and will include the Scottish whitefish fleet and pelagic fleets. Contact person Dick Ferro/Rob Kynoch

Project OMEGA

A series of trials with the prototype gauge were held with scientific staff, members of the Scottish Fisheries Protection Agency and with members of the Scottish Trawl Netmakers Association. In general, reaction has been favourable and a number of recommendations were made. A modified gauge has just been received. Contact person Barry O'Neill

Oil installation/fishing gear interaction

We continue to assess and advise on the impact of UK oil development and abandonment proposals and recommend suitable courses of action. A project investigating overtrawling of a >40 inch pipeline bundle was due to take place during 2003 in conjunction with the Scottish Fishing Industry and UKOOA but was cancelled. Contact person – G. Sangster/ Dick Ferro

11.8 United States of America

11.8.1 Northeast

11.8.1.1 Massachusetts Division of Marine Fisheries - Conservation Engineering Program

Thomas Moth-Poulsen, Michael Pol (mike.pol@state.ma.us), and Mark Szymanski

Further Testing of Cod-Avoiding Trawl Net Designs

Larger-scale testing of two successful Atlantic cod-avoiding trawl designs was conducted in Fall 2003 and March 2004. The two designs, one removing much of the top square, and the other replacing much of the top square with 203 mm square mesh, reduced cod catch rates when targeting flatfish by >72% when tested on smaller (<20 m) fishing vessels. The testing is being conducted using a twin-trawl method, an unusual gear type for fishermen in the region. Testing has been hampered by atypical absence of fish of the right species.

Fleet Selectivity Estimates

We are attempting to determine the fleet selectivity of a small-mesh (2.5-3.0 inch (64-73 mm) codend) *Merluccius bilinearis* trawl fishery using a combination of vessel trip reports, haul-by-haul fishermen's logs, and observer data. Our intent is to compare the overall fleet percent bycatch of certain "regulated" species. The fishery was established in 2000 based on experimental results and observer data using a semi-pelagic raised footrope trawl and recent proposed regulations have included provisions for requiring periodic renewal of exempted fisheries, making determination of fleet selectivity crucial to continuation.

Selectivity Seminar and Consulting

A seminar on the measurement of size selectivity in trawl gear was developed and conducted for regional gear technologists, using the ICES Manual of Methods of Measuring the Selectivity of Towed Fishing Gears and the SELECT method. Also, assistance with design and analysis to fishermen conducting a covered-codend selectivity experiment was continued.

Assessment of Habitat Impact

Technical expertise with underwater imaging was used to help quantify habitat impact of a sub-floor natural gas pipeline. The area impacted supports a substantial lobster (*Homarus americanus*) fishery. An underwater third-wire trawl camera system was updated and modified for use on a towfish. Habitat impact was assessed through visual assessment of video.

11.8.1.2 Manomet Center for Conservation Sciences - Marine Conservation Program

Dr. Chris Glass (glasscw@manomet.org)

Georges Bank Yellowtail Program

A cooperative research programme has been successfully completed demonstrating temporal and/or spatial overlap/separation between target and non-target species in Closed Area II on Georges Bank. The programme has been completed and suggested that yellowtail flounder can be harvested in the closed area without the bycatch of Atlantic cod. The finished results of this programme have successfully made it into the management arena. A plan is being considered by the New England Fisheries Management Council to allocate a possible yellowtail fishery in Closed Area II under the Special Access Program allotted in Amendment 13.

Rigid Mesh Escape Panel

The pilot project exploring the potential of a rigid, large mesh panel for selecting larger fish in the multispecies groundfish fisheries in the Gulf of Maine yielded positive results. As a consequence, further funding was approved to continue to look at the effects of this rigid escape panel. The panel, inserted along the net between the extension and the codend, measured 2 m in length and was constructed of elongate meshes 60 mm wide x 200 mm long. The panel will extend along the entire circumference of the net. Each vessel will tow the experimental codend, equipped with the rigid mesh panel, and a conventional codend in alternate tows and their catches will be compared. Both codends will be made of 6-inch (152 mm) diamond meshes. Planning is underway to continue field research aboard several vessels in May 2004.

Inclined Separator

This programme was designed to look at methods for separating flatfish from round fish (particularly cod) in conventional towed fishing gears. A version of the inclined separator panel also used in Irish Sea *Nephrops* fisheries was tested. Results indicated that significant separation between upper and lower sections of the net, in terms of weight, occurred for cod, monkfish and grey sole, which is more abundant in the upper section, and crustaceans (specifically crab and lobster), which were more abundant in the lower section. These preliminary investigations demonstrate the potential to separate cod from other groundfish species and implications for reducing cod bycatch and discard are significant. Further studies will commence in June 2004.

Codend Selectivity

This project was designed to provide high quality scientific information on the selective efficiency of various codend configurations to allow better and more effective management of fish stocks. The current groundfish regulation for codends stands at 6.5-inch (165 mm) diamond and 6.5-inch square mesh. We tested 4 codends, designed to accommodate possible mesh regulations, in various configurations: 2 single mesh codends and 2 composite codends, based on promising results obtained in previous studies with composite codends that showed a 62% reduction in the catch of sub-legal cod. The 4 codend configurations were: 1) 6.5-inch diamond mesh; 2) 7-inch (178 mm) square mesh; 3) composite 7-inch square mesh in the top panel and 6.5-inch diamond mesh in the bottom panel; 4) composite 7-inch square mesh in the top panel and 7-inch diamond mesh in the bottom panel. Covered codend techniques were employed and selectivity analysis of this data is currently being completed.

Large Mesh Monkfish Trawl

This programme was designed to test a bottom trawl net that reduces bycatch of groundfish and reduces bycatch of undersize monkfish. The experimental trawl constructed of 12-inch (305 mm) diamond mesh throughout the entirety of the net. This was towed in conjunction with a control net made up of a 6-inch body attached to a 6.5-inch diamond codend developed to meet current Northeast groundfish regulations. Data resulted in a promising ability to selectively catch monkfish while releasing other regulated groundfish and undersized monkfish. Field work commenced in 2004.

Morphology

Conventional approaches to reduce bycatch and discard include modification of mesh size and or mesh configuration but generally are not species specific. With the lack of viable information pertaining to fish morphometrics particular to individual species, it is difficult to assess correct mesh geometry in collecting marketable species while cutting down on bycatch. This programme is designed to acquire morphometric measurements (this includes length, width, height, and girth) throughout a calendar year to account for seasonal variability. The work done so far is providing essential data to fine tune the research conducted on species- specific trawls. Work will continue throughout 2004.

11.8.1.3 University of New Hampshire

Pingguo He (pingguo.he@unh.edu)

Reducing bycatch and discard

Two projects to separate roundfish and flatfish during trawling continued with sea trials. A “RollerGrid” was designed and tested, and tests will continue during the summer and fall. A trawl with soft separator panels and visual effects is being tested. Further sea trials are planned for April and September of 2004.

A project to test shallower gillnets to reduce cod has been completed. The new low profile nets of 8 meshes deep (MD) caught significantly less cod than other three types of nets including 12 MD, and 25 MD standard cod nets and 25 MD tie-down nets. Catch of flounders were comparable between the 8 MD nets and the standard 25 MD cod net.

A project to reduce small fish and small shrimps in shrimp trawls has started this winter. The project uses kites to spread meshes in the codend so as to let small fish and small shrimps to escape during fishing. The project is continuing.

Trawl codend mesh selectivity

A project to determine selectivity of five codend mesh sizes/shapes has completed the first year of sea trials. We tested 6-inch (152 mm), 6.5-inch (165 mm), and 7-inch (178 mm) diamond codends and 6.5-inch and 7-inch square mesh codends using covered codend methods. A kite-assisted codend cover was developed and used during the tests. Selectivity properties for cod, yellowtail flounder, American plaice, and witch flounder were determined. Codend meshes were too large for haddock, and no selectivity curves were available for this species. Tests of selected codends with chafing gear and knotless codends are planned for this spring and summer.

Reducing bottom impact of trawling

A semi-pelagic shrimp trawl with doors off bottom was designed and tested in a flume tank in cooperation with the Fisheries and Marine Institute in Canada. Sea trials conducted in the Gulf of Maine pink shrimp fishery during the winter of 2003 showed promising results with catch rates comparable to those of commercial operation by other vessels. Sea trials for the winter of 2004 have just been completed.

11.8.1.4 University of Rhode Island

Kathleen Castro, David Beutel, Laura Skrobe (lsk6311u@postoffice.uri.edu), and Barbara Somers

OUTREACH

Development of a Southern New England Working Group: Focus on Bycatch and Gear Engineering

A working group has been developed focusing on bycatch and gear engineering. The goals and objectives of this group include transfer of information, past, current and future research, defining research needs, developing collaborative efforts, and bringing together the various sectors to fully utilize existing knowledge and funding opportunities. This will be accomplished by holding meetings composed of gear researchers, fish behaviourists and fishermen. The first meeting was held in December 2003 and included discussions on project and regional needs and expectations. A training workshop was conducted on the Design and Analysis of Selectivity Experiments in March 2004 to develop standardized field methods and data analysis. A Gear Conservation Engineering web site has been designed that includes an expert list, references, etc. See http://seagrant.gso.uri.edu/reg_fish/gear/index.html.

Northeast Regional Bycatch Workshop

Northeast Sea Grant is a co-sponsor of a Northeast Regional Bycatch Workshop entitled “Bycatch in Northeast Fisheries: Moving Forward” along with the National Marine Fisheries Service Northeast Regional Office and in cooperation with the Northeast Fisheries Science Center, New England Fishery Management Council, Mid-Atlantic Fishery Management Council, and Atlantic States Marine Fisheries Commission. Sea Grant is on the steering committee for the workshop and is organizing panels and will facilitate panel sub-groups at the workshop. The workshop will be held in Wakefield, Massachusetts from June 29 to July 1, 2004. The purpose of the workshop is to incorporate stakeholder input into the Northeast Region Bycatch Implementation Plan.

RESEARCH

Evaluation of Catch Efficiency and Size Selectivity of Inshore New England Fish Pots for Black Sea Bass and Scup as a Function of Escape Vent Size

Effects of increasing escape vent size on catch efficiency and size selectivity were studied in the New England inshore pot fisheries targeting black sea bass and scup. Commercial fishing vessels fished experimental fish pots equipped with circular escape vents of varying size (2.38, 2.75, 3.10, 3.40 inches (60, 70, 79, 86 mm)); an unvented pot served as the control. In general, the catches of undersize black sea bass and scup were reduced as vent size increased. However, the results suggested that fishing pots with larger size escape vents also reduced the catch of legal-size fish. The estimated selectivity patterns suggested that increasing the escape vent size in fish pots could alleviate fishing pressure on smaller sized fish, though the probabilities of retaining larger size fish could be compromised. Changes in the size of the circular escape vents affected black sea bass and scup differently. As such, proposed management measures need to consider the gear and species-specific nature of selectivity parameters.

Southern New England Yellowtail Flounder Size Selectivity Study for 6.0” Diamond, 6.5” Square, 6.5” Diamond, and 7.0” Square Shaped Mesh Codends

This study evaluated the selection properties of several mesh configurations to provide guidance for assessing the impact of minimum size limits and codend mesh size restrictions on yield of yellowtail flounder. The catch efficiency and size selectivity of four experimental codends (6.0-inch (152 mm) diamond, 6.5-inch (165 mm) square, 6.5-inch diamond, and 7-inch (178 mm) square) were measured with the alternate haul method using a small mesh codend as the control. Comparison of catches between the test codends indicated that increasing the square mesh size to 7.0-inch square can significantly reduce the mean number of sublegal fish caught. The estimated selectivity patterns suggested a potential for reduced retention of legal-size fish with increasing mesh size. However, no significant loss of legal-size catch with an increase in the square or diamond mesh size was detected. Winter flounder data was also collected and analysis is currently underway.

Effects of Increasing Mesh Size in the Summer Flounder Fishery in Southern New England and Inshore Rhode Island Waters

A project on the effects of increasing mesh size in the summer flounder fishery in inshore Rhode Island waters was conducted from spring to fall 2003. Data was collected onboard commercial fishing vessels. Mesh size selectivity of summer flounder was investigated for codend mesh sizes and shapes, 6.5 and 7.0 inch diamond, and 7.0 and 8.0 inch square. Analysis of data is currently underway.

Bycatch Characterization and Reduction from Codend Mesh Size Increases in the Directed Scup Bottom Trawl Survey

Commercial fishing vessels were used to conduct a study on the effects of increasing mesh size on the characterization and reduction of bycatch from the directed scup bottom trawl fishery in the fall and winter of 2003. The project investigated the bycatch characterization of the currently regulated mesh size (4.5 inch diamond for 25 meshes with 100 meshes of 5 inch immediately forward of the 4.5 inch) and 2 experimental nets (6.0 inch and 6.5 inch square shaped meshes). The change of bycatch between the regulated mesh size and the experimental sizes will be evaluated.

Effect of Weather on the Performance of the NMFS NEFSC Survey Trawl

Joseph DeAlteris (jde6039u@postoffice.uri.edu) and Philip Politis

This research addresses the following questions:

1) Does weather (sea state) affect the catch efficiency of the NMFS NEFSC survey trawl by reducing the contact time of the sweep with the seabed? Is this due to vessel motion that is transmitted down the towing warp to the trawl doors and net, or to wave generated currents at the seabed, or both?
2) Is there a limit to sea conditions above which sampling gear performance and/or catchability are unacceptably compromised, such that the establishment of a maximum threshold for sea conditions would reduce statistical variability in the survey index?

To investigate the performance of the NMFS NEFSC survey trawl as a function of sea state we instrumented the vessel and trawl with sensors to monitor and record in real time their dynamic behaviour. With regard to the vessel we are using three-dimensional inertial acceleration sensors that record at 1 second intervals, so as to define the motion of the vessel at the gallows frame as those motions are transmitted to the tow warp. With regard to the net, we have instrumented the net headrope with speed sensors referenced to both water and the seabed, and video cameras. Additionally, the net sweep is instrumented with bottom contact sensors that operate acoustically and mechanically. The time series data from all sensors will be evaluated using correlation analysis to identify causal relationships between net sweep contact with the seabed, and either vessel motion or net motion in response to bottom currents. Finally, we will evaluate the decline in survey trawl performance (sweep bottom contact and fish behaviour in the trawl mouth) as a function of sea conditions and determine if there is a point after which the performance is compromised, and recommend that as a threshold for survey operations.

Matching Minimum Legal Fish Size to Codend Selectivity Patterns to Minimize Bycatch in the Georges Bank Trawl Fishery

Joseph DeAlteris (jde6039u@postoffice.uri.edu) and David Chosid

The results of codend mesh size selection studies for 6.5-inch (165 mm), 7.0-inch (178 mm) and 8.0-inch (203 mm) square and diamond shaped webbing have been incorporated into single and multi-species yield per recruit (YPR) and spawning stock biomass per recruit (SSBPR) analyses for the Georges Bank trawl fishery. Winter flounder dominated the catch in the 2002 investigation, but sufficient data were also collected on yellowtail flounder and Atlantic cod to be included in the analyses. The results of these analyses indicate that the current minimum mesh sizes nearly maximize the YPR and that further increases in mesh size will only marginally increase SSBPR for the three groundfish species. The current minimum legal fish size for winter flounder and yellowtail flounder correspond to approximately the L_{10} on the selection curves for 6.5 inch square and diamond shaped codends. While the existing legal minimum fish size minimizes the discard of sub-legal sized flounder, it also maximizes the loss of legal sized fish to commercial trawl. This provides an incentive to fishermen to circumvent the minimum codend mesh size regulations, so as to decrease the loss of legal sized fish, and thus ultimately results in an increase in actual (unobserved) discards. An increase in the minimum legal fish size to the L_{50} (15-16 inches (381-406 mm)) would increase observable regulatory discards, but would significantly reduce the incentive to circumvent minimum mesh size regulations, thus minimizing actual discards. The current minimum legal fish size for Atlantic cod approaches the L_{50} of the 6.5 inch codend selection curves, therefore no change in the minimum legal fish size for this species is suggested. Reducing the incentive to circumvent minimum codend mesh size regulations protects all fish species from excessive discarding of sub-legal sized fish that will undoubtedly be captured when using a codend with less than 6.5 inch mesh.

Ongoing Research

We are currently working on purse seine selectivity in the Philippine tuna fishery, the effect of scientific survey trawling on the benthos of Narragansett Bay, Rhode Island, and the quantitative analysis of fish behaviour in the mouth of a bottom trawl.

11.8.2 Northwest

11.8.2.1 Oregon Department of Fish and Wildlife - Marine Resources Program

Robert W. Hannah (bob.w.hannah@state.or.us)

Development and Testing of a Selective Flatfish Trawl

We tested the potential of a selective flatfish trawl to reduce rockfish bycatch in the upper continental slope bottom-trawl fishery. The trawl net we tested differed from typical slope trawl nets in that it was a low-rise, two-seam trawl with a severely cut-back headrope. The study used an alternate haul, randomized block design to compare catches of the experimental trawl with those of a typical 4-seam, high-rise design. A similar protocol was used to investigate diurnal changes in catch rates for both trawls. The experimental trawl produced similar catches to the control net for all commercially valuable flatfish except arrowtooth flounder (*Atheresthes stomias*), which was reduced 24%, and Pacific halibut *Hippoglossus stenolepis*. Catches of most rockfish and roundfish were significantly reduced in the experimental net (50-94% depending on species). However, the catches of darkblotched rockfish (*Sebastes crameri*) and redbanded rockfish (*Sebastes babcocki*) were not reduced significantly in the experimental trawl. Diurnal comparisons showed night time catches were reduced 30-99% for most rockfish species, with the greatest reductions observed in the experimental net. The night time catch reduction for dark blotched rockfish with the control trawl (-86%) along with no reduction in Dover sole catches, suggests that fishing only at night may be a viable bycatch reduction strategy for dark blotched rockfish. The variation in relative catch rates of the two nets we tested, both diurnally and with increasing depth, suggests that selective flatfish trawls may be more dependent on light for efficient performance than conventional trawls.

11.8.2.2 NOAA Fisheries Alaska Fisheries Science Center

Fisheries Behavioral Ecology Program, Newport, Oregon, USA

Bycatch-Related Gear Research

Michael W. Davis (michael.w.davis@noaa.gov)

In the past year studies with sablefish have shown the importance of fish size, physical injury, and behaviour impairment in determining delayed mortality rates in discards and escapees from net gear. Sablefish discards and escapees showed physical injury and behaviour impairment at a greater proportion in smaller fish than in larger fish. High-grading and discarding of smaller fish can result in increased unaccounted fishing mortality. Behaviour impairment was correlated with delayed mortality and may be a good measure of potential mortality for future use in field discard experiments. Behaviour impairment may be an important source of unaccounted mortality through predation on discards and escapees from trawling operations.

Performance of Baited Fishing Gear

Al Stoner (al.stoner@noaa.gov)

Capture of fish with baited fishing gear depends upon feeding motivation, movement patterns, and sensory capabilities in the target species as well as the design of gear. In 2003, feeding trials in large laboratory tanks were completed to determine how changing environmental variables influence responsiveness of Pacific halibut and sablefish to baits. Light level had a strong effect on ability of halibut to locate baits and attack rates, consequently depth, season, and time of day will impact the efficiency of baited gear. Social facilitation in halibut feeding motivation will affect density-dependent, non-linear capture rate functions. In sablefish, feeding motivation was strongly influenced by both water temperature and food deprivation. Population sizes based upon baited gear surveys can be greatly underestimated in conditions where environmental variables such as light, temperature, and fish density reduce locomotion, feeding motivation, or bait location.

Trawl Efficiency Research

Cliff Ryer (cliff.ryer@noaa.gov)

Efficiency of trawl gear relies upon fish herding in response to the approaching gear. Responses by flatfishes to simulated passage of trawl sweeps were examined in a large laboratory flume equipped with controlled light, infrared illuminators and video cameras. Ambient illumination influenced the behaviour of northern rock sole, Pacific halibut and English sole. Under conditions where fish could see the approaching gear, they lifted off the bottom in advance of the sweep and initiated herding behaviour. In darkness, the fish were often struck by the gear, and when they did respond, they typically rose into the water column, letting the gear pass beneath them. This suggests that the sweeps on bottom trawls may be relatively ineffective at stimulating herding behaviour in flatfish at night or at great depth, influencing catch rates.

NOAA Fisheries Alaska Fisheries Science Center

Conservation Engineering Project, Seattle, Washington, USA, Contact: Craig Rose (craig.rose@noaa.gov)

Our research focused on developing a salmon excluder for pollock trawl fisheries. Prototype devices, based on the superior swimming ability of salmon, were built and test fished with cameras and the DIDSON sonar (rapid-update, high-resolution). Effectiveness experiments during late summer and winter fisheries indicated low pollock loss (2–5%), but limited salmon escapement (10–12%). Problems with salmon returning to the main trawl from the recapture net during haulback may have affected escape estimates.

NOAA Fisheries Alaska Fisheries Science Center

Survey Trawl Gear Research, Seattle, Washington, USA

Effect of differences in port and starboard warp length on bottom trawl geometry

Ken Weinberg and Dave Somerton (Dave.Somerton@noaa.gov)

A research cruise was conducted in September 2003 to examine the effect on the geometry of the 83-112 Eastern trawl (the standard Bering Sea survey trawl) caused by differences between the lengths of port and starboard warps. Primary emphasis was placed on the bottom contact at three positions along the lower bridles as well as at five positions along the footrope measured using recently developed versions of the AFSC bottom contact sensor. Differences of 3, 5, 7 (the maximum allowed under the new U.S. National Bottom Trawl Survey Protocols), 9, 11 and 20 meters were considered. Results of the experiment will be presented at the 2004 FTFB meeting.

Effects of autotrawl systems on bottom trawl geometry

Stan Kotwicki and Ken Weinberg (Ken.Weinberg@noaa.gov)

Included in the above research cruise, an experiment was conducted to examine the effects of using a constant-tension auto-trawl system, a Scantrol symmetry auto-trawl system and locked winches on trawl geometry. Wing spread, door spread, headrope height, distance off bottom at three points along each bridle and at five points along the footrope were measured. Aspects of trawl geometry that were considered include bilateral symmetry, mean distance off bottom and variability of bottom contact along the bridles and footrope. Results of the experiment will be presented at the 2004 FTFB meeting.

Effect of surface waves on the variability of trawl bottom contact

Dave Somerton (Dave.Somerton@noaa.gov) and Ken Weinberg

Ship roll, pitch and heave data were collected during all aspects of the above research cruise and are now being analyzed to determine how ship motion influences bridle and footrope contact. Although surface waves are known to influence trawl efficiency, none of the surveys considered under the U.S. National Bottom Trawl Survey Protocols explicitly specify the maximum sea state allowed before survey operations must be suspended based on trawl efficiency, rather that crew safety, issues. The objective of this study is to determine if such an operational protocol can be specified. Analysis is in progress.

Effects of increasing wing spread with depth on the CPUE of bottom trawl surveys

Paul von Szalay and Dave Somerton (Dave.Somerton@noaa.gov)

Unless restrictor cables are used, trawl wing spread will increase with depth due to increasing warp length. Many surveys compensate for the increase of swept area by measuring wing spread and tow length then computing CPUE based on actual area swept. This correction, however, assumes that trawl efficiency remains constant. In this study, 15 years of Bering Sea survey data on catch, depth and wing spread were analyzed to demonstrate that CPUE decreases with increased wing spread independent of depth. For strict benthic species, this effect is related to an increase in off-bottom distance measured at the centre of the footrope, however, the effect is much greater for sessile organisms like starfish than it is for actively swimming fish species. A manuscript on this study will soon be submitted to Fisheries Research.

11.9 England and Wales

11.9.1 CEFAS, Lowestoft, UK

a) Main gear technology related projects undertaken during April 2003 – April 2004
b) Trials with benthic release panels to reduce the environmental impact of beam trawling in the English Channel beam trawl fishery.
c) Trials with reduced headline height aimed at reducing the bycatch of cod in the North Sea beam trawl fishery.

d) Review of technological innovation in the capture fishing industry and the likely effects upon environmental impacts.
e) Aquarium based trials with water jets as alternative stimuli to tickler chains.
f) Investigations into the abrasive resistant properties of fishing twines

Main gear technology related projects planned during April 2004 – April 2005

g) Further trials with benthic release panels to reduce the environmental impact of beam trawling in the English Channel beam trawl fishery.
h) Trials to reduce the unwanted fish bycatch in the Farne Deeps *Nephrops* (North Sea) fishery
i) Trials with increased cod end mesh sizes in the English Channel beam trawl fishery
j) Further investigations into the abrasive resistant properties of fishing twines

11.9.2 SEAFISH, Hull, UK

Main gear technology related projects undertaken during April 2003 – April 2004

a) Semi-pelagic trawl development in Cornwall inshore fisheries and development of trawl control systems
b) *Nephrops* size selectivity trials
c) Further development of fish excluding *Nephrops* trawl
d) EU cod RECOVERY project, modelling devices to separate out cod
e) Co-management in the Firth of Clyde as a means of improving uptake of technical conservation measures
f) evaluation of cetacean-deterrent acoustic pingers

Main gear technology related projects planned during April 2004 – April 2005

a) Further development of fish excluding *Nephrops* trawl for 800HP vessels
b) EU cod RECOVERY project, modelling devices to separate out cod
c) EU NECESSITY project on *Nephrops*
d) Continuing semi-pelagic trawl development in Cornwall inshore fisheries and development of trawl control systems
e) Continuing co-management in the Firth of Clyde as a means of improving uptake of technical conservation measures
f) Endurance and infrastructure trials on cetacean pingers

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11.10 Ireland, BIM, Dublin

Inclined Separator Panel

During 2003 several trials were carried out in ICES Area VIIg following consultation with industry representatives and to address discard problems in identified fisheries. In February-March, trials testing inclined separator panels in the *Nephrops* fishery on the Smalls grounds off the Cumbria coast for separating juvenile roundfish species from *Nephrops* catches were carried out on a 24m twin-rig vessel. These trials followed on from work carried out since 2000 in the Irish Sea as part of the EU Cod Recovery Programme looking at the potential use of the inclined separator panel to release spawning cod from *Nephrops trawls.* Data on size separation of roundfish species from *nephrops* along with a preliminary analysis of the potential economic loss to fishermen in terms of loss of marketable *nephrops* and commercial fish catch of using the inclined separator panel in this fishery was collected.

Whitefish Selectivity

Also during March-April 2003, trials were completed looking at the potential impact of using 110 mm and also 90 mm full square mesh sections fitted to standard rockhopper trawls in the traditional spring whitefish fisheries (cod, haddock and whiting) in the Celtic Sea off the south-east coast of Ireland. These trials were carried out on two Irish whitefish vessels as catch comparison exercises over 20 day periods. They provided data on the potential reduction on discards and an assessment of the economic implications to the fishery of increasing codend mesh size to 110 mm from 100 mm and also of installing full top and bottom sheet sections of knotless square mesh panels in standard trawls used by Irish vessels in this fishery.

Queen Scallop

Other gear research work in 2003 in Ireland has looked at the use of simple release panels in rockhopper trawls used in the Queen Scallop fisheries in the north-west and south-east coast fisheries, as well as release panels in crab and lobster pot fisheries to prevent "ghost fishing" by lost pots. An ongoing assessment of the national V-notch lobster scheme introduced in Ireland in 1995 has also been continuing on a nationwide basis.

Acoustic Deterrents

Following on from work commenced in 2002, further trials testing the effectiveness of acoustic "pingers" and a prototype triggered acoustic deterrents to minimise the bycatch of cetacean species in the Irish Albacore tuna pair pelagic trawl fishery were carried out on two pairs of vessels in the summer of 2003 in the Bay of Biscay. The remotely triggered acoustic device developed specifically for use in trawls was designed in conjunction with Loughborough University and the UK acoustics company Aquatec Subsea Ltd and is activated manually whenever there is deemed to be a risk of dolphins might be in imminent danger of being caught. While the results have been promising the trials have identified that due to the sporadic nature of bycatch it is difficult to establish the extent of this problem and in exactly which fisheries. It has been found that it is imperative to establish under what conditions and during which phase of the fishing operation the animals are caught in pelagic trawls, as this remains largely undetermined. Earlier experiments have only resulted in indicative conclusions, such as the animals are feeding on fish caught and consequently retained in the trawl during hauling.

Project NECESSITY

Due to these identified gaps in knowledge BIM (Irish Sea Fisheries Board) will be participating in the EU funded study NECESSITY over the next 3 years along with a number of other fishery institutes, commencing March 2004. Along with an analysis of cetacean reaction and behaviour to pelagic fishing gear, as part of this project BIM will also be working with Aquatec Subsea Ltd to develop an interactive acoustic deterrent device. The prototype device developed will be for deployed in pelagic fisheries with an identified cetacean bycatch over the duration of the project.

In addition, as part of the EU NECESSITY project, trials looking at acceptable gear modifications in the Celtic Sea *nephrops* fishery including the use of coverless trawls and inclined separator panels will be carried out in 2004 jointly on Irish and French vessels. This work will be supplemented by joint national research being carried out by BIM and the Irish Marine Institute attempting to assess the consequences of technical conservation measures on stock development for selected Irish fisheries through the inputting of appropriate selectivity data in simulation model being developed by the Marine Institute. The Irish Sea cod stock and the impact of the EU cod closure are being used as a pilot study for this work

Project DEEPNET

BIM and the Marine Institute are also involved in a joint collaboration project (DEEPNET) with the Norwegian Marine Institute and the Seafish Industry Authority in the UK investigating the impact of "ghost nets" associated with the Anglo Spanish tangle net fishery for monkfish and deepwater shark species fishing off the west coast of Ireland and Scotland and in international waters west of Rockall and at the Hatton Bank. This study involves a description of the development and current level of effort of this fishery, simulation studies assessing discarding and spoilage rates in this fishery as a result of excessive soak times, as well as putting forward recommendations to EU and NEAFC for the future management of these fisheries, which are currently largely unregulated.

11.11 Spain

Fishing Technology related projects carried out at AZTI Fundación (Technological Institute for Fisheries and Food) by the Marine and Fishing Gear Technology Research Area.

*A study to identify, quantify and ameliorate the impacts of static gear lost at sea (FANTARED **2)**. Financial Support: EU; EC-FAIR-CT98-4338.*

The study aims at evaluating the extent and impact of the loss of static fishing gears in European waters in collaboration with other European research centres. The first approach of the study has been to characterise the main reasons for loosing gillnets and quantify the amount of gear lost in the different types of gillnet fisheries. Later on a experiment to characterize the fate of experimental lost tangle nets (*rasco* nets) was carried out in order to study their evolution both in summer and winter starting conditions. Information on species caught and their stage were recorded to estimate the catch rate of the nets in the short, medium and long term. The results focus on the evolution of fish catch rate compared to commercial *rasco* nets. An estimation of the residual mortality of lost tangle net is provided and estimated “ghost catches” are compared with the annual catches of the commercial fleet in the Cantabrian Sea (ICES sub-area VIIIc). Although the study shows that the residual catches due to lost nets are of minor importance (monkfish catches due to lost nets have been estimated to represent 1.22% of the annual commercial landings) recommendations are made so as to minimize the gear losses.

Final report of the project submitted and approved in 2003.

Artificial baits alternatives mainly based on fish waste (ARTIBAIT). Financial Support: EU, Contract Nº Q5CR-2000-70427.

The aim is to develop artificial bait for hake and other commercial deepwater species based on waste from fish processing plants. The bait should have better or similar effectiveness than the natural bait (such as sardine, squid and mackerel); a competitive price compared with the natural bait and should be more adequate than the natural bait for mechanised longline. Several fishing trials hade been performed to estimate the catch performance of different bait preparations giving promising results for some commercial species.

Final report of the project submitted in 2003.

*Mechanization and automatization of the mackerel hauler/reel in the hand line fishery (Projects RP2002238 and RP2003257). Financial Support: Department of Agriculture and Fishing/Basque **Government***

In the mackerel fishery with hand lines a large number of hooks are moving dangerously on deck. To improve safety on board, several hauler prototypes have been selected and tested on commercial fishing conditions. In the end, an automatic hauler for catching mackerel has been developed that coil the lines with hooks in a reel. An assessment of the performance of the first prototypes has been done (safety, ergonomics, catch rates,…) and modifications on the design had been suggested. New fishing trials are planned for 2004 with the modified prototype in order to make a final assessment of the hauler performance.

The project is under way (2003-2004).

Evaluation of the artisanal fishing sector in El Salvador in order to define a cooperation project on the development of the fishing communities. (Project RP2003SALVADOR). Financial Support: NGO Mugen Gainetik.

The project aims at evaluating the present situation of the small scale fishing sector in El Salvador in a broad meaning (marine resources, fishing technology, aquaculture, conservation, process and commercialisation of the fishing products) in order to establish technical criteria for the definition of a cooperation project for the development of the Salvadorian fishing communities. A technical mission was carried out in El Salvador (Nov. 2003) visiting the most representative fishing communities of the country and contacting with fisheries minister representatives to collect technical information. A final report is going to be produced in 2004 establishing guidelines of cooperation initiatives in El Salvador artisanal fishing sector.

The project is under way (2003-2004).

*Evaluation of the artisanal fishing sector in Chile in order to define a technical programme on the development of the small scale fishing. Project RP2003CHILE. Financial Support: Department of Agriculture and Fishing/Basque **Government.***

The objective of the project is to evaluate the condition of the artisanal fishing sector in Chile particularly in the fields of fishing technology, fish handling, conservation and processing. In the end the project will identify and define potential technical projects to improve the present situation in the previously mentioned fields. An evaluation visit to some of the main artisanal fishing communities of the country (Dec. 2003) has provided information on the present situation and has allowed to identify the main technical needs. A final report is going to be issued in 2004 covering among others the definition of a technical programme for the improvement of the artisanal fishing sector.

The project is under way (2003-2004).

Testing of safety equipment for fishermen onboard fishing vessels. Project RP200241. Financial Support: Department of Agriculture and Fishing/Basque Government.

Several safety equipment have been selected to be tested on commercial fishing conditions in order to improve the fishermen work conditions: face protection helmet for the pole and line tuna fishery, portable personal beacon for incidents with fishermen falling at sea, fishermen clothes for safety and comfort. Different technical equipments have been selected and preliminary tested on commercial fishing conditions and by means of preference tests; some others need to be developed (face protection helmet). Trials on the equipments will continue in 2004.

The project is under way (2003-2004).

Technical study of the artisanal fisheries of the Basque Country (Northern Spain) in order to establish the basis for their regulation. Project RP2003015. Financial Support: Department of Agriculture and Fishing/Basque Government.

Artisanal fisheries are seen as an important fishing sub-sector for the maintenance of the coastal communities. The study aims at compiling the previous technical information regarding fishing gear performance to provide the basis for the improvement of the present regional fishing regulation.

Special attention is paid to the gillnet fisheries which have experience the more dramatic changes in the last years in terms of fishing effort. Fishing trials have been carried out at sea on board commercial vessels to improve the knowledge of the species and size selectivity of the small gillnet fisheries targeting a wide variety of fish species. As a complementary study, experimental work has been done to characterise the sediment characteristics of the fishing grounds in the inshore area in order to establish the relationship between type of sediments and fishing resources in an attempt to establish the basis for the cartography of fisheries resources in the coastal area.

The project is under way (2002-2005).

Development of an electronic log-book for the Basque fishing fleet. Project RP2002227. Financial Support: Department of Agriculture and Fishing/Basque Government.

In the last years, AZTI has developed and provided to the Basque fishing fleet an electronic catch reporting software for on board utilization. The aims of the project is to help fishermen to better manage the information regarding fishing activities using information from the individual fishing operation, as well as to get detailed information on the activities of the fleet to improve the fisheries data base used by AZTI in fisheries monitoring and fish stock assessment. Training on the use of the software and preliminary trials of the equipment were performed in the summer tuna fishing season.

As a result, several improvements on the software and the data collection were made. New trials are planned for the next summer fishing season. The long term aim of the project is on one hand that the electronic log-book becomes a routinely tool for fishermen, on the other hand to guaranty the collection of complementary information for fisheries monitoring on a routinely basis.

The project is under way (2002-2005).

Development and testing of a new objective mesh gauge (OMEGA). Financial Support: EC contract– Q5CO-2002-01335.

AZTI has been subcontracted by the Spanish Inspectorate Services of the Agriculture and Fisheries Ministry (an OMEGA partner) to carry out comparative tests on mesh size measurements between anew objective mesh gauge prototype (OMEGA gauge), developed within the project partnership, the EU gauge used for inspection purposes and the ICES gauge used by the scientific community. The mesh measurement test will be done in 2004 on a wide range of netting materials used in the different Spanish fisheries. AZTI has contributed to the organization of the 1st OMEGA Workshop in Bilbao (October 2003) in which the new mesh gauge was presented to the potential users.

The project is under way (2003-2005)

Fish Aggregating Devices as Instrumented Observatories of Pelagic Ecosystems (FADIO); Financial Support: EC contract QLRI-CT-2002-02773

The general objective of the project is to develop prototypes of new autonomous instruments (electronic tags and instrumented buoys) to create observatories of pelagic life. The project tries to establish the first steps towards the development of new methods for providing meaningful indices of local abundance based on data collected by pelagic observatories deployed either singly or in networks. Nine European partners are involved in the project. AZTI is mainly involved in the description of the fishing fleet activity in relation with fishing aggregating devices (FADs), the characterisation of the fishermen experience in relation with FAD colonisation, as well as the study of the collective tuna fish behaviour using the technological developments of the project.

The project is under way (2003-2006).

AZTI Remote Sensing Service. *Project RP2002007. Financial Support: Department of Agriculture and Fishing/Basque Government.*

AZTI has been studying remote sensing in relation with pelagic fisheries. AZTI HRPT Ground Station receives and processes data from NOAA, SEASTAR and FENGYUN satellites to obtain SST images and isotherms and chlorophyll 'a' concentrations maps. By means of HF transmission AZTI is sending these maps during the tuna fishing season to the Basque coastal tuna fishing fleet. From the 2002 fishing season on the Service has included altimetric and weather maps. The aim of the project is to provide basic oceanographic information to the fishing fleet in order to detect areas of maximum probability of catching tuna and to reduce the time and energy costs of searching for fish.

The project is under way (routinely project).

Summary of the work to be conducted between 2004 and 2005, Spain.

Excepted FANTERED 2 and ARTIBAIT projects, most of the projects described in the progress report 2003 will continue during 2004; some of them will last until 2005 (see lifespan of each project).

In addition to this project, AZTI is involved as a partner in the European project NECESSITY (*Nephrops* and Cetacean Species Selection Information and Technology; UE 6th FP contract # 501605) in the part of the project dealing with the minimisation of the cetaceans bycatch in pelagic fisheries by means of selective or acoustic devices as well as alternative fishing tactics. The project has started in April 2004 and will finish in 2007.

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11.12 Sweden

11.12.1 Institute of Marine Research, Fisheries technology group. P-O Larsson, M. Sköld, M. Ulmestrand and D. Valentinsson

Reduction of fish bycatches in Nephrops trawls by grid and square meshes in the codend

Species selectivity trials in *Nephrops* trawls carried out in 2002 was analysed and reported during 2003. Results show that a grid with 35 mm bar space, in combination with 70 mm square mesh, using a codend and extension piece of 8 m total length, significantly reduce the bycatch of fish. There was no significant reduction of full-sized *Nephrops*. Current regulations for *Nephrops* trawls, specifying 70 mm diamond mesh, imply that more than 1800 tonnes of protected undersized commercial bycatch species are caught and discarded each year. Assuming that trawling effort does not change, the results from this study indicate that discards in the Skagerrak/Kattegat *Nephrops* trawl fishery could be reduced to one fourth of current level, i.e. to about 400 tonnes per year. Beside the bycatch reduction, the resulting improvement in species selection would also simplify management of the target species as log book data on landings and effort targeting *Nephrops* more easily could be distinguished from other fishery in the log book.

Improved selectivity in roundfish bottom trawls

The work with BACOMA windows in cod bottom trawls in the Baltic Sea continued in the spring 2003, aiming to find a suitable mesh size to meet the MLS of 38 cm in that area. A mesh size of 110 mm proved to have a L_{25} close to 38 cm, while the current minimum size, 120 mm, gave a L_{25} of ca 42 cm. This led to a change in the regulations to 110 mm as minimum mesh size.

Species selectivity in eel fyke nets; reduction of cod bycatch.

Fyke netting for eel is identified as one of the more non-selective fishing methods in the Skagerrak/Kattegat inshore fishery. This fishery catches large numbers of juvenile cod during April-November each year. A series of bycatch reduction trials was initiated in 2003. Promising results in cod bycatch reduction (cod size +20 cm) was achieved with a stop-net (30-43 mm bar length) mounted on the first entrance of the fyke net, with only minor losses of marketable eel.

However, the results also indicated increased catchability for 0-group cod (8-16 cm) during the autumn months. Further research and development of possible gear modifications is needed.

Studies on fish behaviour in relation to gears.

Fish behaviour has been registered by under water video recording trying to find species selective measures based on specific behaviours. Two fisheries were considered in 2003, vendace (*Coregonus albula*) trawling in the northern Baltic Sea and eel fyke nets at the Skagerrak coast.

In the former case the behaviour of vendace in relation to grid and square mesh panels was filmed with a camera inside the trawl. Trawling for vendace is performed during spawning which is mainly in October. At that latitude (close to the polar circle) the low light intensity created difficulties to get good shootages in the trawl.

In the latter case cod and eel behaviour was studied when approaching an eel fyke net and also within the net. The results were however non-consistence and therefore difficult to interpret.

Effects of bottom trawling on sediment and benthic fauna

In 1996/97, an extensive manipulative experiment investigating the effects on benthos of trawling for *Pandalus borealis* in Gullmarsfjorden was performed. In 2003 a follow-up experiment was planned and initiated. The repeated experiments runs over two consecutive years (2003-2004) and will study the long-term effects of shrimp trawling on infauna, epifauna and sediment characteristics in a temporally and spatially replicated design.

Quantifying amounts of lost cod gill nets in the Baltic Sea, and retrieval experiments

A third expedition was undertaken in 2003 using a further developed retrieval gear with a standard grapnel/hand line as control gear. The new gear performed well and with its six grapnels it has a much wider coverage of the bottom. During 9 sea days 48 samples were taken covering 370 km^2 of the investigated area (1940 km^2). A total of 17 km of lost netting was retrieved, some of it being older than 10 years, which can explain the small cod catch, totally only 55 kg.

11.12.2 Institute of Coastal Research. T. Aho

Improved size selectivity in vendace bottom trawls

The selectivity work in vendace bottom trawls is targeted at selecting out the juvenile fish from the catch. A selection panel with Swedish Exit Window meshes were tested in bottom trawls and the selectivity was compared with the ordinary square mesh panels commonly in use in the vendace trawls. No statistic significant difference was found between the two methods, although the selection efficiency of the Exit Window panels tended to be higher. Not all fishermen reported which method they had in use, which makes the results unclear.

A pilot test with a 9 mm selection grid was done, and the results were promising.

Improved size selectivity of a seal-safe wire-pot for perch fishery

Traditionally along the Gulf of Bothnia a small wire trap-net (pot) has been used in the perch fishery as a complement to gill-net fishing. However, the proportion of smaller fish in the catches tend to be high. Therefore, in order to improve the selectivity of the pots, three selection grids were tested in collaboration with fishermen along the Gulf of Bothnia. The largest mesh size tested was clearly the most effective in selecting out the smaller perch.

Planned work 2004-2005.

Institute of Marine Research, Fisheries technology group. P-O Larsson, M. Sköld, M. Ulmestrand and D. Valentinsson.

Reduction of fish bycatches in Nephrops trawls by grid and square meshes in the codend.

Further development and documentation of the species selective properties of using grid and full square mesh codends is planned for 2004. This is also the starting year for the EU-project NACESSITY, in which we will participate.

Improved selectivity in bottom trawls

Plans for 2004 include testing of a prolonged BACOMA window in Baltic cod trawls. Fishermen have experienced reduced selectivity with large catches, probably when the catch bulb reaches ahead of the BACOMA window. The tests aim at showing if there are problems with gear behaviour or catching efficiency with a longer window.

In the herring bottom trawl fishery in the southern Baltic Sea, cod are frequently caught, and periodically juvenile cod appear in large amounts as bycatch. Raised foot-rope will be tested aiming at reducing such bycatches.

Survival of cod escaping from trawls

Cod escaping from a trawl, while fishing at the bottom, have been shown to have in most cases a very high survival, close to 100%. When the haul is finished and, especially with side trawlers, the trawl is resting for a while when preparing for lifting the catch on board, more meshes open and some cod escape, in some cases in large numbers. Those cod, escaping close to the surface, certainly have a higher mortality, due to higher pressure and temperature differences, exhaustion in the end of a haul, vulnerability to predation by sea gulls, and so on. This mortality is difficult to estimate, but trials are planned to study that in 2004, principally based on the collecting method used by Suuronen *et al*. (Assessment of mortality and skin injury of Baltic cod (*Gadus morhua*) that escape from trawl codend under commercial fishing conditions. ICES CM 2002/V:23).

Species selectivity in eel fyke nets; reduction of cod bycatch.

The promising results achieved in 2003 will be followed up. It is however clear that further development of the stop-net gear modification described is needed as catchability for 0-group cod tended to increase. One promising idea is to place an escape opening for 0-group cod in the roof of the first compartment of the fyke net. Further development and field testing will be carried out in close collaboration with the industry.

Studies on fish behaviour in relation to gears.

Further studies on fish behaviour will be performed using a new under water video camera, which will be used in most of the selectivity experiments.

Effects of bottom trawling on sediment and benthic fauna

The follow-up study on the long-term effects of shrimp trawling in Gullmarsfjorden will run over both 2003 and 2004. The results will be published in a scientific journal.

Quantifying amounts of lost cod gill nets in the Baltic Sea and retrieval experiments

An interview survey of gill net fishermen will be done aiming at identifying potential host areas for lost nets. Those areas will be searched, using the new developed retrieval gear, during the cod fishing closure in the summer of 2004. Attempts will be done to estimate the total amount of “ghost nets” emanating from the Swedish gill net cod fishing fleet, and the unaccounted cod mortality caused by them.

Institute of Coastal Research. T. Aho

Improved size selectivity in vendace bottom trawls

A full scale experiment with a 9 mm and 11 mm selection grid will be carried out in the Bothnian Bay. Together with the selectivity, the behaviour of fish will be studied by underwater video recordings.

Improved size selectivity of a seal-safe wire-pot for perch fishery

Survival of the perch that has passed through the selection panel on the wire pots will be studied in collaboration with fishermen in the Bothnian Bay.

12 New business

12.1 Recommendations

12.1.1 Date and venue for 2005 WGFTFB Meeting

WGFTFB proposes a five-day meeting in 2005 at the FAO premises in Rome, Italy. A 5-day meeting was deemed necessary due to the high workload expected. The suggested dates are Monday 18-Friday 22 April 2005.

12.1.2 Proposed Terms of Reference for the 2005 WGFTFB Meeting

The ICES/FAO Working Group on Fishing Technology and Fish Behaviour (WGFTFB) (Chair: Dr. Norman Graham, Norway) will meet in Rome, Italy, from 18–22 April 2005:

a) bycatch in shrimp trawl fisheries;
   - i) to review and evaluate recent technical developments in bycatch reduction;
   - ii) to estimate global usage of bycatch reduction in shrimp fisheries;
   - iii) to review implementation plans in shrimp fisheries;
   - iv) to assess adequacy of size selection in shrimp fisheries.

   (Thomas Moth-Poulsen, Mass. Div Marine Fish, Wilfried Thiele, FAO Rome, and Norman Graham, IMR, Bergen)

b) to address some issues relating to legislation on technical conservation measures relating to fishing gear design;

   (Dick Ferro, FRS, Aberdeen and Dominic Rihan, BIM, Dublin)

c) review work done, identify information gaps and recommend research priorities on interaction between fishing gear; and
   - i) pipelines and other sub sea structures;
   - ii) cuttings piles.

   (Dick Ferro, FRS, Aberdeen)

d) review the use of multiple size selection devices in towed gears;

To work by correspondence and meet at the WGFTFB meeting 2005 and report to the WG in 2006
   - i) review recent trawl size selection experiments where multiple selection systems have been assessed, e.g. square mesh panels, grids etc., considering the impact on the target and bycatch species;
   - ii) review developments in modelling multiple selection data;
   - iii) consider practical issues relating to additional measures such as on board handling and material strength and enforcement issues.

   (Norman Graham, IMR, Bergen and Barry O'Neill FRS, Aberdeen)

e) explore the potential for alternative fishing gears for traditional species that are environmentally friendly and a responsible fishing method;

To work by correspondence and meet at 2005 WGFTFB meeting and report at the 2006 WGFTFB or the ICES Symposium on Fishing technology in the 21st Century

   (Bjarti Thomsen, Faores)

Supporting information

Priority	The current activities of this Group will lead ICES into issues related to the effectiveness of technical measures to change size selectivity and fishing mortality rates. Consequently these activities are considered to have a very high priority
Scientific justification	Action Item 3.1, 3.2, 3.16 -a Action Item 3.16 –b Action Item 2.13 -e Action Item 3.16 –d Action Item 3.17, 3.18 –e a) Shrimp trawl fisheries (including *Nephrops*) are generally associated with the highest levels of discarding. Globally, a considerable amount of research has been conducted into technical gear modifications to minimise the degree of unwanted bycatch, some of mandatory in a number of fisheries. The objective of this TOR is to review the state of the art with respect to technical development, global usage and the current plans to implement such devices into commercial fisheries and to provide estimates of the potential benefits to fish stocks. b) This could provide technical assessment of the problems to inform decisions on the need for changes in this legislation e.g. changes to European legislation EC 850/98. i) There has been a trend to increase mesh size in many fisheries in order to improve selectivity. Larger mesh size codends will expand to greater diameters and hence each twine will support a proportionally greater volume and weight of fish. For safety reasons it can be argued that these codends should be strengthened and this is most easily done be done by altering twine thickness or the number of open meshes around the codend circumference or by using a lifting bag. It is known that these features of codend design also influence selectivity and may reduce the effect of the initial mesh size increase. ii) Currently in many fisheries twine thickness is limited to a maximum value. Twine stiffness rather than thickness may be the characteristic governing selectivity. Evidence of

	these effects needs to be assessed. iii) meshes with unequal sides are banned in European legislation because selectivity may be reduced with codends made of such netting. It is doubtful whether a prosecution would succeed since there is no accepted means to measure the sides of a mesh (bar length). Formulation of a suitable definition of bar length should be considered. iv) fishermen have complained that an increase in mesh size disproportionately affects certain sectors of the fleet, which are thereby at an economic disadvantage. It is claimed that gears (such as seines) are already highly selective or have less impact on the environment. It is also asserted that lower powered vessels cannot take action to limit the increase in selectivity (e.g. by increasing towing speed). An assessment of these claims using all available evidence is required. c) The oil/gas industry in the NE Atlantic has matured and abandonment of structures at the end of their useful life is being considered. Policies and strategies for abandonment which need to be formulated by national governments should be informed by knowledge of interactions of fishing gear with associated sub sea structures and residues in order to assess potential problems such as loss of fishing opportunities, damage to fishing gear, safety to fishermen and fishing vessels and pollution. ICES is an appropriate body to collate existing knowledge and review the need for further work. In particular there are recent proposals to install larger diameter (bundled) pipelines, which, over substantial distances, may not be buried or trenched. Work has been done and is planned on interaction of fishing gear and these pipelines. Mitigating measures have also been devised for many sub sea structures on the basis of model or full-scale trials but the information is not easily available. Drill cuttings piles, which have accumulated under drilling platforms, may be of the order of 10m high and may contain hydrocarbon and heavy metal residues. These cuttings piles could be left on the seabed after the removal of abandoned drilling platforms. The interaction of fishing gear with them is unknown. There are issues of dispersal rates and the initial impact with fishing gear components. d) There are a considerable number of fisheries worldwide that have mandated the use of additional devices (other than codend mesh size) for adjusting size selection. These include the use of escape panels (BACOMA etc) and grids such as the Sort-X There is an increasing volume of evidence that suggests that, in some instances, the same effect can be achieved simply by increasing the mesh size. The introduction of such devices this may place an additional financial cost on the fishermen and complicate legislative procedures may be important considerations. In other fisheries, particularly multi-species, the benefits of such devices are that they are more effective with one species (or group) while not impacting on others, square mesh panels and *Nephrops* trawls being one example. There may also be other benefits for managers; for example, these ‘additional’ devices may provide more predictable selectivity. e) Many fishing practices are essentially the same as when developed centuries ago. Many are energy inefficient and are deleterious to the environments. Here we aim to use the natural behavioural patterns of fish to develop energy efficient non-deleterious harvesting practices that may have applications in fisheries worldwide.
Resource requirements:	The research programmes which provide the main input to this group are already underway, and resources already committed. The additional resource required to undertake additional activities in the framework of this group is negligible. Having overlaps with other meetings of expert groups of FTC increases efficiency and reduces travel costs.
Participants:	The Group is well attended
Secretariat facilities:	N/a
Financial:	None required. Having overlaps with other meetings of expert groups of FTC increases efficiency and reduces travel costs.
Linkages to Advisory Committees:	The questions of bycatch reduction and survey standardization are of direct interest to ACFM and seabed damage is of direct interest to ACE.
Linkages to other Committees or Groups:	This work is of direct relevance to the Working Group on Ecosystem Effects of Fisheries, WG on Fishery Systems, WG on International Bottom Trawl Surveys, Baltic Committee, Marine Habitat Committee, Resource Management Committee and Living Resources Committee
Linkages to	The work of this group is closely aligned with similar work in FAO

other Organisations:	
Cost share:	ICES: 100%

12.1.3 Workshop on Changing Expectations of Fisheries Based Advice

A Joint WGFTFB, SGDFF, SGFI and WGFS Dialogue Workshop on Changing Expectations of Fisheries Based Advice (Co Chairs: Norman Graham, (Norway). Paul Marchal, (France), Cornelius Hammer (Germany), and Martin Paastoors (The Netherlands)) will be established and will be held in February, 2005 in conjunction with NSCFP to:

a) discuss how to coordinate among the four groups the requirements for and inputs to, fishery-based forecasting;

b) discuss data needs and methods of collection of data from fleets and fisheries that would be valuable for assessment working groups and ACFM in fishery-based forecasting;

c) discuss the best way that the four groups can interface in providing information for fishery-based forecasts;

d) discuss a framework for monitoring developments in fishing technology; and

e) outline requirements for the quantitative assessment of the effects of gear technology (prediction of proposed changes or post-hoc analyses of implemented changes).

Supporting Information

Priority:	High: There are a number of new initiatives on fisheries-based forecasting that WGFTFB have been invited to participate in providing inputs relevant to ACFM changing expectations for advice. There is an urgent need to develop dialogue on this topic with several other ICES groups in order to coordinate the way forward.
Scientific Justification:	The objective is to provide a forum to discuss the interaction of WGFTFB, SGDFF, SGFI and WGFS in formulating requirements and inputs into fisheries based forecasting.
Relation to Action Plan:	Provide sound credible, timely, peer-reviewed, and integrated scientific advice on fishery management and the protection of the marine environment.
Resource Requirements:	No ICES resources
Participants:	Members of the four groups
Secretariat facilities:	None require above report compilation
Financial:	Specific funding requested from European Commission
Linkages to other Committees or Groups:	ACFM. ACE and all assessment groups
Linkages to other organisations:	None
Secretariat Cost:	ICES:100%

12.1.4 Study Group on Survey Trawl Standardization

A Study Group on Survey Trawl Standardization [SGSTS: TBA] (Chair: xxxxx) will be established and will meet in Rome, Italy from 16–18 April 2005 to:

a) review the current status of survey trawl design, recent developments in design and new technologies which could be suitable for application in revised survey trawl designs aiming to reduce trawl performance variability or for use in absolute abundance estimation, for example;
b) design and discuss the implementation of a generic ICES survey trawl standardization programme for all survey bottom trawls inside and outside the ICES areas;
c) design and discuss the implementation of a quality control programme for survey trawl procurement, construction, rigging, repair and maintenance;
d) define the requirements and analysis procedures to be used in inter-calibration studies;
e) publish the findings in an ICES Cooperative Research Report.

Supporting Information

Priority:	High: Bottom trawls provide fisheries independent data used in stock assessment of many commercial finfish and shellfish species worldwide. Minimizing survey variability is a key issue in developing accurate and reliable time series of abundance. ICES in 2003 have mandated that all users of survey gears within ICES should develop a programme of standardization.
Scientific Justification:	There are continuing developments in trawl design and instrumentation available for surveys. Requirements for surveys may be changing such as the possibility of absolute abundance estimates being needed as a result of lower reliability of fishery dependent data. In recent years there have been criticisms of protocols associated with some surveys. As a result of all these developments, it is recognised that a review and possible development of a new programme of standardization and quality control are needed. For example, a Study Group (SGSTG) has recently identified the need for some changes to current practice in the IBTS Western Waters surveys. It is proposed to review possible options for developing survey trawl design and at the same time to develop a generic programme of standardization which would achieve wider benefits to all survey users within ICES.
Relation to Action Plan:	Provide sound credible, timely, peer-reviewed, and integrated scientific advice on fishery management and the protection of the marine environment.
Resource Requirements:	No ICES resources
Participants:	Members of the WGFTFB, WGFAST, WGIBTS
Secretariat facilities:	None require above report compilation
Financial:	Specific funding requested from European Commission
Linkages to other Committees or Groups:	ACFM, ACE and all assessment groups
Linkages to other organisations:	None
Secretariat Cost:	ICES:100%

12.2 Advice requested from FTFB through IBSFC

1. Evaluate the appropriateness of the mesh sizes allowed in the Herring trawl fisheries (rule 10 of IBSFC Fishery Rules) in relation to the correspondence between mesh size and the herring population size structure.

WG Actions

Petri Suuronen and Ulrik Hansen will be contacted – to be coordinated by the WGFTFB Chair Norman Graham. A group of people will be set up to deal with this problem. A comment was made that many fishermen use T90 meshes to avoid the problem of stickers (e.g. Swedish and Danish herring fishers fishing in the Baltic).

2. When new data are available perform an evaluation of the selective properties of trawls using 90 turned diamond meshes and advice on appropriate mesh sizes corresponding to the BACOMA gear 110 mm window.

12.2.1 WG actions

See discussion in Section 8.5.

3. Advise on hook parameters (size, shape etc.) in long line fisheries that correspond with the minimum landing size of cod of 38 cm. Evaluate the relations between the numbers of hooks fished in longline settings and discard rates.

WG Actions

The WGFTFB agrees that insufficient information is at hand to deal with this issue during the present meeting. Guidelines will, however, be given on how to deal with the problem. Svein Lokkeborg (Norway), Mike Pol and Henry Milliken will be contacted to take up this task.

Item 1 and 3 should report to FTFB 2005 or earlier.

12.3 Proposals for ASC Theme Session 2006

12.3.1 Survey trawls

Presented by Norman Graham.

Survey trawls: current status, development, new technologies, standardisation and quality control

Bottom trawl surveys are the most important fisheries independent data source used in stock assessment of commercial groundfish. Representative sampling constitutes a key quality aspect of to all trawl survey indices and also in converting echo abundance in combined surveys. IBTS and FTFB WGs have put standardisation of gear design and rigging in international surveys on the agenda, and development of new survey trawls has been requested. Relevant behaviour studies that can contribute towards a better understanding of sampling variability are also needed. The effects of sampling time and trawl speed have also been found to affect the capture in terms of species and/or size selectivity.

Topics to be addressed include:

1) Power of the survey trawl to quantify abundance and stock structure for targeted commercial species, species assemblages and rare or invading species

   Justification: Evaluation of survey trawl data in large spatial or time scales can reveal trends not found in commercial landings that can give valuable information on structure changes in the ecosystem. To quantify the power of the survey trawl in this context requires analysis of large scale trends.

2) Effects of gear rigging on catch variability; particularly those related to bottom contact and sweep herding effects in different bottom types

   Justification: Information from trawl surveys is important both regarding indices for commercial species, as well as for understanding the ecological relationships between species. Information on distribution of rare or invading species is are often relegated, but it is valuable in ecosystem advice context.

3) Effects of haul duration and towing speed on catch variability

   Justification: Knowledge on the variable effects of haul duration and towing speed is insufficient, and proper documentation is lacking. When changes in survey protocol are implemented such information is required.

4) Relation between material use and quality

   Justification: Materials used in survey trawls can often be too weak for the application. Effects of fastened gear and repairs at sea are not quantified. To understand the implications of trawl material properties regarding the quality of data, relevant information must be collected and presented.

5) New developments in survey trawl design

   Justification: What advances have been demonstrated in survey trawl design and development? How can this improve our surveys and understanding of the ecosystems?

6) Behaviour of target species in the sampling situation

   Justification: Behavioural interaction between target species and sampling gear represents the basis of understanding variability and weaknesses of survey data. All quantifiable information on behaviour in the sampling situation will increase our knowledge and will eventually improve the accuracy and precision of survey indexes.

7) New instrumentation for survey trawls

   Justification: The documentation of the development and applications of sensors for measuring trawl parameters must be continuously updated to assure quality of survey trawls and data.

8) Quality control and variation in criteria for valid hauls

Justification: Knowledge on quality control protocols used within ICES is valuable for assessing uncertainty in survey results. To collect and catalogue such information represents a first step towards a successful application of quality control.

Discussion

It was stated that these are a comprehensive series of topics. There is, however, an ICES Symposium on Fishing Technology in the 21st Century in 2006 with a similar topic. It is advisable to drop this theme as a proposed theme for the ASC and to redirect efforts to the World Gear Symposium in 2006.

12.3.2 Use of data storage tags to reveal aspects of fish behaviour important for fisheries management

Presented by Norman Graham.

Conveners: David Somerton (NMFS, Alaska Fisheries Science Centre, USA, WGFTFB) and Julian Metcalfe (CEFAS, Lowestoft Laboratory, UK, WGFTFB)

Priority:	The current activities of this Group will lead ICES into issues related to the effectiveness of technical measures to change size selectivity and fishing mortality rates. Consequently these activities are considered to have a very high priority
Scientific justification:	The use of data storage tags has expanded greatly in recent years as the tags have become smaller and less expensive. Data from these tags has revealed detailed aspects of diurnal, tidal and seasonal movement patterns that influence our ability to assess and manage commercial species. For example, daily vertical migration can influence the availability of demersal species to bottom trawl surveys and has the potential of changing the target strength of pelagic species and thereby influencing their assessment by acoustic surveys. Likewise, the timing of seasonal migrations, relative to the time of assessment surveys, can change the proportion of the stock within the survey area and therefore change the effective catchability of the survey. Besides the use of data from data storage tags for stock assessment, such data may also have uses for fisheries management, especially the timing of permitted fishing periods. Presentations for both demersal and pelagic fish species are welcome. The use of data storage tags on commercial fish species has expanded greatly over the last decade as tags have become smaller and cheaper. Tag data has revealed new insights into the diurnal, tidal and seasonal movement patterns that affect our ability to assess and manage stocks. For example, daily vertical migration can influence the availability of demersal species to trawl surveys and has the potential of affect the target strength of pelagic species - thereby influencing their assessment by acoustic surveys. Likewise, the timing of seasonal migrations, relative to the time of assessment surveys, can change the proportion of the stock within the survey area and therefore change the effective catchability of the survey. In addition to its implications for stock assessment, such data is also useful for fisheries management, especially in setting the timing, location and size of Marine Protected Areas. Presentations for both demersal and pelagic fish species are welcome.

Discussion

There are doubts whether this is sufficient in terms of fish behaviour. There are also doubts whether there is enough work to report but there is an ongoing EU-project on this topic and work being done in Canada and the USA.

There is support from the WG for this Theme Session.

12.4 ICES/FAO Working Group on Fishing Technology and Fish behaviour Bill Dickson Prix d'Excellence (best of WGFTFB) Award

Polish members of WGFTFB proposed an award should be instituted in memory of Bill Dickson, in recognition of his contribution to gear technology. A Committee was nominated to discuss the different options for this prize to present their conclusions at this FTFB meeting. The committee includes Arill Engas, Dick Ferro, Erdman Dahm, Steve Walsh, Waldemar Moderhak and Andrzej Orlowski. Following conclusions were presented and adopted by WGFTFB:

Background

William (Bill) Dickson (died 01.02.2003) was one of the leading gear technologists of his generation. His career spanned many continents and his expertise and enthusiasm was shared with a number of institutes. He joined the Marine Laboratory, Aberdeen in 1952 where he established a research group in fish capture technology, which to this day, is one of the leading international groups in its field. Following his period in Aberdeen, Bill worked for the FAO in Rome (1964-68) where he was one of the key personnel involved in the production of the FAO Catalogue of Fishing Gear Design. Bill then worked as a project leader in both Cuba and Poland where, among other things, he supervised the building and run-in trials of two large fisheries research vessels. Between 1977 and 1999, he worked part time in Bergen, at the then Institute of Fishing Technology Research, fishing gear and methods division, where he published a number of important papers on the modelling of fish behaviour in relation to fishing gears.

His colleagues fondly remember Bill, for his humour and singing abilities as well as his scientific skills, and in recognition of this, the proposal by our Polish Colleagues for the WGFTFB to set up a Bill Dickson Memorial Prize was warmly received.

His widow has been approached and has welcomed the initiative.

Objective

This award, presented once every 3 years, honours the best, most exemplary contributions among WGFTFB members. This award is designed to extend formal recognition to WGFTFB members for their exceptional contributions. This may include, but is not limited to, a sustained high level of contribution exceeding normal expectations or a significant accomplishment in advancing the ideals of ICES and WGFTFB.

12.5 ICES Symposium

12.5.1 ICES Symposium on Fishing Technology in the 21st Centaury

The symposium will go ahead in Oct/Nov 2006 in New England with Co-conveners Chris Glass (USA), Bob van Marlen (Netherlands) and Steve Walsh (Canada).

13 Annexes

Annex 1 Table of Participants and associated theme groups WGFTFB Meeting Gdynia, Poland, 2004

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Bavouzet	Gérard	IFREMER 8, rue Francois Toullec, 56100-Lorient France gerard.bavouzet@ifremer.fr Tel. +33 297873830 Fax: +33 297873838	Efficiency increases
Dahm	Erdmann	Bundesforschungsanstalt f. Fischerei Institut für Fisschereitechnik Palmaille 9 D-22767 Hamburg Germany erdmann.dahm@ifh.bfa-fisch.de Tel: +47 40 38905188 Fax: +47 40 38905264	Baltic Cod (Convener)
Eigård	Ole	DIFRES, Charlottenlund Castle, 2920 Charlottenlund, Denmark ore@dfu.min.dk Tel: +45 33963300 Fax: +45 33963333	Efficiency increases
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Fonteyne	Ronald	CLO Sea Fisheries Department Ankerstraat 1 B-8400 Ostende Belgium ronald.fonteyne@dvz.be Tel: +32 59342254 Fax: +32 59330629	Mitigation measures
Glass	Chris	Director, Division of Marine Fisheries Center for Conservation Sciences 81 Stagepoint Road P.O. Box 1770 Manomet, MA 02345 USA glasscw@manomet.org Tel: +1 5082246521 Fax: +1 5082249220	Colour and Contrast
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Grimaldo	Eduardo	Norwegian College of Fisheries Science, Breivika 9037, Tromsø, Norway eduardog@nfh.uit.no Tel: 00 47 77 64 45 36 Fax: 00 47 77 64 60 20	Baltic cod selectivity
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Kotwicki	Stan	AFSC/NOAA, 7600 San Point Way NE, bldg 4 98115 Seattle, WA, USA Stan.kotwicki@noaa.gov Tel: +1 2065266614 Fax: +1 2065266723	Standardized trawl surveys (Joint session)
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Lucchetti	Alessandro	CNR, ISMAR - fisheries section Largo Fiera Della Pesca 2 60125 Ancona, Italy a.lucchetti@ismar.cnr.it Tel: +39 071 2078828 Fax: +39 071 55313	Efficiency Increases
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Polet	Hans	CLO Sea Fisheries Department Ankerstraat 1 B-8400 Ostende Belgium Hans.polet@dvz.be Tel: +3259342253 Fax: +3259330629	Rapporteur WGFTFB Role of FTFB in advice
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Thomsen	Bjarti	Faroese Fisheries Laboratory Noatun 1 P.O. Box 3051 110 Torshavn Faroe Islands bjartit@frs.fo Tel: +298 353900 Fax: +298 353901	Efficiency Increases (Convener)
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Annex 2 The reaction and behaviour of fish to visual components of fishing gears and the effect on catchability in survey and commercial situations Emma Jones, Chris Glass and Henry Milliken.

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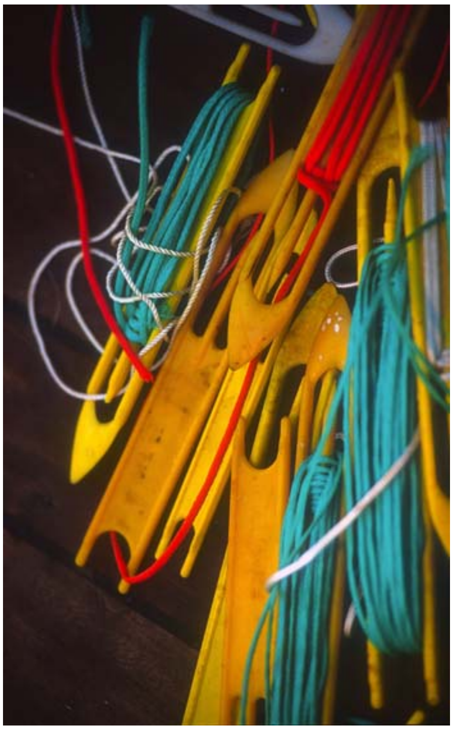
The reaction and behaviour of fish to visual components of fishing gears and the effect on catchability in survey and commercial situations.

Emma Jones
Chris Glass
Henry Milliken



1.0 Justification

It is widely acknowledged that environmental conditions, such as the underwater light field have a significant effect on fish catchability (e.g. ICES Coop. Res. Rep. 215, Wileman *et al.* (1996)). Past and current studies have also examined the effect of netting colour and contrast on the behaviour of fish. No synthesis of this work has been made but there are potential implications for both commercial and survey fishing operations.

In particular

- Review past studies on the use of the colour and contrast of fishing gear to modify fish behaviour and improve size and species selectivity.
- Identify current initiatives in this field and also studies encompassing the effect of varying light conditions on fish reactions to fishing gear.
- Gather information on the range of coloured twine in use commercially and the rationale behind these choices.
- Compile a list of recommendations on the use of coloured netting to improve selectivity in commercial nets and also possible techniques for improving the efficiency of survey trawls.

2.0 Background and Introduction

It is known that all species of fish commonly caught commercially in trawls and other fishing gears have well developed and efficient visual systems which have been found to be particularly well adapted to detect very small differences in contrast in the generally monochromatic underwater environment in which they exist. Many species, particularly fast swimming pelagic ones, have been demonstrated to have excellent visual acuity and low light sensitivity. Many commercially important fish species can form visual images at light intensities well below those at which human visual systems cease to perform. In some species these minimum light intensity thresholds occur at extremely low levels ($<10^{-6}$ lux) that are difficult to detect and measure reliably. Consequently, environmental conditions, such as the underwater light field have a significant effect on fish catchability (Wileman *et al.* (1996)). Observations of the reactions of fish to towed fishing gears have shown us that when light of one form or another is present fish are not sieved from the sea but react in quite subtle ways to the components of the gear. Light levels also influence the availability of fish to fishing gears and this subject is touched on, as it is not always straightforward to elucidate the relative importance of these two affects. Despite the excellent performance of fish visual systems, there will clearly be times and or depths at which their visual systems will cease to perform. We review studies that seek to elucidate the effects of varying light conditions on fish reactions to fishing gears with primary focus on trawl gear.
A number of studies have examined the effect of netting colour and contrast on the behaviour of fish, however, until now no synthesis of this work has been attempted. Here we review past studies on the use of colour and contrast of fishing gear to modify fish behaviour and improve size and species selectivity, and identify a number of current initiatives (worldwide). In addition, we have attempted to gather information from netting manufacturers and fishermen on the range of coloured twine in use commercially and attempted to explore the rationale behind these choices. (Results from this survey are included in Appendix 1).

Finally we present a summary of the report and a series of recommendations as to how the information included here should be extended and used to improve selectivity in commercial fishing gears and identify areas where further investigation may be necessary.

3.0 The influence of light levels on availability of fish to fishing gear

The availability of fish will depend on their patterns of movement, which, although varying widely in scale, are rarely random. Routine activities such as feeding, spawning, aggregating, resting, and predator evasion are usually linked to changes in the environment, such as season, tidal state and light levels. The majority of fishes can be divided in to one of three feeding groups; diurnal, nocturnal or crepuscular. Flexibility in feeding times does occur, reflecting opportunism in many species, but the proportion in each category is generally consistent among different assemblages: 1/2 - 2/3 being diurnal, 1/4 - 1/3 being nocturnal and the remainder being crepuscular (Helfman 1993). Foraging fishes will be more active, but their foraging behaviour will determine their availability to particular fishing gears.

3.1 Vertical Migrations

The vertical migrations of many pelagic species result in them being found closer to the surface at night than during the day (Beamish 1965; Blaxter 1974). These movements often mirror the diel migrations of their zooplankton prey and are generally considered to be a result of the combination of optimal foraging conditions and predator avoidance (Neilson and Perry 1990). Recently documented examples include juvenile walleye pollock (*Theragra chalcogramma)* which form a diffuse layer at around 30m depth at night and descend to around 100m (up to 30m off the bottom) forming much denser aggregations by day (Brodeur and Wilson 1996). Herring and sprat in the Baltic Sea follow a similar pattern, dispersing at night near the surface and aggregating at dawn close to the bottom (Cardinale, Casini *et al*. 2003).

Demersal species also migrate vertically in search of prey. Konstantinov (Konstantinov 1963) noted that cod in the Barents Sea rise into the mid water layers at night and that these diurnal migrations varied seasonally with a more pronounced difference in March compared to December. In the North Sea, catch rates for cod vary over the course of the day and vary differently for deep stratified areas compared to shallow non-stratified areas (Adlerstein and Ehrich 2003). These variations were related to availability of different prey. In deep stratified waters cod fed mainly on sandeels and Norway pout. Sandeels burrow into the sandy seabed at night and feed in the water column during the day. They are therefore vulnerable in the early morning when they emerge. The cod stayed close to the bottom during the early morning, ascending towards the surface during the day. At shallower depths, cod were found to feed mostly on crustaceans, herring and sprat, which are demersal during the daytime. The cod performed semi-diurnal vertical migrations and were near the bottom in the early morning and around midday. Plaice are known to show diurnal feeding patterns (Jones 1952; de Groot 1963). The distribution and movements of juvenile plaice *Pleuronectes platessa* and their potential predators and competitors in a small bay on the west coast of Sweden was found to be triggered primarily by changes in light intensity (Gibson, Pihl *et al*. 1998). Young plaice moved upshore at dusk and returned to deeper water at dawn. Larger predatory fishes also moved upshore at night but later, and not as far as the juvenile plaice and left for deeper water earlier.

3.2 Resting behaviour

As light levels change and fish cease to forage, they become less active, either forming resting aggregations or seeking hiding places (Helfman 1993; Sims, Nash *et al*. 2001). Such behaviour may result in them being more or less vulnerable to fishing gear.

3.3 Reported effects on catch and composition from different fishing gears

As a consequence of these diel behaviour patterns, catch rates of different species vary between day and night. Fishermen have long recognized this and directed their efforts accordingly. Early reports of the British trawl fishery for hake off the west coast found much lower catch rates at night than during the day (Hickling 1935; Rae 1947). Some boats even ceased to fish through the night time period (Hickling 1927) In his review of the Scottish fishery for lemon sole on the Faroe Bank, Rae noted that catches were higher at night for most of the year but this was reversed during the summer (Rae 1947). Purse seining for pelagic species is only profitable at night in some areas, when the fish shoal at the surface. In other regions, such as the North sea in summer, the herring and mackerel fishery takes place during the day when the fish form dense schools (Freon and Misund 1999).

In his investigation into the effect of the addition of sweeps and bridles between the trawl door and the wing end of a trawl in order to increase the herding effect, Bagenal found consistent and significantly higher catches during the day with both rigs (Bagenal 1958). The impact of diurnal differences in catch on the measurement of CPUE and assessment of fish stocks was considered in an ICES Symposium in 1963 (Konstantinov 1963; Parrish, Blaxter *et al*. 1963; Woodhead 1963). Parrish *et al*. (Parrish, Blaxter *et al*. 1963) reported variations observed in the commercial fishery and also results from Scottish research vessel experiments carried out in the north west North Sea. They achieved consistently higher catches of Lemon sole, Dab and Plaice by night, whilst cod, especially those less than 50cm were caught in higher numbers during the day. Haddock catches varied depending on the area.

4.0 The influence of light levels on catchability of fish

In addition to the effect on availability of fish to a particular gear, light levels influence the catchability of fishing gears, defined as the proportion of fish in the path of a gear that are captured. Once in the path of a towed fishing gear, behaviour towards it is thought to be largely governed by visual stimuli. Therefore changes in light levels would be expected to affect the ability of fish to see these stimuli and react to them.

4.1 Observed behaviour at “high” light levels

The reactions of fish to fishing gears in circumstances where light levels are sufficient for vision have been well documented and will not be covered in any detail her. Early underwater observations were made by divers hanging onto a Danish seine net (Hemmings 1973). The herding effect of the ropes was noted as well as the optomotor response of the haddock in the mouth of the net, resulting in the fish swimming in the mouth of the net until they tired. The development of towed vehicles which allowed both direct and remote observation of trawl nets was pioneered at the Fisheries Laboratory in Aberdeen and produced a wealth of information on fish reactions to trawl doors, sweeps, sandclouds and the net itself (Hemmings 1973; Main and Sangster 1981; Main and Sangster 1981; Wardle 1983; Main and Sangster 1984; Wardle 1989; Wardle 1993).

4.2 Observed behaviour at low light levels

Observations of fish to towed fishing gears made at high light levels often show groups in the mouth of the net swimming in the same direction as the net is being towed (Wardle 1983; Wardle 1993). Using stills flash cameras mounted on trawl nets, Parrish and co-workers found little orientation of fish at light levels less than 0.5-0.05 lux (Parrish, Blaxter *et al*. 1962; Parrish and Blaxter 1964). The authors concluded that both general level of activity of fish was lower and level of organisation is less in the dark, reducing their ability to escape from towed gears. In a similar study in the northwest Atlantic, at depths of between 30-50m Beamish found similar results for cod, noting that the greater the number of fish observed at a time, the more consistent the direction of swimming. From daytime observations, in groups, 90% swam in the direction of the tow, whilst 74% of single cod swam in the same direction of the tow. At night, lower numbers and fewer groups were observed and a higher percentage were photographed being herded towards the wings (Beamish 1966). In this study, Beamish reported that haddock swam in the direction of tow both day and night, but in a later report he observed that haddock displayed unusual behaviour with instances of fish swimming towards the wings more frequent by day than at night (Beamish 1969). Beamish also found no obvious difference in behaviour for flatfish. Glass and Wardle, recognising the potential influence of bioluminescence on light levels carried out their experiments in February, off Orkney. At this time of year, there are minimal bioluminescent organisms in the water and a maximum contrast between “day” and “night” conditions. Analysis of stills photographs and video tape showed that at light levels below 10^{-6} lux the ordered pattern of reaction to an approaching net seen at higher light levels (>10^{-3} lux) ceased (Glass and Wardle 1989). The authors suggested that trawl samples taken at night effectively sample a smaller volume due to the ineffectiveness of visual herding. At high light levels however, fish may be more able to detect and avoid the net completely. Walsh and Hickey reached similar conclusions finding a cessation of ordered reactions at light levels of <10^{-4} lux. Addition of artificial light seemed insufficient to induce ordered reactions (Walsh and Hickey 1993). Most recently, Olla *et al.* used infra red illumination and an ICCD camera to look at swimming and orientation of walleye pollack in a trawl under light and dark conditions (Olla, Davis *et al*. 2000). Tows were in 70-100m, with a towing speed of 1.5msec^{-1}. Under light conditions, measured at 3.99 lux, fish swam actively and were orientated parallel to the principle axis of the trawl. Under dark conditions, measured at 0.307 lux, little or no active swimming and large deviations from the principle axis of the trawl were observed.

In the controlled environment of tank experiments, using herring, cod, haddock, whiting, plaice and flounder Blaxter and Parrish (Blaxter and Parrish 1966) observed that the reactions of all these species to moving panels of netting dropped as light levels were dimmed below 0.66 – 0.005 mc (metre candles) with herring exhibiting the most dramatic drop off. The authors also investigated the herding effect of non-visual stimuli such as banging chains and air bubbles but found these were also ineffective at low light levels. Combining these laboratory experiments with field-based observations Blaxter and Parrish proposed that herring moved to the surface at dusk to a light level of between 10 - 0.1mc. Shoaling ceased at light levels below 0.1mc and fish dispersed to form scattering layers. Once light intensity increased from 0.1-10mc they reformed schools and descended towards the seabed (Blaxter and Parrish 1965). The authors calculated that the light levels at the depth of drift nets were often above the 0.006mc threshold for net avoidance and therefore may be quite inefficient at capture. More recent experiments quantified the light level thresholds for the visual reactions of mackerel (*Scomber scombrus*) to monofilament netting were –1 log lux and – 4 log lux (1 – 0.001 lux) for multifilament (Cui, Wardle *et al*. 1991). At light levels below these thresholds, fish were unaware of the netting barriers and swam straight through them. At higher light levels, the fish paused at the barriers. In laboratory simulations of the capture of fish in a codend, juvenile walleye Pollock (*Theragra chalcogramma* were able to maintain position, swimming clear of netting panels in nets at light levels simulating daylight at depth in clear oceanic water (0.5µmol photons m^{-2} s^{-1}). If light intensity was dropped to less than 0.002µmol photons m^{-2} s^{-1}, fish became entrained in the mesh. Juvenile sablefish became entrained at light intensities, lower than 0.0004 µmol photons m^{-2} s^{-1} (Olla, Davis *et al*. 1997). Further experiments with juvenile walleye pollock used IR lids to illuminate the tank (peak at 880nm). The response of individuals to an approaching panel of netting under light (1.7x10^{-3}µ photons) and dark conditions (<1 x 10^{-8}µ photons) was examined. In darkness the fish swam closer to the net and struck the net more frequently (Ryer and Olla 1998).

Both the laboratory and field-based studies indicate that at light levels above certain thresholds, fish can see and react to the components of fishing nets. Fish reactions to twine that they can see is generally to avoid the panel regardless of whether the mesh size is large enough for them to easily swim through. Below a certain light threshold, fish are unable to see the net and do not react to it. This suggests that herding by trawl doors and sand clouds is less effective at low light levels with the consequence that fewer fish are herded into the path of the trawl. In the mouth of the net, at low light levels it seems that fish are unaware of the presence of the net until it is very close and the ordered reaction of fish swimming ahead of the ground gear is not observed. This may make fish more or less vulnerable to the fishing gear. Once inside the trawl, the avoidance of netting panels that are visible to the fish will have implications for the effectiveness of escape and separation mechanisms which require fish to swim actively towards netting.

Observations of fish reactions to trawl nets at lower light intensities are hampered by the limitations of using visual methods requiring a minimum level of light themselves. This can be overcome to some extent by the use of acoustic methods. Using a high frequency scanning sonar mounted as a net sonde, Engås and Ona (Engås and Ona 1991) recorded the behaviour of fish in the mouth of a Norwegian bottom-sampling trawl. Fishing took place at depths of 70 – 80m off Finnmark, Norway. They found significantly different distribution patterns by day and night. During the daytime fish entered the net irregularly throughout the whole net volume with some haddock being lost over the headline. At night however, fish entered the middle of the trawl close to the bobbins with none observed rising up over the headlines.

Table summarising results from Engås and Ona, 1991.

	Night	*Dawn*	*Day*
Hour (GMT)	03:00	07:00	11:30
Light intensity (lux)	2×10^{-6}	0.01	5
Fish counts on sonar	141	655	267
Sonar scans	139	169	325
No. of Saithe	327	966	372
No. of Haddock	700	1331	702
No. of Cod	118	88	87

At night, 98% of the fish registered on the sonar, entered in the lower half of the trawl, 80% were within 1m of the seabed and all in the central area. At dawn fish again were mostly in the lower part of the net with a slight horizontal displacement to starboard. In daytime hauls, the proportion entering the in the lower half dropped to 80%. Echosounder data collected simultaneously indicated a vertical migration of fish with higher concentrations near the ground during the day. Given this, a more dispersed night time entrance position might have been expected. This was not the case, with fish entering the net very close to the bottom and more centrally. The authors proposed a number of possibilities; that the fish may be being herded using other stimuli such as noise or bioluminescence, or that they are not herded at all but those in the path of the wings and sweeps escape leaving only those fish in the centre of the trawl path.

4.3 Impact of diurnal variation in catchability and availability in survey trawls

Recently, the impact of diurnal variation on fishery-independent data collected using survey trawls has been highlighted. If catchability of a given species is not constant over time and space, then the survey will not accurately reflect variations in species density. There have been a number of studies focusing on both gadoids and flatfish species in the Northwest Atlantic, and gadoids, (mainly cod and haddock) in the Barents Sea and North Sea.

Walsh (Walsh 1988) noted that the numbers and weights of yellowtail flounder (*Limanda ferruginea*) caught on the Grand Banks off the coast of Newfoundland were significantly higher during the hours of darkness than during daylight, for both adults and juveniles. Changes in the vulnerability of various size-groups was thought to be related to active feeding behaviour and increased gear avoidance during daylight and a reduction in both behaviours at night. Estimates of catch rates of the stock were significantly higher at night independent of season and trawling gear used. In further experiments, the diel effect on escapement underneath the ground gear was assessed using bags underneath the ground gear (Walsh 1989). Again, catches were higher at night (up to nine times larger for yellowtail flounder) and the trawl was more efficient at capturing the larger size classes of cod, American plaice and yellowtail flounder. Smaller size classes escaped underneath the footgear, regardless of light conditions, but escapes were significantly higher at night for all three species. Walsh concluded that this survey trawl was inefficient at catching small fish regardless of time of day, but more efficient at catching larger cod, plaice and flounder during the night.

Though not significant, the higher night time catches for cod were unexpected given that gadoids catches are usually highest during the daytime. It was suggested that the larger fish were perhaps more able to escape during the day. Another explanation may be the additional influence of tidal currents on vertical migrations of gadoids. Michalsen *et al.* (Michalsen, Godø *et al.* 1996) found a semi-diurnal pattern in availability of cod and haddock to bottom trawls in the Barents Sea with fish descending to the seabed in periods of decreasing or minimal current speed and rising off the bottom as tidal currents increased. Semi-diurnal vertical migrations have also been observed for cod in the North Sea (Adlerstein and Ehrich 2003). Later analyses of survey data for cod in the nearby Southern Gulf of St Lawrence and Newfoundland and Labrador Coast have also found variable diel behaviour for cod amongst different regions (Casey and Myers 1998; Benoit and Swain 2003).

The international bottom trawl surveys (IBTS) in the North Sea are mainly conducted during daytime to avoid bias caused by variation in fish catch rates between day and night. However, neither the design, nor the estimation of quarterly indices for North Sea species considers the potential effects of diel migration or changes of trawl efficiency within daytime hours. In their study of fine scale information from the 1999 German summer small-scale bottom trawl surveys (GSBTSs) in 10 small areas evenly spaced in the North Sea Adlerstein and Ehrich found significant variation in catch rates within the daytime period which were different for deep stratified areas compared to shallow non-stratified areas.(Adlerstein and Ehrich 2003). The analysis was performed for cod ages 0-4+ using generalised linear models, where catch rates are modelled as a function of time of day together with environmental covariates. Catch rates were low, around 10 per hour. In shallow areas, where the water column was not stratified, catches were relatively low in the early morning, increased to a peak at around 14.00h and returned to low levels thereafter. Except for age 0 fish, rates in deep stratified areas catches decreased during daylight hours. To help interpretation of the patterns, analysis of data from hauls conducted around the clock during 1996 GSBTS in stratified areas were performed. Results indicated diurnal fluctuation with a peak at around 8.00h and low night rates. The changes in catch rates reflected the different vertical migration patterns made by cod feeding on different prey. The authors recommend randomising the survey design with respect to time of day and collecting additional information to allow modelling of the patterns.

In the Barents Sea and Svalbard area, diurnal effects on bottom trawl survey catches have been extensively studied. Catch rates of cod and haddock, are higher by day with the most pronounced difference for smaller size classes (Engås and Soldal 1992; Aglen, Engas *et al.* 1999; Korsbrekke and Nakken 1999). Seasonal variations occur; in

February, catch rates are almost the same and in Autumn, the proportion of smaller size classes in daytime catches was especially pronounced, whilst in winter catches of small fish were negligible, both day and night (Engås and Soldal 1992). In addition to the effects of light intensity on fishing, the vertical migrations of cod in this area follow a tidal pattern resulting in peak catches occurring at sunrise and midday (Michalsen, Godø *et al*. 1996). Engås and Soldal concluded that if day catches alone are used to estimate trawl indices, they tend to give an over-estimate for both cod and haddock during the Autumn and that trawl samples cannot be relied upon to provide a truly representative sample of the entire length range. Using acoustic data and pelagic trawl sampling Aglen *et al.* found that small haddock tended to be pelagic at night, large haddock ascended from the seabed during the day and cod of all sizes was generally found near the bottom (Aglen *et al.*, 1999). However, in the same year, Korsbrekke and Nakken (1999) stated that in winter, Barents Sea cod and haddock are commonly found in the scattering layers, up to 100m off the bottom and also that large cod are more likely to dive as a vessel passes overhead.

The studies reviewed here highlight the complexities of diurnal effects on catch composition and the variability between species and regions. The changing availability of fish can explain much variation in day and night catches and collection of acoustic data and pelagic trawl samples clearly enhances the interpretation of bottom trawl samples. However, the impact of varying light levels on herding efficiency of doors and sweeps and the reaction distances of fish should not be overlooked, although more difficult to quantify. In addition to reaction distance and potential to avoid the gear, light levels also influence the levels of aggregation and ability of fish to school and this in turn can affect efficiency of fishing gear. A number of studies have noted that in schools, fish orientation is more consistently in line with the direction of tow and are more likely to swim until exhausted, whilst individual fish display more erratic swimming and potentially higher probabilities of escape (Korsbrekke and Nakken 1999).

Clearly diel effects and the variation associated with length, depth, geographic area and season should be accounted for in surveys. A number of recent studies have attempted to do so using generalized linear (Casey and Myers 1998; Benoit and Swain 2003) and stochastic models (Hjellvik, Godo *et al*. 2002). Benoit and Swain found their results to be consistent amongst different vessels, areas and previous studies and proposed that adjustment of the data gave an increased accuracy through reduction in bias that outweighed the decrease in precision. Hjellvik and colleagues studied the annual variation of the diurnal amplitude as a function of species and length and found that, whilst stable for large fish, for smaller size classes, amplitude was unstable and resulted in the correction of diurnal bias occurring at the expense of a large increase in variance. Such approaches should be applied with caution given the potential for confounding length and depth dependencies.

5.0 The use of coloured twine in fishing

The visibility of an object underwater depends on its contrast with the background and therefore is dependent on the nature of the object, the background and the properties of the medium and the direction and intensity of illumination. One of the properties of objects that influence their visibility is colour. Researchers in Russia and Japan performed some of the earliest work on the use of colour to manipulate fish reactions to fishing gear. In his study of the theory of fish capture by gill nets, Andreev (Andreev 1955) recommended darker coloured nets in good light conditions and clear water and lighter coloured nets in turbid conditions. Kanda and colleagues examined the barring effect of coloured netting on *Trachurus trachurus*, *Atherion elymus* and *Cyprinus carpio*. The barring effect of twine panels decreased in the following order: red > orange or yellow > blue> green. Attributed the weak effect of green and blue to low contrast made by these nets to the surroundings (Kusaka 1957; Kanda and Koike 1958; Kanda, Koike *et al*. 1958; Kanda, Koike *et al*. 1958). In the clear waters of the Mediterranean, off Malta the maximum horizontal distance at which netting of various colours could be seen by divers was assessed (Hemmings 1966). It was found that natural white twine was visible as far as 16m away, green at 13m, tan-brown at 12m and orange 9-10m. In the Moray Firth, not surprisingly, these distances were much reduced!

Where fishing nets are intended to enmesh fish, such as gill nets, they must be inconspicuous and there have been a number of studies that have acknowledged the importance of colour and brightness of the twine used. The effect on catch rates of different species of fish in a lake of using 9 different colours of twine was investigated in an experiment lasting 8 years (Jester 1973). Each colour was used for a year along side 2-3 others. Brown nets caught more catostomids, carp and fewer game fish than white nets; sunfish species were caught at higher rates with orange nets and largemouth bass were taken selectively in yellow nets. It was suggested that the use of different coloured nets could allow selection of species and less unwanted bycatch. In his review of gillnet selectivity, Hamley included net colour as a significant factor that could result in a several-fold difference in catch (Hamley 1975). It was acknowledged that this colour effect would vary with time of day and with species. The importance of brightness contrast was also noted. Steinberg ((Steinberg 1964)) found that more visible nets caught a smaller prop of larger, older fish, which may have better visual abilities or are more cautious. For the gillnet fishery for hilsa (*Hilsa toil* and *H. ilisha*) and pomfret (*Pampus argenteus* and *Parastromateus niger*) in the coastal waters off Veraval, Kunjipalu *et al.* (1984) recommend yellow or white netting. In Monkey Bay, Malawi, the effectiveness of gill nets dyed khaki and pink with natural plant extracts as well as undyed white was examined (Tweedle and Bowa, 1990). Khaki nets significantly outfaced white nets, which in turn out fished pink nets, although the latter was not significant. Red and black nets were also tested and found to be less effective. Bright artificial colours gave poor catches whereas nets dyed pale shades of green, brown and khaki gave the best catches. The study acknowledged that the catch ratios differed in relation to different species' dependence on vision as the primary sense. Using a three-layered drift net made of light green or blue polyamide twine that matched the colour of the water Lu (1998) managed to increase catches 23% over a white drift net.

The importance of colour of artificial lures in the Taiwan longline fishery for mackerel was examined by Hsieh and colleagues. Hooking rates for the different colours tested were, from highest to lowest; red>black>yellow-green>yellow-orange = reddish-orange=pink>white>blue>purple>transparent. Transparent, purple and blue lures had significantly lower hooking rates than the other colours. Lures made in nine different shades of grey, with varying luminous reflectance did not show significant differences in catch rates and the authors therefore concluded that the spectral colour effect was the major influence causing differences in this study.

Using observations made from tank experiments and an examination of the origin of highlights in monofilament line Wardle *et al.* (1991) found that the appearance of monofilament varies according to its dyed colour and the angle relative to the sea surface. In mid water, those colours which reduce the amount of green illumination as it passes into and out of the filament are least visible in the horizontal. The knots in a panel of netting have different properties due to the variation of the angle of the twine in relation to the surface. Following on from these studies, the brightness contrast of netting, floats, otter boards etc. were examined by comparing their luminance to that of their visual background of water, sea bed or self (Kim and Wardle 1998). Coloured twines viewed in underwater, monochromatic light, against the underwater background were seen as a darker silhouette, when views from below (i.e. 0 degree zenith angle) and when viewed from above (180 degrees) became brighter than the background except for the darkest colours such as red, black and dark green. Pale coloured twines and their knots appeared darker than the water background when viewed from vertically below and showed high values of negative brightness contrast. The same twines were bright against a dark water background when below the viewer and showed a high positive brightness contrast. At zenith angles in between, the same twines are less visible but may still be detected due to self-contrast within the knots.

Unlike gillnets and longlines, fishing trawls are designed to herd fish rather than act as sieves. The herding process relies on the visual response of fish to components of the gear. The response is generally to avoid these stimuli, be they trawl doors or netting panels unless there is no alternative. This concept, of fish choosing the route perceived to be the "least hazardous" is called Balken's theory. This presents the problem that the inclusion of bycatch reduction devices requiring fish to make an active escape may not achieve their full potential if fish are deterred from approaching these devices in the predicted way. Laboratory tank experiments have shown that fish will actively choose to penetrate meshes when alternative routes are blocked or appear blocked due to visual stimuli(Glass, Wardle *et al*. 1995). In this case the visual stimuli was a black tunnel, which was believed to appear to be the gaping mouth of a large predator. Further sea trials were carried out, applying this theory to square mesh panels using a sheets of black pvc-coated canvas laced into the extension behind the panel to create the black tunnel effect. Video observations showed that the behaviour of fish was modified, despite being exhausted. Fish approaching the tunnel tail first were seen to speed up and attempt to hold station ahead of it. With a square mesh extension the addition of a black tunnel increased the proportion of fish escaping from 18 – 77%. With a diamond extension and square mesh panel, the proportion was raised from 20 – 60% (Glass and Wardle 1995).

Despite these promising results, subsequent attempts to use this kind of device in commercial nets has not always achieved the same effect. In their assessment of bycatch reduction devices in a tropical Australian prawn trawl fishery, Brewer *et al.* tried square mesh panels made out of glow twine and also the use of a black canvas cylinder and a hummer device behind the panel. All the trials were carried out at night. The use of a standard square mesh panel reduced fish bycatch by approx 25%. With a hummer the reduction was slightly more (30) whilst retaining the same prawn catch, but with glow twine it was only 20% and with a black tunnel, just under 20% (Brewer, Rawlinson *et al*. 1998). Madsen and colleagues incorporated contrasting netting in their selectivity study of escape windows in Baltic Sea bottom trawls (Madsen, Moth-Poulsen *et al*. 1998). A "Danish" square mesh panel with 115 mm mesh size was used. To study the effect of contrast netting, three codends were used:

1) Entire codend aft of the window (2.1m length) stained black
2) A band of netting 80cm long extending from the lifting becket forward into the window panel dyed black
3) Entire codend and extending into the window dyed black.

A tar product called Stenolin was used to dye the netting. The windows themselves and presumably the extension they were fitted into were standard green (4 mm PE). Twin trawl experiments were carried out with a conventional green codend as a comparison. Codend 1 retained the greatest proportion of small fish. Codend 2 did not differ significantly from a normal codend. Codend 3 showed a small difference but it was not statistically significant; fewer cod below MLS were caught and more cod above MLS were retained in this codend. The authors concluded that dying the netting may have affected the stiffness of the twine and therefore its selective properties and the normal escape behaviour of the cod. It was also suggested that in the Baltic Sea where visibility is usually poor, visual stimuli might be of limited use. It might also be the case that the choice of colour was perhaps not optimal for increasing contrast. Staying with square mesh panels, recent trials examined the difference between black and white square mesh panels in the Scottish demersal whitefish fishery. Whilst there were differences between the panels, which suggested that the white panel released more haddock than the black panel at lengths below 30 cm, a formal hypothesis test showed this difference is only marginally significant (Appendix 2). It should be noted that this was based on just 4 hauls with a white panel and five with a black panel.

More positive results have come from experiments with strategically placed panels of transparent mesh in an esturine seine net (Gray, Larsen *et al*. 2000). The panels were placed in the anterior region of the bunt and made from transparent netting (mono and multi-filament). Covers over the bunt and codend allowed the numbers of fish escaping to be quantified. The panels resulted in an improvement in size selection of targeted commercial species (mainly sand whiting *Sillago ciliata*) and a reduction the bycatch of other species. The authors did acknowledge that the cover was seen to modify the escape responses in some cases, with some smaller fish re-entering the main net. In the Northwest Atlantic the small mesh bottom trawl survey for silver hake is subject to bycatch limits for flatfish species. Experiments using large mesh escape panels of different colour in the belly of the net showed that using orange coloured twine resulted in a 73% reduction in flatfish bycatch with no adverse effect on catch of silver hake (Milliken and DeAlteris 2004).

6.0 The use of coloured twine in the fishing industry; the net-makers perspective.

Most documents regarding the effect of colour and contrast of netting on fish behaviour focus on information gathered from scientific sources. Here we broaden the scope of this survey to canvas commercial net manufacturers and net suppliers with the aim of understanding fishing industry perceptions and preferences with respect to net colour. We conducted surveys in the USA (Northeast region), Europe (Scotland, Portugal, Belgium), Iceland, New Zealand, Namibia and Japan. Further questionnaires were sent to netting manufacturers in France, Spain, England and Norway without response. Manufacturers/suppliers were asked a series of questions including (but not limited to) those outlined below:

Steering questions used to solicit information during interviews with trawl manufacturers.

- *Manufacturers and fishermen often have specific colours that they use when constructing fishing gear. Do you know of any importance net/twine colour has in the catchability of the gear?*
- *Do you think that the colour of the twine has any influence on the catchability / selectivity of the gear?*
- *Do you prefer a certain colour twine: why?*
- *If twine colour is not a factor in the selectivity / catchability of your gear type, do you think it is important in other gear types (i.e. longline, gillnet, trawl, weir)?*
- *Can you suggest a knowledgeable gear manufacturer or other person who may value the importance of colour in designing fishing gear?*
- *What colours of netting are available?*
- *What colours of netting do you stock?*
- *Why don't you carry other colours?*
- *Do any fishermen ask for specific colours? If so, why?*
- *Do you consider colour to be important, or do you simply worry about material strength and what is available?*
- *Where do you get most of your netting from?*
- *Do different countries seem to prefer different colours? If so why?*

Full and detailed responses are outlined in Appendix 1.

In summary, responses were qualitative and highly variable, ranging from "colour is not important" to very specific instances where a particular twine colour was preferred either by a fleet (the French pair trawling fishery for tuna (Albacore, Bonito and some Bluefin) in the Northeast Atlantic uses only black nets) or within a specific area or region (suppliers mentioned a preference for green twine by New England fishermen while west coast US fishermen preferred orange twine). In many cases decisions on twine were based on more practical matters such as abrasion resistance, strength and perhaps more importantly cost. But where colour and or netting contrast were deemed to have an affect on fish reactions, this superseded all other concerns. It is not our intent to list all the individual responses here but it is interesting to note that while many manufacturers and fishermen responded by stating colour did not affect catchability, there was a very common theme regarding picking a colour of netting that matched the colour of the water, the unstated but implicit inference being that minimal contrast, and therefore minimal visibility was preferred. Stated another way, there appeared to be a tacit acceptance that colour/contrast may in fact be significant but an unwillingness (sub-conscious or otherwise) to articulate its acceptance.

7.0 Summary and Recommendations

This report represents a synthesis of work carried out, spanning 50 years, and many countries. It is recognised that the relevance of visual stimuli depends on parameters such as time of day, depth and water clarity. However few of the studies encountered have attempted to explore the frequency or extent of such dark conditions or attempted to discuss what proportion of commercial fishing activities are conducted either above or below these absolute visual thresholds for target species. Obviously these conditions occur more often in certain fisheries, such as those in shallow coastal or clear waters. This proportion could be estimated but a pre-requisite of this would be standardized an accurate measurements of light intensity.

The survey canvassing commercial net manufacturers and net suppliers to understand fishing industry perceptions and preferences produced variable responses, but indicated that in certain fisheries, this aspect is considered important.

Where fishing occurs under visual conditions, the opportunity exists to manipulate visual stimuli in order to improve selectivity, bycatch reduction or catchability. These changes are potentially very simple and relatively cheap to make. The same manipulations could also be used in survey trawls to either increase or reduce herding.

Recommendations

- Produce a reference document that establishes a recommended methodology for measurement of light levels and provide guidelines for appropriate instrumentation.
- Assess to what extent visual conditions exist at fishing depth on commercial fishing grounds.
- Given the implications highlighted in this study, the group recommends that appropriate light intensity measurements be incorporated into routine survey operations.
- Explore the influence of netting colour (contrast) on reaction behaviour of other animals such as cetaceans and sea birds, which may be caught as bycatch.
- Append the current review to incorporate studies not covered including those pertinent to cetacean, turtles and other threatened or endangered species.
- Examine why colour of twine is still perceived as important in some fisheries and not others.

APPENDIX 1

The following are notes from interviews with various people involved with the supply and utilization of netting materials used in fishing operations.

NET MANUFACTURERS AND NET MAKERS SURVEY - USA

Sites Visited by Henry Milliken and Chris Glass

Trawlworks RI
IMP New Bedford MA
Levine Marine Supply Fairhaven MA
Gear Locker New Bedford MA
Reidars Fairhaven MA

Steering questions used to solicit information during interviews with trawl manufacturers.

- Manufacturers and fishermen often have specific colours that they use when constructing fishing gear. Do you know of any importance net/twine colour has in the catchability of the gear?
- Do you think that the colour of the twine has any influence on the catchability / selectivity of the gear?
- Do you prefer a certain colour twine: why?
- If twine colour is not a factor in the selectivity / catchability of your gear type, do you think it is important in other gear types (i.e. longline, gillnet, trawl, weir)?
- Can you suggest a knowledgeable gear manufacturer or other person who may value the importance of colour in designing fishing gear?
- What colours of netting are available?
- What colours of netting do you stock?
- Why don't you carry other colours?
- Do any fishermen ask for specific colours? If so, why?
- Do you consider colour to be important, or do you simply worry about material strength and what is available?
- Where do you get most of your netting from?
- Do different countries seem to prefer different colours? If so why?

GEAR LOCKER

- Mentioned that twine was sold by the pound so some lighter weight twines were preferred because they were cheaper.
- Gear locker carries blue, orange and green – this is what is available from their local suppliers – blue comes from Reidars, orange from IMP and green from ship supplies.
- Fishermen are charged by the lb. so many of them pick the lightest material.
- They have never had any fishermen talk about colour being important.
- They sell orange twine mainly to scallop fishermen for twine tops and most consider it totally unimportant in the context of scallop dredges.

LEVINE MARINE SUPPLY

- Traditionally all nets were made with white nylon
- Levines buys mostly from Euronete – Portugal.
- Green is very popular but also supply orange and blue. Mentioned that on the East coast green is the preferred colour.
- Felt that fishermen liked green because they felt it matched the colour of the water.
- Orange is very popular on the west coast USA and there is some market for it in Maine and Canada.
- Stocked orange twine at one point but found that Portuguese fishermen in New Bedford/Fairhaven would not buy it because they thought it did not catch fish as well as green. Seems that they want mesh that matches water colour – so colour and contrast do seem to be important in terms of catchability. He actually called orange mesh a jinx for fishermen in the area.
- Recently, one fisherman has requested blue netting and says he has increased his catch of groundfish.
- In their opinion it is usually tradition and superstition that drives preferences – this may be especially so for this small ethnic group of fishermen but may not be so in larger more cosmopolitan ports.
- They stock Euroline premier – this is bright yellow – but don't sell much mainly because of the cost of the material.

- Orange is used on the west coast but is not popular on the East Coast. Mentioned that silver hake fishermen often request black twine.

Reidars

- Silver hake fishermen like black webbing but Reidar does not know why.
- Can order most any color of twine if a sufficient quantity is ordered.
- Hampidjan makes grey twine and Dynex (DYNEX products are made from DSM's Dyneema UHMWPE fibres)
- They get their twine from Contesi in Portugal.
- Supply mostly green twine on the east coast of the US. But note that Maine requests a lot of orange netting. They supply ultracross netting which comes only in black and note that west coast fishermen tend to use orange.
- Twine tops that they sell to the scallop fleet are almost invariably blue – there seems to be no real reason for this only to differentiate it from other nets. Many boats have dual capability and stockpile netting so colour differentiation help keep things separate.
- Reidars considers colour and contrast only to be important in very shallow water – did not specify what they meant by shallow but impression is that it was much shallower than would be defined by performance of a fish eye.
- Hampidjan will make any colour of netting – it is just a tub of powder of the correct colour in the mixing process – but are rarely asked to do so.

IMP

- Large suppliers of gill net material and have extensive sample books with just about every colour under the sun. Monkfish fishermen tend to ask for blue netting while groundfish fishermen ask for yellow material. Some RI fishermen use pink gill-net material while NY fishermen will not touch pink – this is not a macho thing apparently – they think pink attracts crabs!
- For trawls they get all their netting from Cotesi a Portuguese Co. and get the nets put together in Canada.
- All the material is green. Orange will sell due to price per lb. and is also stronger than green twine but is not net of choice – fishermen seem to be prepared to give themselves a competitive disadvantage in fishing in order to save front end costs.
- They sell orange twine tops to scallop fishermen.
- Most trawlers have a preference for green twine.
- In NC they like light green twine (gillnet monofilament).

Trawlworks

- Euronet is their supplier for most of their twine.
- Do not believe there is a colour preference
- Heard talk of yellow lobster pot entrances – believes it is a fad.
- Utzon nets use large white mesh (Note: Utzon recently purchased by Hampidjan)
- Do not know of a preference for twine colour in silver hake fishery. They were making a small mesh twin trawl using Dynex grey twine.
- Whiting fishermen in RI use grey netting.
- They are asked to stock yellow mesh for lobster trap funnels – to attract lobsters.
- International Marine Marketing markets purple netting.
- Codends are a different matter and come in many colours – black, green, yellow etc. – only manufacturer.net maker to say this.
- Paul Schumann (net designer) never used different coloured markers between panels as he thought it affected behaviour of fish (exactly as we have seen) so he used double meshes of the same colour. Nobody seems to do this now, and Mary O'Rourke thinks it is unimportant and uses orange markers.
- Mary noted that there has been an historical change in common usage – they were asked for lots more orange netting 15 years ago but not now.
- Had an important point – colour of new netting is often driven by patent/copyright issues – that is, it is almost impossible to get a patent for new material that is the same colour as already existing material so a new stronger material (or more abrasion resistant) will be made in a new colour to clearly identify it as different.

Summary notes from USA manufacturer / netmaker survey

- Two suppliers mentioned a preference for black twine for fishermen targeting silver hake.
- Three suppliers mentioned that orange does not sell well in New England.
- Three manufacturers mentioned that fishermen were eager to purchase a new colour twine that they thought might increase their catchability.
- All the suppliers mentioned a preference for green twine by New England fishermen.
- Most suppliers felt that colour did not significantly influence the catchability of the gear.

Net Manufacturers and Net Makers Survey - Tokyo

- Different colours of netting are required by fishing methods. Gillnet fishermen severely choose netting colour because they believe that affects catch. Other fishermen working with trawls and purse seine do not care so much about colour but base their decisions on price. Generally they use "quiet' colours in water.
- Most common colour used for netting is colour of "Persimmon Tannin" (dark red) for most fishing methods. Because fishermen traditionally used natural fibre netting that are dyed by persimmon tannin for prevention against degradation. This custom still remains for synthetic fibres.
- Black and grey netting are commonly used for most fishing methods next to persimmon tannin. These colours are believed to be stealth colour in deep water.
- Other colours: White (non-dyed) and blue colours are also used for specific fisheries. For gillnetting, fishermen prefer dark green, and this colour is called "fish body colour" among fishermen.
- Red colour is mostly used for sink-gillnet targeting Japanese spiny lobster.
- Netting manufacturers provide specific colours of netting to identify which manufacturer users employ.

Notes from gillnet manufacturer survey in western Japan

- Salmon driftnets, Spanish mackerel driftnets, sink gillnets for most groundfish such as flounder and flatfish: most fishermen order grey colour, and green is second favourite all over Japan.
- But fishermen in Hokkaido, northern Japan prefer pink netting for walleye pollack sink gillnets. For catching rockfish in deep water, red netting is frequently ordered. Gillnet fishermen in turbid water such as Seto-Inland sea, sometimes order light-blue netting for Spanish mackerel drift net or flounder sink-gillnet.

UNIQUE USES OF NETTING COLORS IN JAPANESE TRAWLERS ARE;

- Coastal otter trawl in Ise-Bay(<40m deep), middle Japan.Nylon monofilament netting is used at square and baiting parts not only to reduce drag, but to add stealth function at those parts to catch strong swimmers such as Spanish mackerel or barracuda in slower towing speed(<4knots). Many fish are gilled at these parts.
- Also many coastal fishermen in Japan have started using nylon monofilament netting for main body, but reasons are to reduce drag and to obtain faster towing speed.
- Survey mid-water trawl for Pacific saury (<30m deep)
- White netting are used at wing and main body of trawl, while black netting is used at extension and codend. This colour arrangement is mainly because of use of high-strength fibre (Dyneema) at wing and main body. But researchers admit herding effectiveness of white netting and leading effect of black netting in contrast to white netting.
- Also, white "glow" netting was used at wing and main body part of trawl when trawlers operated in Bering Sea. This is for the same reason as above. Use of this netting is not so common because of its high cost.
- And in case of fish weir;
- Yellow and orange colour netting are frequently used for the leader net of fish wire. Fishermen believe these colours are best to be recognized through fish eyes in shallow water.
- For the bag net, fishermen are keen on brightness in the bag net rather than netting colours. Experiment proved that sea bream are tended to be captured in the bag net that has stronger contrast (brighter environment) than dark bag nets. However, bag net made from nylon monofilament, which was brightest environment, was not good to retain fish since fish in the net did not keep staying.

Net Manufacturers and Net Makers Survey – EU

Scotland
Faithlie Trawls Fraserburgh

- Supplies nets for whitefish, groundfish, prawn, shrimp and squid fishing.
- Lists colours used as: white, green, orange, blue, yellow, purple, red and black.
- The rationale behind different colours is predominantly driven by manufacturers desire for twine to be easily identifiable as their product. Is therefore a sales tool.
- Uses twine predominantly from Le Drezen, including:
- Brezline , blue with yellow flecks (see below)
- Tricolor Elite (white with blue and red flecks)
- Standard green PE twine.
- Also standard orange PE
- Has also used purple netting in the past (above right), though not recently, from a Spanish company Redes Salinas. Apparently came on the market about 10-12 years ago and was cheaper. Was popular for a period, but not any more.
- Also mentioned yellow twine from Euronete. Has only ever used in codends.
- Stated that white twine was generally unpopular because it is harder to see tears and holes in the netting.
- Fishermen will often mend a tear with a different coloured twine so these areas are easy to identify on return to net makers for proper repair.
- A standard whitefish trawl would be made from green braided twine at the front with maybe PEPA as strengtheners with Brezline further back and in the codend. May use orange twisted in some nets as it is lighter than braided.
- Mentioned that Danish shrimp trawls traditionally made from green twine.
- Did have some PEPA (combination of nylon and polyethylne) which is usually white with a colour fleck. Is stronger but also holds water so used for tearing strips only.
- When putting in square mesh panels, tend to use green PE (?) on the square inserted into a blue codend.

Gundrys Nets Fraserburgh

- Mends pelagic nets and makes whitefish nets.
- Buys netting mainly from Eurored
- For whitefish nets, generally uses green twine with a purple fleck in it, called alpha and alpha-compact (below left). Also “Polytit” which is high tenacity, orange twine (below right). Will use alpha-compact at the mouth with orange for the bag and extension, as it is harder wearing.
- Mentioned recent requests from fishermen to use old-style standard green PE were purely driven by cost.
- Also stocked Blue 2001 (a purpely-blue colour see left) from Sicor, but not popular as it tended instead of tearing, to rip a whole sheet out of the net.
- Square mesh panels made using knotless green nylon.
- A black and white twine also from Eurored used for guards. Bruce’s own choice.
- Tend to use red or black for joining sections.
- Has had one request for blue twine, but mainly because it is flat pleated.
- Do mend in different colours when at sea for ease of ID back in port.
- Mentioned the tradition of twisted twine being orange in Scotland, but in Spain, it is blue and green.

Pelagic nets

- Always use white nylon with different coloured flecks to identify different panels (4 panels in a standard pelagic trawl) e.g. Red and green. Netting is made in Ireland.

Jackson Trawls Peterhead

- Supplies nets to the pelagic whitefish and prawn sector. Their main suppliers are Sicor and Gareware in India. The supplier in India was sourced through INT (International Net and Twine Ltd of Northern Ireland). INT make Olivene, a high tenacity polyethylene netting made in green with an orange fleck (see below).
- Has used Euroline netting in the past, made by Euronete (Portugese company, Woodrope in Aberdeen is the supplier). Its another high tenacity twine, yellow with a green fleck. Not used so much now as it is relatively expensive. Euroline premium is braided netting claiming 50% stronger than standard polyethylene.
- Also uses Brezline (blue with yellow fleck) and orange twist. Purple twine made by Hi-Lene from Spain was popular for a while but is off the market now. Red twine was used a few years ago and Blue 2001 which was a very bright blue. The twine was too strong and used to rip out whole sheets so not used so much.
- Previously the traditional green PE twine was used. Then high tenacity twine was developed and different companies used different colours to identify their high tenacity product.
- White nylon polyamide is used for pelagic nets. The 4 selvedges often made with different colour for ease of identifying parts of the net.
- Mentioned that pelagic nets have been dyed black for some skippers in the past who believed that black was better for blue whiting (have to pay extra for dying process). Historically, purse seine nets were made from black twine. The colour was probably a consequence of the fact that they tarred the twine to preserve it.
- Ultrakross, black knotless nylon is still popular for square mesh panels as is green twine turned on the square.
- Often use “Polysteel” around the mouth and wings as its very resistant to abrasion. Its PP, but extruded differently. Is a very light green.
- Both Jacksons and Gundrys stocked a grey twine with a blue and white fleck through it. Think this is some type of PEPA which is used in guard strips behind the ground gear and headline.

Summary of interview with Gavin Thain, skipper of Challenge II (Peterhead)

The French pair trawling fishery for tuna (Albacore, Bonito and some Bluefin) in the Northeast Atlantic uses only black nets. The dying process costs an extra £2500. At the mouth of the net 4 different colours are used for the four different panels but they are all “dark” colours – dark blues, red, green and purples. Behind this the main bag is made from dyed black nylon twine. The light level is critical to this fishery, cannot be done during the daylight or even at night if there is a full moon. At night the fish shoal close to the surface and the net stays very close to the surface (4-5m). Can often see the wires running down to the net with the bioluminescence.

Summary Notes Manufacturer / Supplier Survey - Scotland

Historically, the whitefish and *Nephrops* trawl fisheries seem to have used green and orange twine. As different companies started to produce higher tenacity polyethylene twines, they used different colours to enable easy recognition of their products. The colours used include, dark blue, bright blue, shades of purple, red, green and orange netting with different fleck of colour and yellow. Therefore the choice of netting type determines the colour of the net and the 3 net makers interviewed were not aware of any skippers preferring a certain colour as such. One mentioned that white twine was unpopular in the demersal fleet as it was difficult to see tears. As different coloured and potentially contrasting twine was often used to mend holes whilst at sea.

Underwater visibility –

- Codends all made from heavy duty double twine in blues, purples, dark green and red which would all look very dark at depth. The only light coloured twine is the yellow Euroline Premium, but so thick, would be visible in any colour?
- The main body of the trawl often made from single twine, green or orange twine. The latter might present less contrast. Could you get the “black tunnel effect” at the taper using orange twine and then something like the blue brezline?
- Tearing strips and guard strips seemed to be made out of PEPA; white with flecks or grey or the polysteel, which was pale green. These colours seem like the most likely to produce low contrast and possibly look like an escape route, depending on the positioning (i.e. just behind the headline, the lower wings, at joins)
- The pelagic fisheries for herring, mackerel and blue whiting traditionally used netting which was tarred and therefore black. With the introduction of nylon, some skippers in the past have requested the nets be dyed

believing they are better for catching blue whiting, but this is costly and the majority use undyed white nylon with different colours in the selvedges for identification purposes.

- The only clear evidence of use of colour in netting being important seems to be the tuna pair trawlers that pay to have their nets dyed black. All images on web sites of tuna fishery nets were black. Does this include purse seine trawls as well, I think so.

Euronete, Portugal

Questionnaire sent out and returned by Aida Campos

1. What fishery do you supply nets for?
   - Trawls in twisted and braided twine. In PE, PP, PA EURONEEMA, EUROLINE, EUROLINE PREMIUM and EUROLINE PREMIUM PLUS.
2. What are the colours of the netting you supply currently?
   - Green, orange, blue, white, black and yellow.
3. Have you used different coloured twine in the past? If so, what colours?
   - No
4. Are there reasons for using certain colours? For example, netting of certain specification only comes in one colour?
   - Not to our knowledge.
5. Does the twine you order come in other colours?
   - Yes
6. Do fishermen ever request certain colours or combination of colours?
   - The orders are always according to client's instructions.
7. Are you aware of the reasons behind these choices? For example are colour combinations chosen for ease of mending?
   - No
8. Do certain fishermen prefer certain colours as they believe they are more efficient at catching fish?
   - Not to our knowledge.

Belgian Net maker and twine supplier

Questionnaire sent out and returned by Ronald Fonteyne

1) What fishery do you supply nets for?
   - Beam trawls and Otter trawls
2) What are the colours of the netting you supply currently?

Beam trawls

Flatfish

- Chain matrix gear: green (polyethylene-PE)
- Tickler chain gear: white (polyamide-PA or polyester-PES)
- Shrimp trawls: white (PA)
- *Nephrops*: green (braided PE)

Otter trawls

Roundfish:

- green (braided PE) or orange (twisted PE); (green) braided netting is preferred because this material seems to shrink less

Nephrops:

- green (braided PE)

3) Have you used different coloured twine in the past? If so, what colours?

- White (PE)
- Green with white spots (Euroline)
- Blue with yellow spots (Brezline)
- Yellow with green spots (Euroline Premium)

4) Are there reasons for using certain colours? For example, netting of certain specification only comes in one colour?

- There seems to be no reason for using a specific colour. Netting of certain specification indeed comes in one colour only.

5) Does the twine you order come in other colours?

- Yes, if asked for.

6) Do fishermen ever request certain colours or combination of colours?

- No

7) Are you aware of the reasons behind these choices? For example are colour combinations chosen for ease of mending?

- Twines of a colour different from the netting colour is generally used for joining different netting panels. This is done for practical reasons (easy identification of the netting panels)

8) Do certain fishermen prefer certain colours as they believe they are more efficient at catching fish?

- No

Additional surveys were sent to the following manufacturers Suppliers *(no responses were received*).

1) **Le Drezen**
12, rue de Kélareun
Léchiagat - Tréffiagat - B.P. 46
F 29730 LE GUILVINEC
FRANCE

2) Redes Salinas
Alicante, Spain

3) Eurored
Vigo, Spain

4) Sicor International
Bridport
Dorset

5) International Net and Twine Ltd
Northern Ireland

6) **Gareware-Wall Ropes Ltd.**

7) India

8) CosmosTrawl

9) Hirtshals, Denmark
Notkajen 2
P.O. Box 89
DK-9850 Hirtshals

E-mail replies received from the Hampidjan Netting Group

Hampidjan has studied a lot of fish behaviour. Now Hampidjan is using technology that is called self spreading technology that is used in our midwater trawls. Different twist in ropes to let the flow spread the trawl. It is said that there is less noise in the trawl mouth so the fish is more relaxed entering those trawls. Of course there is not always visibility on the bottom of the seabed, current, mud cloud and feed blocking. But it is known that by making visible difference in the trawl the fish behaves differently if the visibility is there.

I would think that making circles with black and white netting could maybe attract fish quicker down to the belly of trawl, that is if the fish is strong and swimming long in front of the trawl.

But now the newest thinking is to put in belly 90 degree netting (tow on side knot), actually Waldemar Moderhak from "Morski Instyrut Rybacki" Sea Fisheries Institute Poland did studies on this for over 10 years mostly concentrating on the codend. But by doing so you increase flow in trawl.

Our opinion on the use of coloured netting in trawling fisheries, is similar to what you have heard from our colleagues in Scotland.

Few years ago we used black, green and white nylon netting - today mostly white. On ground fisheries, most PE netting brands are green - with some few high strength brands like Euroline Premium Plus and Magnet Grey in different colours. Not a question about catch efficiency - only a matter of branding.

In New Zealand, however, I recall some fishing companies have used luminously netting for night fishing.

On gill/mono nets fishing coloured netting could be important in the fish catching process. However, as our experience here are rather limited, we suggest you to contact some of the more engaged companies/suppliers in this type of fishing.

Nylon netting in white, as I write about - is for pelagic trawls (Herring, Mackerel, Blue Whiting).

We also use white nylon netting for aqua culture cages.

Nylon in black colour is used for our purse seines for Herring/Mackerel and Capelin - standard colour worldwide.

Appendix 2: Working Documents:

The influence of twine colour and contrast on the effectiveness of square mesh panels in a demersal whitefish trawl.

Jones, E.G.*, Fryer, R., Kynoch, R., and Summerbell, K.

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The influence of twine colour and contrast on the effectiveness of square mesh panels in a demersal whitefish trawl.

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Abstract

Introduction

Square mesh panels inserted in trawl nets ahead of the codend can be used to improve selectivity by providing an escape route for under-sized fish (Briggs 1992; Robertson 1993; Robertson and Shanks 1994; Gosden, Stewart *et al*. 1995; Broadhurst and Kennelly 1996; Armstrong, Briggs *et al*. 1998). Such panels have been mandatory in the Scottish white fish and *Nephrops* fishing fleet for a number of years. Selectivity experiments indicate that a 3m long square mesh panel inserted ahead of a 100-110 mm codend give a significant improvement in selectivity and is most effective when positioned immediately ahead of the codend, 6–9 m from the codline (Graham and Kynoch 2001; Graham, Kynoch *et al*. 2003). However, the position of the panel, in the top sheet of the net, requires fish to swim actively towards and through the panel in order to escape.

The escape behaviour of fish in a trawl is influenced by gear and environmental factors, including the visual impact of the netting. Although a clear escape route may be present, for example, a square mesh panel, the opportunity to escape may not be taken. This is thought to be due to the natural behaviour of many species of fish, which is to avoid approaching or penetrating netting that is visible to them (Cui, Wardle *et al*. 1991; Glass, Wardle *et al*. 1995). The aim of this study was to attempt to improve the number of fish escaping through a square mesh panel by manipulating the colour and therefore the contrast of the panel in relation to the surrounding netting. When viewed from inside the net it is proposed that pale coloured netting should present a lower contrast with downwelling light from the surface compared to darker coloured netting (e.g. black or green) and may therefore appear to be a more “attractive” escape route. Anecdotal observations have also indicated that the majority of fish escape in the first few meshes of the square mesh panel (Briggs 1992). This may be a response to the change in light penetration between closed diamond meshes and more open square meshes. It was therefore also proposed that breaking up the square mesh panel with a section of diamond meshes might also enhance the number of fish escaping.

The concept of manipulating twine colour had been applied with some success in experimental situations. A square mesh panel was constructed with black netting on one side and white netting on the other. A towed underwater vehicle, positioned alongside the panel allowed prolonged monitoring of fish escaping from the two sections. Regardless of which side the panel it was on, between 60 – 80% of the fish escapes were made out of the white netting section (Anonymous 1993-1994). Whilst these principles had been tried in finely tuned nets onboard a research vessel, the concepts had never been applied to a commercial setting and this was the aim of this study.

Methods

The 900hp *Challenge II* was twin rigged with standard whitefish trawl nets. For the purposes of this experiment, different combinations of coloured square mesh escape panel and codend were attached to the boat's own nets. All square mesh panels were 3m long and 25 open bars across constructed from 90 mm knotless polypropylene twine and inserted into a standard extension of 110 mm diamond mesh constructed from 5 mm double green polypropylene twine. Both selectivity and video observation tows were made on the Buchan Deeps and Klondyke Bank fishing grounds (57º 38.5’ – 57º 20.5’N and 1º 20.3’ – 1º 35.6’ W) between 30 August and 5 September 2002.

For observational work, “split” design square mesh panels were fished in combination with 40 mm codends. The panels were constructed from a section of black and a section of white square mesh netting, each 3m long and 12½ open bars across joined together longitudinally. Low light CCD cameras (ROS) were attached to the trawl nets on the top sheet of the codends looking along the square mesh to view fish escaping from the net. Floats were positioned on the codend to counter the weight of the camera, and to prevent twisting of the extension. A second underwater housing containing a SONY Video Walkman and battery pack was attached inside a netting bag to the selvedge approximately 20m forward on the extension. The cable linking the camera to recorder was run loosely along the selvedge. The RCTV was used on some trawls in order to monitor the nets and the CCD camera position. The vehicle carried a low-light Silicon Intensified Target (SIT) camera, with a cable providing a live signal to monitors on the boat.

Light intensity in the water column was measured at depth before and after each trawl using a photomultiplier tube and Chelsea logger. The instruments and their battery packs were mounted on a frame that was lowered towards the seabed. The frame was held steady when it reached approx. 5 metres above the sea-floor to prevent damage to the fragile instruments and also to prevent light levels being affected by sand clouds created on impact with the sea-floor.

Video footage from valid tows was analysed frame by frame in order to count the number of fish escaping from the black and white sides of the panel over the period of the tow. Escaping fish were identified as haddock and whiting where possible and “small gadoids” where identification was uncertain. Pelagic species (herring and mackerel), flatfish and “other” were also recorded. Counts started when the net had touched the sea-bed, indicated by the appearance of sand clouds.

For selectivity tows, one of three test panels was fished on one net in combination with a small mesh codend (40 mm) and an identical codend but without a panel was used on the other net. The three different panel configurations tested were:

1) 3m long white 90 mm square mesh panel

2) 3m long black 90 mm square mesh panel

3) Identical to panel 1 but with a middle section, 1m in length of 110 mm, green diamond mesh.

Whilst observational tows were restricted to peak daylight hours (between 10:00-15:00h), selectivity tows were carried out between 05:00 and 20:00. Depths ranged from 80-100 m and tow duration was approximately 1hour. The data were analysed using the methods described in Fryer *et al.* (Fryer, Zuur *et al*. 2003).

Results

A total of 4 observation hauls were made. Two tows were carried out with split panels and cameras on both nets. In both cases the black half of the panel was on the starboard side of the trawl. In this way the black half was on the inside of the port net and the outside of the starboard net. One camera was attached to the netting directly looking from the codend along the panel. The other was attached using a metal frame which raised the camera approximately 0.5m above the net, orientated downwards using the counter effect of a towed float and a "fin". Two additional hauls were made where only the starboard net was utilised as an experimental net, with the panel attached the opposite way round, i.e. black half to port on the "inside" and the white half to starboard, on the "outside". In both hauls the camera was mounted on the raised frame. Achieving an acceptably low level of distortion in the square mesh panel proved difficult and only 3 videos were considered suitable for analysis. Table 1 gives the pooled numbers of gadoid and pelagic fish escaping from each side of the panel. For both species groups, there was no significant difference in the number of fish escaping from each side of the panel.

Table 1 Numbers of gadoids (haddock, whiting and small gadoids) and pelagic (herring and mackerel) escaping from the black and white halves of a square mesh panel pooled from three 1 hour tows.

SPECIES	***BLACK HALF***	***WHITE HALF***	***WHITE/BLACK SPLIT***
GADOID SPECIES	1181	1185	0.51
PELAGIC SPECIES	1053	1242	0.54

A total of 15 valid selectivity tows were achieved for the 3 test cases considered here; 5 with a black panel, 4 with a white panel and 6 with the white square and diamond mesh combination panel. A smoother was used to describe how the proportion of haddock retained in the test codend (of those caught in both the test and control codends) changed with length for each haul in turn (Figure 1). These smoothers were then combined over hauls to estimate the mean proportion of haddock retained in the test codend for each panel-type (Figure 2). The three mean curves are superimposed in Figure 3.

The differences between the mean curves are plotted on a pair wise basis in Figure 4. The differences are plotted on the logistic scale and can be interpreted as the log relative catch rates of each pair of nets. The greatest difference is between the white panel and the black panel. The confidence bands in Figure 4 suggest that the white panel releases more haddock than the black panel at lengths below 30 cm. However, a formal hypothesis test shows that this difference is only marginally significant (T_{ave} = 5.6, ASL = 0.08, test restricted to lengths below 30 cm).

Discussion and Conclusions

Contrary to previous experimental observations, no significant difference was found in the split panel experiment with equal numbers of fish escaping overall from each side of the panel. The earlier experiments were conducted with a design of net that resulted in a much rounder, more open extension shape, allowing fish more freedom to move. The current study used standard commercial rigging of the panel and extension that results in a flatter, more restrictive cross section. The design of the experiment relies on the fish being evenly distributed beneath the panel. It was not possible to ascertain if this was indeed the case. Unobtrusive video observations were found to be difficult to achieve and distortion of the panel was unavoidable.

The issues of altering panel geometry and light restrictions are avoided with selectivity experiments. The data for haddock did suggest that the white panel released more fish below 30cm than the black panel. However the difference was only marginally significant. The square / diamond combination panel appeared to retain less haddock than the black panel but was not as effective as the white panel although neither difference was significant. This reduced proportion of escapes therefore suggests that fish do utilise the entire length of the panel.

Manipulating colour and contrast of twine can produce subtle effects and require more data than was collected in this study to properly elucidate. The prevailing environmental conditions such as depth, time of day and turbidity of the water will clearly influence effectiveness, but there are indications that a simple change of twine colour can improve the performance of escape panels.

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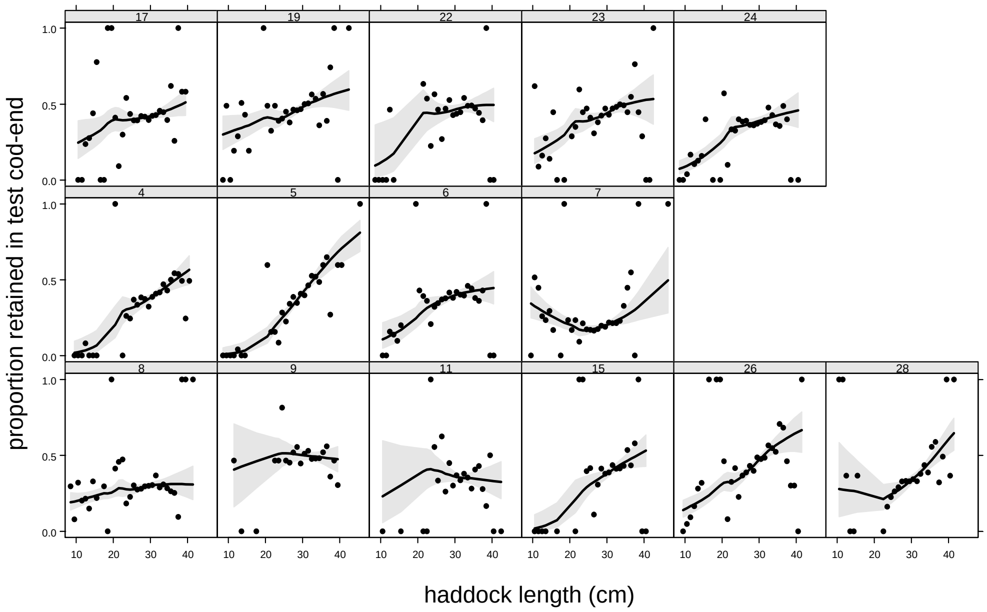

Figure 1. The proportion of haddock retained in the test codend of those retained in both the test and control codends. The fitted lines are loess smoothers based on a window containing the 17 nearest length classes. The shaded bands are pointwise 95% confidence bands. The top, middle and bottom rows correspond to the black, white and square / diamond combination (“double white”) panel respectively.

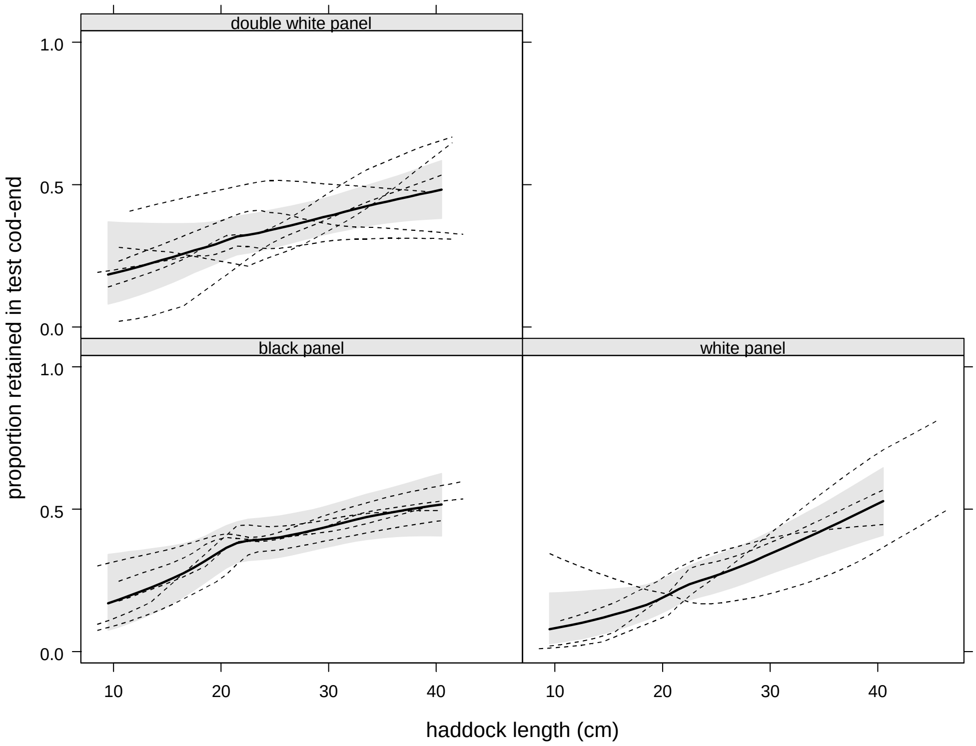

Figure 2. The mean curves for each panel-type (solid lines) with pointwise 95% confidence bands (shaded areas). The dashed lines are the individual haul curves.

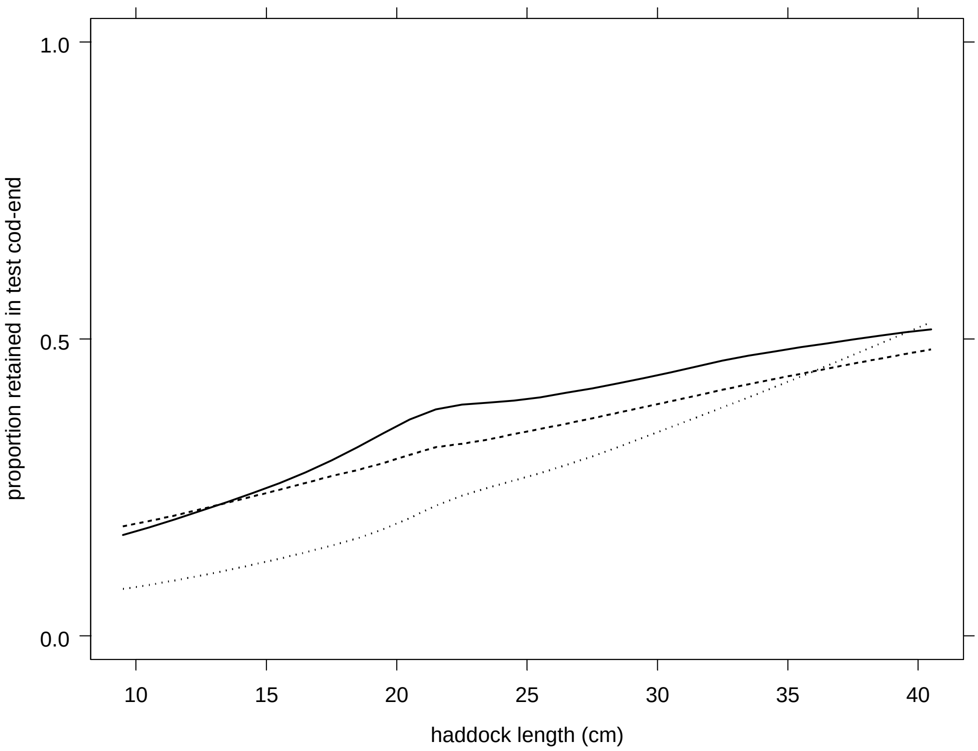

Figure 3. The mean curves of the three panel-types: black (solid), square / diamond (dashed), and white (dotted).

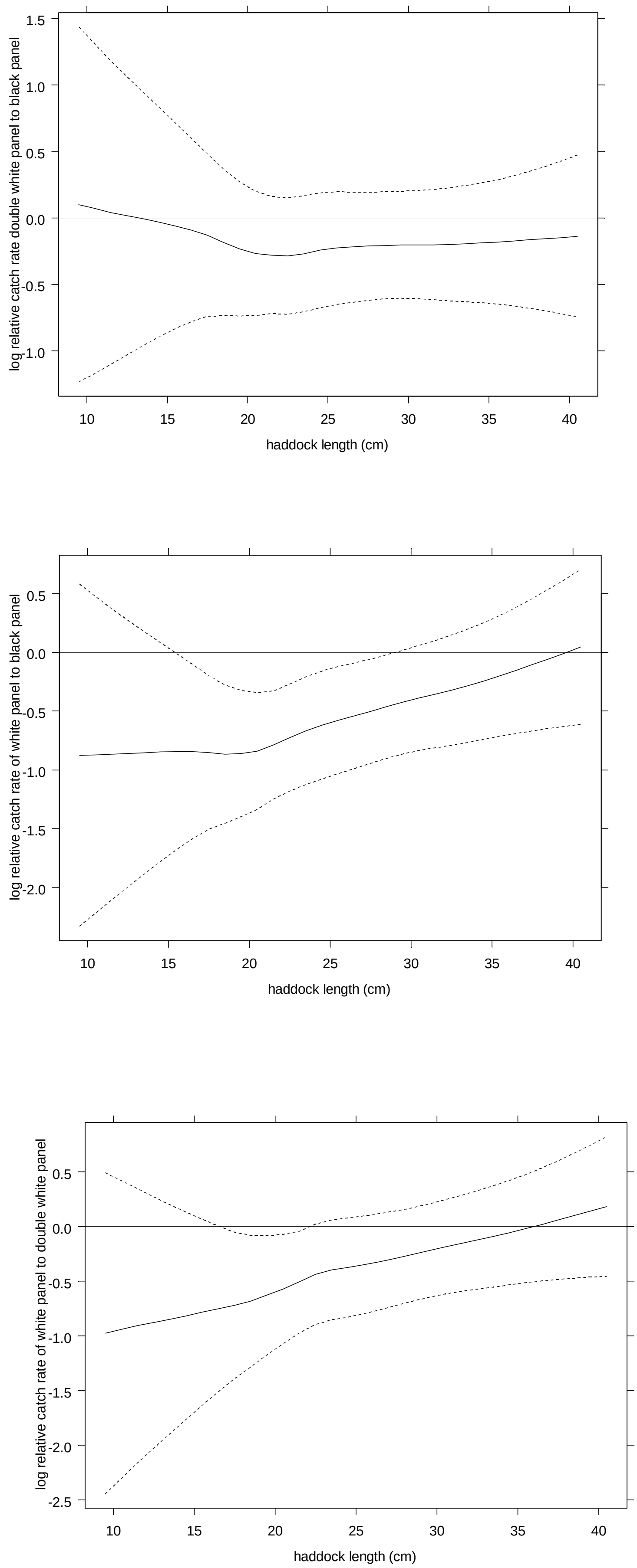

Figure 4. The log relative catch rate of the test nets with pointwise 95% confidence bands. The horizontal line at zero indicates an equal catch rate.

Working Document:

Evaluation of a Large-Mesh panel to reduce the flatfish bycatch in the small mesh bottom trawls used in the New England Silver Hake Fishery.

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Evaluation of a Large-Mesh Panel to Reduce the Flatfish Bycatch in the Small-Mesh Bottom Trawls Used in the New England Silver Hake Fishery

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Abstract.-Fishermen must use small-mesh bottom trawls to capture certain species of fish that cannot be retained by standard groundfish mesh sizes. These fisheries are subject to bycatch limits when such trawls are used in areas where regulated species reside. Bycatch of regulated flatfish in the small-mesh bottom trawl fishery for silver hake *Merluccius bilinearis* in the northwestern Atlantic is a concern of management because silver hakes are captured in areas where juvenile regulated flatfish are common. An evaluation of flatfish and silver hake behaviours using low-light underwater cameras suggested that the two species could be separated within the mouth of a bottom trawl. Using the alternate tow method, four different large-mesh panels positioned in the lower belly of the trawl were separately evaluated. One of them proved to be effective in reducing flatfish bycatch while not reducing the catch of silver hakes; a large-mesh panel constructed of 40.6-cm (16-in) stretched mesh that was diamond shaped using orange-coloured nylon twine 1.6 mm (0.06 in) in diameter in the lower belly resulted in a 78% reduction in flatfish catch with no effect on the catch of silver hakes.

The silver hake *Merluccius bilinearis* is an abundant and commercially important finfish occurring throughout the Gulf of Maine, Georges Bank, and southern New England regions (Figure 1). Silver hakes are caught almost exclusively with bottom trawl gear, and it occupies the entire water column from the surface to 550 m, exhibiting diurnal movement up and down to acquire food (Helser et al. 1995). No significant recreational fisheries presently exist for silver hakes (Brodziak 1998). Two stocks of silver hakes are currently recognized on the basis of morphological differences, trawl surveys, and commercial landings: a northern stock in the Gulf of Maine-northern Georges Bank area and a southern stock in southern Georges Bank-Middle Atlantic area (NEFSC 1994). Both stocks are currently managed under the Northeast Multispecies Fishery Management Plan. Based on standardized relative abundance indices, the northern stock is not overfished while the southern stock is considered to be overfished (Brodziak 2001). Bottom trawl surveys indicate a rising trend for the northern stock biomass and a declining trend for the biomass of the southern stock. Landings for both stocks were approximately 14,000 metric tons per year in 1999, which is down from 20,000 metric tons per year in 1990 (Brodziak 2001). Both stocks cohabit with other regulated and nonregulated species, including flounder species (order Pleuronectiformes), Atlantic cod *Gadus morhua*, and red hake *Urophycischuss.*

To harvest silver hakes commercially, U.S. fishermen in the northwestern Atlantic use small-mesh nets with mesh sizes less than 7.6 cm (3.0 in) because adult silver hakes have a small girth and can easily pass through the 15.2-cm (6-in) mini- mum stretched-mesh size that is mandated in this region. Because fishermen must use small-mesh trawls to harvest silver hake, this fishery is ex- empted from the minimum mesh size regulations imposed on directed fisheries for the regulated groundfish species. Managers have required that the silver hake fishery achieve a bycatch rate of 5% of regulated species or less in order to continue. Therefore, this fishery must demonstrate that the bycatch of regulated groundfish is 5% or less of the total catch. Bycatch in this fishery is monitored by observers on a small percentage of the vessels. The silver hake fishery is commercially valuable; however, there is concern over the by- catch of regulated groundfish species. The term ‘‘bycatch’’ has been defined by the National Marine Fisheries Service (NMFS) as ‘‘fishery discards, retained incidental catch, and unobserved mortalities resulting from direct encounters with fishing gear’’ (NMFS 1998). Fishery discards are

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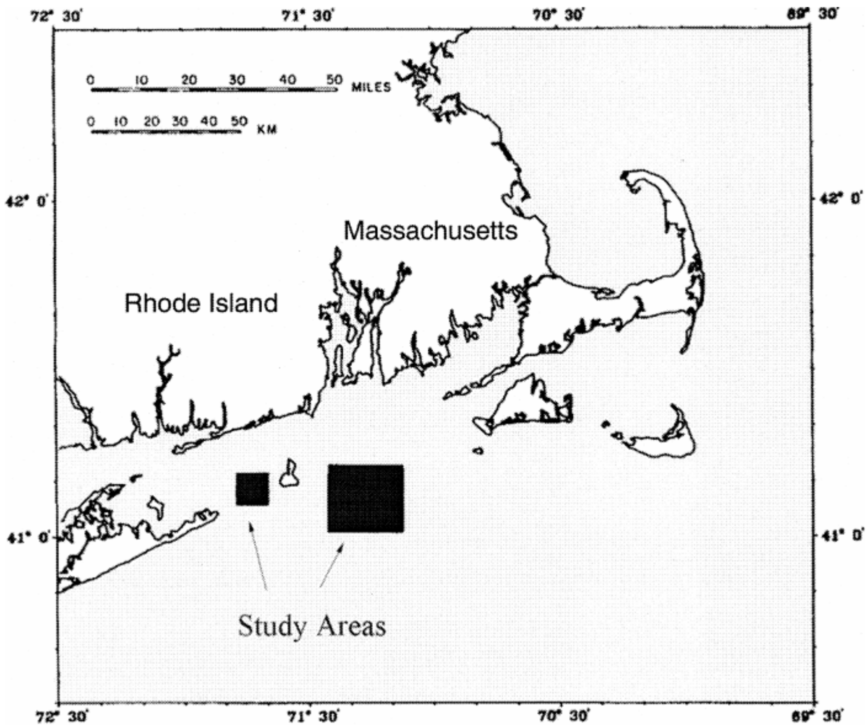

FIGURE 1.-Study area in the northwestern Atlantic (dark squares) for all the experimental studies of using large-mesh panels to reduce the bycatch of flatfish.

composed of animals for which there is no profitable market (economic discards) or animals for which regulations prohibit landing (regulatory discards). The NMFS has recommended the development and implementation of methods for assessing the response of fish to fishing gear to aid in the design of more selective fishing gear and promote high survival of bycatch (NMFS 1998); it has also proposed that the first priority for reducing bycatch should be to avoid catching by- catch species wherever possible (Brodziak 1998).

Five regulated flatfish species-yellowtail flounder *Pleuronectes ferrugineus*, winter flounder *Pleuronectes americanus*, witch flounder *Glypto-cephalus cynoglossus*, windowpane *Scopthalmus aquosus*, and American plaice *Hippoglossoides platessoides*-constitute the majority of the regulated bycatch species in the southern New England silver hake fishery (Almeida *et al*. 1989). Bycatch of regulated species in the silver hake fishery has been problematic. A raised footrope trawl developed in the 1990s by the Massachusetts Division of Marine Fisheries allowed the silver hake fishery to continue because it has been demonstrated to reduce the catch of regulated species, predominantly flatfish, below the 5% limit mandated by fisheries managers (McKiernan et a. 1998). This device performed well in field research, but in practice the performance of the sweep is highly variable and is determined by individual adjustments to the gear. Additionally, fishermen can easily modify the sweep rigging to reduce the height of the footrope and thus thwart the bycatch reduction benefits of the raised footrope. An effective bycatch reduction technology must not substantially affect the catch of the targeted species, along with being manageable and enforceable, easily constructed and used without interference to the fishing operation, and difficult to circumvent by fishermen.

The behavioural response of fish to twine colour in a bottom trawl has been studied previously and provided the basis for our selection of the twine colour used in the escape panel of our experimental trawl (Wardle *et al*. 1991; Wardle 1993; Glass and Wardle 1995b). Fish have functional vision at light levels to 10-7 lx (Glass and Wardle 1989; Wardle 1993). Underwater, white, green, and blue all become light and bright, while red becomes dark. Orange and grey become a shade of grey and are invisible in water greater than 20 m. Consequently, netting material can be designed to be transparent or opaque to fish by using orange or grey twine. Wardle (1993), in an attempt to induce certain behaviours in fish within the bottom trawl net, investigated the effect of varying the colours of the twine used in the construction of the net. With respect to making a net panel appear invisible when it is near the bottom, he found that matching the colour to the seabed was the important factor. Wardle (1993) noted that fish see contrast and that orange webbing provides little contrast to the surroundings; the most contrast occurs when white webbing is positioned near dark webbing. Glass and Wardle (1995a) found that the addition of a black fabric tunnel in the cod end helped to induce the escape of haddock *Melanogrammus aeglefinus* and European whiting *Merlangius merlangus* in front of the tunnel due to the visual stimulus presented by the black fabric.

The principle objective of this study was to develop an alternative technology to reduce flatfish bycatch in the silver hake fishery that would be less sensitive to adjustment and that would not negatively affect catch efficiency for silver hakes. Based on video analysis of fish behaviour, we believed that a large-mesh panel in the lower belly of the trawl had the potential to reduce bycatch, not be sensitive to fine adjustment, and not adversely affect the catch of the target species.

Thus, we evaluated the following hypotheses: (1) that the addition of a large-mesh panel to the lower belly of the net would not affect the total catch of silver hakes in the net and (2) that the addition of a large-mesh panel to the lower belly of the net would not affect the capture of flatfish in the net.

Methods

Behavior.-Data on fish behaviour were collected with underwater, low-light (silicon-intensified-tar- get) video cameras (Figure 2; Milliken *et al*. 1992). Most of the video data were collected with the camera attached to the headrope looking aft to- wards the sweep. This location afforded a view of the entire centre of the sweep and the lower belly. Occasionally, two cameras were used, one being placed on either the port or starboard wing facing aft towards the sweep. These locations provided a better view of the vertical location of the fish in relation to the mouth of the net. Each usable tape was time coded. The video was analyzed to determine the behaviour of flatfish and silver hakes within the mouth of the bottom trawl. When flatfish

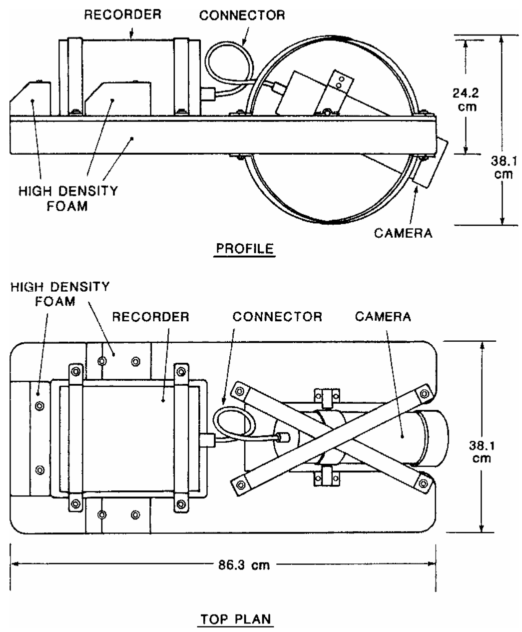

FIGURE 2.-University of Rhode Island underwater camera system composed of a Photosea silicon intensifier target (SIT) camera and Photosea in situ recorder. The unit has the capability to record up to 2 h of data at depths up to 1,000 m (Milliken et al. 1992).

were viewed, their behaviours were documented in 1-s intervals (Castro et al. 1992).

Net standardization.-Prior to the comparative panel study, net mensuration was conducted on both nets to quantitatively determine that both the control and experimental nets performed equally. The experimental net was outfitted with a 6.4-cm (2.5-in) mesh panel that was the same twine and mesh size used in the lower belly of the control net. Scan-Mar net mensuration equipment with Model 4016 display unit and door, wing, and head- rope height sensors were placed on both nets for three pairs (6 tows). The resulting measurements were compared to determine that both nets were fishing similarly. The net mensuration equipment was also used to monitor net performance at various times during the course of the study. Net measurements were compared by means of a two sample *t*-test assuming unequal variances.

Net description.-The experimental trawl net designs were adapted from a commercial net plan and made by a commercial net manufacturer. The basic net was a common commercial two-seam net used in the silver hake fishery with 12.7-cm (5- in) mesh (stretched measurement) in the wings and 6.4- cm (2.5-in) mesh in the remainder of the net

(Figure 3). The twine used was 2.3-mm (0.09-in) and 1.7-mm (0.07-in) black nylon, respectively. The cod end was constructed of 8.9-cm (3.5-in) stretched-mesh black 4-mm (0.16-in) polyethylene. It measured 100 meshes around by 60 meshes deep with a liner of 200 meshes of 5.1-cm (2-in) webbing constructed of 1.6-mm (0.06-in) nylon. The footrope was 34.1 m (112 ft) long and the headrope measured 25.9 m (85.0 ft). The sweep was constructed from 1.0-cm (0.4-in) Trawlex chain with five links to the trawler. Forty 20.3-cm (8-in) center-hole, heavy-duty Nokalon floats in strings of four were attached to the headrope to provide lift.

Specifications of the large-mesh panels.-Four experimental large-mesh panels were evaluated. Each panel was rectangular, measuring 7.6 3 2.6 m (25 3 8.5 ft) and framed with 0.95-cm (0.4-in) diameter polyester rope (Figure 4ooo). All panels were sewn into the lower belly of the net 61 cm (24 in) back from the center of the footrope. The back section of the panels, the section closest to the cod end, went from gore to gore in the aft section of the lower belly of the two-seam net (Figure 3).

Experimental panel 1 consisted of an orange large-mesh panel with 1.6-mm twine. This panel was constructed from 40.6-cm (16-in) meshes of 1.6-mm (0.06-in) diameter nylon twine that were sewn 37.5 meshes across 3 7.5 meshes deep. It had a primary hanging ratio (the ratio of the width of the mesh opening to the stretched mesh length) of 0.5 and a secondary hanging ratio (the ratio of the length of the mesh opening to the stretched mesh length) of 0.87. The webbing was dyed dark orange.

Experimental panel 2 consisted of a white rope panel with 9.5-mm ropes. The rope panel consisted of 0.95-cm (0.04-in) diameter poly-Dacron ropes hung every 38.1 cm (15 in). Eighteen white ropes were hung in the 7.6-m 3 2.6-m (25-ft 3 8.5-ft) panel with the ropes running parallel to the length of the net.

Experimental panel 3 consisted of a white large-mesh panel with 4.8-mm twine. The white panel was constructed of 40.6-cm (16-in) meshes of 4.8- mm (0.2-in) diameter polyester twine that were sewn 37.5 meshes across 3 7.5 meshes deep. It had a primary hanging ratio of 0.5 and a secondary hanging ratio of 0.87. Experimental panel 4 consisted of an orange large-mesh panel with 4.8-mm twine that was otherwise identical to panel 3.

Experimental design.-An experimental net out-fitted with a large-mesh panel was compared with a control net without the panel during all experiments. The two trawls were identical except for the inclusion of the lower-belly escape panels in the experimental net. The net was towed by the FV *Wallaby*, a 21.9-m (71.8-ft) wooden-hulled stern trawler. The vessel used steel Thyboron 76 doors and fished with 73 m (240 ft) of 2.0-cm (;¾- in) wire covered in 7.0-cm (2 ¾-in) rubber disks (cookies) between the doors and the wing ends. The vessel was equipped with a hydraulic sorting belt and two net drums. The additional net drum enabled the crew to easily switch between the experimental and control nets.

To minimize bias, the experimental and control nets were fished using the alternate-paired method whereby the control and experimental nets were paired and the nets were switched according to an A, B, B, A protocol (DeAlteris and Castro 1991). Thus, if the experimental net (‘‘A’’) was fished first, the net would subsequently be switched to the control (‘‘B’’) and the next pair would start with the control. This method was used to reduce the number of net changes required. Furthermore, if an even number of tows were completed in a day, the subsequent day the pairs were reversed so as to reduce bias that could result from varying catches of the first early morning tow.

The captain’s estimates were used to quantify total catch weight. These estimates were calibrated by the placement of coloured rings that incrementally marked the length of the cod end. As only one captain participated during the study, the relative catch sizes were considered consistent. A subsample from the catch was obtained by placing a 1-m^2 brail (dip net) randomly within a pen (checker). Fish were dumped randomly within the checker and the filled brail was then removed. This method reduced any sorting bias. Fish in the sub- sample were first sorted by species and then weighed, counted, and measured. Total catch number by species was estimated by comparing the weight of the subsample with that of the estimated total catch.

All variables related to the fishing operation were held as constant as possible for each pair fished. This included tow direction, tow speed, wire set, length of tow, and area fished. The areas fished were those normally used by commercial fishermen engaged in the silver hake fishery in southern New England. The catch weights between pairs were compared by means of a paired *t*-test. To detect differences in the length-frequency distributions, a Kolmogorov-Smirnov test was per- formed on the unadjusted silver hake length data

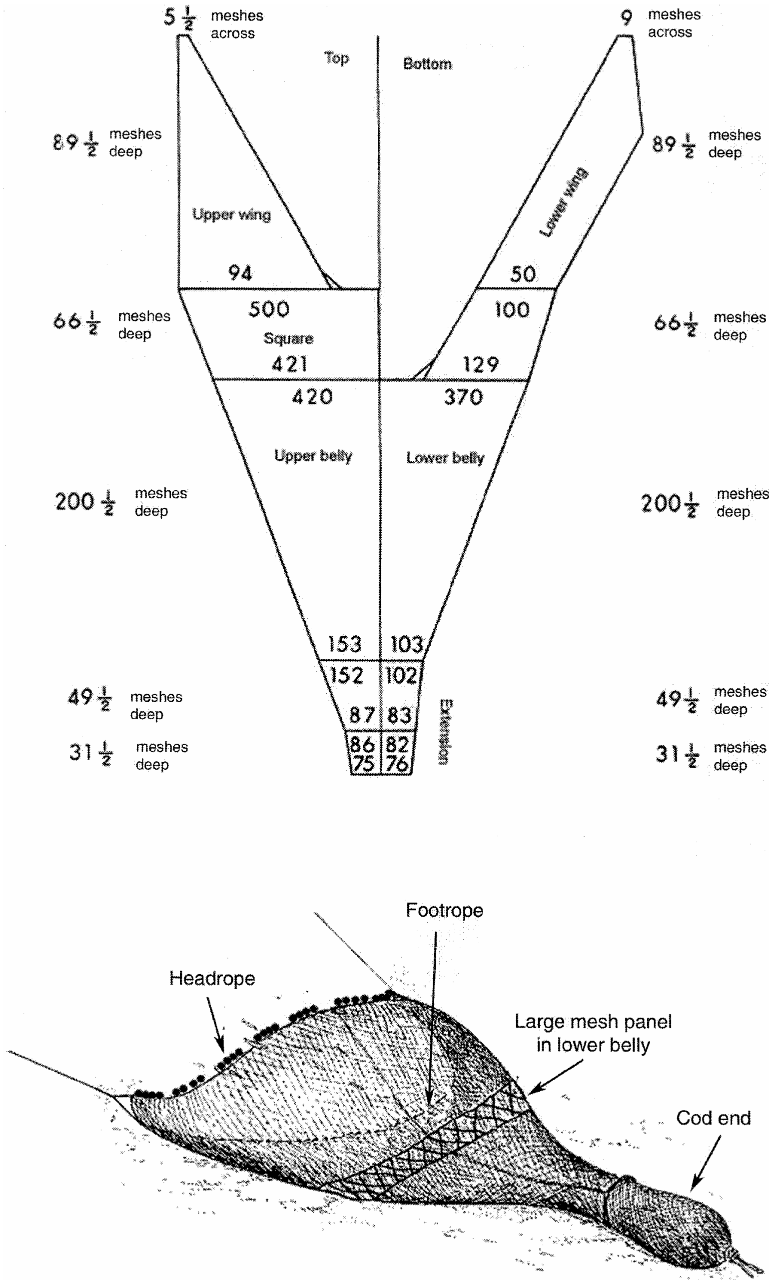

FIGURE 3.-Diagram of the nets used in the study and the placement of the large-mesh panel. Nets were identical except for the addition of an escape panel in the lower belly of the experimental net.

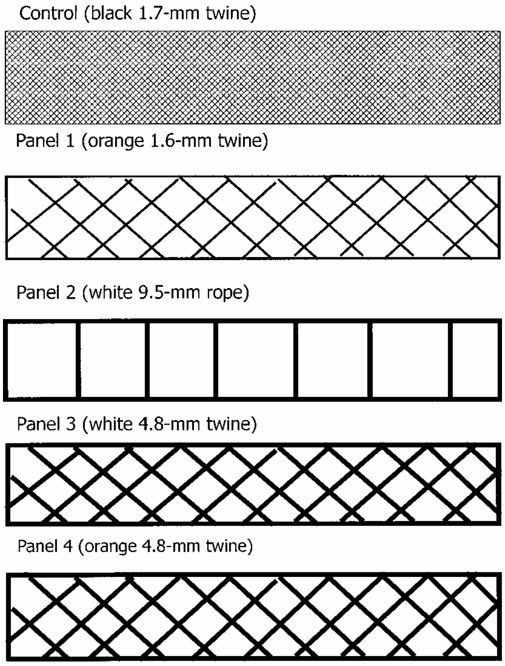

FIGURE 4.-Escape panel arrangements for the control and experimental trawls.

aggregated from tows by each experimental net panel (Sokal and Rohlf 1981).

Results

Fish Behaviour

Twenty-three hours of video data were analyzed, which produced behavioural data on 134 different flatfish. Flatfish species differentiation from the video was determined to be unfeasible, so that all flatfish observances were grouped as simply ''flat-fish.'' Behaviours were recorded for each second that the flatfish were present in the video, resulting in 654 recorded behaviours. Based on the video analysis, it appears that almost all of the flatfish entered the net or escaped under the net near the center section of the gear. Flatfish were oriented toward the vessel in 77% of the observations; 99% of the flatfish were observed at or near the sub-strate, only 1% of the flatfish being observed rising towards the middle of the net; and there were no observations of the flatfish near the top of the net. Thus, flatfish were never more than 1.8 m (5.9 ft) above the substrate, and rarely rose more than 0.9 m (2.9 ft) above it.

When flatfish encountered the gear after swimming in front of the sweep, 72% passively passed over the footrope. The term ''passively passing into the net'' refers to the fish's behaviour entering the net. Regardless of the behaviour prior to entering the net, when the flatfish entered the net it was not due to their voluntary action; they were over-come by the net and were forced into it because the net was moving forward at more than 5 km/h.

Few silver hakes were observed. They were difficult to discern from other species in the video data and did not swim in the mouth of the gear for any length of time. In each instance when silver hakes were observed, they were located near the substrate until they were near the net. The silver hakes were all observed to rise as the sweep ap-proached and to rush towards the upper panel of the net or into the net. These qualitative observations are supported by other research on silver hake or related species (Carr and Caruso 1992; Arkley and MacMullen 1996). Although not ob- served in the video, many silver hakes were gilled in the net section (square) behind the headrope and directly above the sweep in both the experimental and control nets.

Net Standardization

Net mensuration data were analyzed by means of a two-sample *t*-test for unequal variances (a 5

TABLE 1.-Two-sample *t*-test analysis of trawl mensuration data collected from Scan-Mar net mensuration gear assuming unequal variances.

	Vertical opening (m)		Wing spread (m)	
Statistic	Control	Experimental	Control	Experimental
Mean	2.56	2.70	14.60	14.70
Variance	0.50	0.11	2.43	0.44
Observations	36	36	30	30
Pearson correlation	20.30		0.29	
Pooled variance	1.50		24.23	
Degrees of freedom	92		66	
t-statistic	20.43		20.07	
P-value[a]	0.67		0.94	
Critical *t*-value[a]	61.99		62.00	

[a]Two-tailed test.

TABLE 2.-Species composition by mean weight (kg) and results of the paired-comparison analysis on the predominant species retained by different experimental nets; *P* , 0.10*, *P* , 0.05**, *P* , 0.01***.

	Panel 1			Panel 2		
Species	Control	Experimental	*P*	Control	Experimental	*P*
Silver hake All	360.74	269.61	0.125	207.29	94.18	0.004***
flatfish	165.08	44.81	0.000***	199.41	40.21	0.000***
Regulated fish	135.33	37.82	0.000***	181.37	35.8	0.000***
Butterfish *Peprilus triacanthus*	154.71	114.57	0.148	251.18	243.68	0.923
Spiny dogfish *Squalus acanthias*	37.47	72.12	0.035**	71.39	96.53	0.454
Herring (*Clupeidae*)	79.01	135.61	0.053*	92.13	33.36	0.155
Goosefish *Lophius americanus*	37.58	26.22	0.438	20.66	5.29	0.133
Hakes *Urophycis* spp.	52.27	26.53	0.002***	48.41	4.71	0.027**
Skates *Raja* spp.	120.73	48.14	0.000***	120.23	28.13	0.001***
Longfin inshore squid *Loligo pealeii*	12.50	11.30	0.618	31.69	35.00	0.606
Scup *Stenotomus chrysops*	16.31	16.5	0.974	22.09	17.03	0.734
Ocean pout *Macrozoarces americanus*	58.35	17.44	0.013**	5.48	1.98	0.148
Longhorn sculpin *Myoxocephalus octodecemspinosus*	3.62	1.61	0.154	1.43	0	0.117
% of total catch consisting of regulated species	12.2	4.7		16.8	5.7	

0.05) and showed that both nets exhibited similar wing spreads and headrope heights (Table 1).

Panel Comparisons

Experimental panel 1 versus control.-Based on 28 alternate-paired tows (56 total) over the periods May 16-22, 1995, and May 52June 13, 1996, the total catch of regulated groundfish in nets with experimental panel 1 (an orange large-mesh panel constructed of 1.6-mm twine) was 4.7%, compared with 12.2% for the control nets (Table 2). There was no significant difference in the catch of silver hakes and a highly significant difference (*P* , 0.01) in the catch of flatfish between the two nets. There was also a significant decrease in the catch of red hakes in the experimental net catch. Panel 1 resulted in no significant decrease in the catch of silver hakes (Table 2; Figure 5A) and nearly a 75% reduction in the flatfish catch (Table 2; Figure 6A). The experimental net significantly reduced the catch of herrings, hakes in the genus *Urophycis*, skates, and ocean pouts and did not reduce the catch of butterfish, goosefish, longfin inshore squid, scup, and longhorn sculpin. The experimental net caught significantly more spiny dogfish than the control. The silver hake length-frequency data were analyzed by means of a Komodo- rov2Smirnov test to detect differences between their distributions. No differences in the length frequencies retained by the nets were found between the control and experimental panel 1 (Table 3; Figure 7A).

Experimental panel 2 versus control.-Based on 13 alternate-paired tows over the period May 232June 2, 1995, the total catch of regulated flat- fish in nets with experimental panel 2 (which had 9.5-mm ropes spaced 38.1 cm apart) was 5.7%, compared with 16.8% for the control (Table 2). There were highly significant differences (*P* , 0.01) in the catches of silver hakes, other hakes, and flatfish between the two nets, indicating this experimental design led to the loss of a high percentage of both hakes and flatfish (Table 2; Figures 5B, 6B). The Kolmogorov2Smirnov test indicated differences in the length frequencies of silver hakes retained by the control and experimental nets (Table 3), though a comparison of the length frequencies showed overlap (Figure 7B).

Experimental panel 3 versus control.-Based on nine alternate-paired tows over the period September 10-23, 1995, the total catch of regulated groundfish in nets with experimental panel 3 (a white large-mesh panel constructed out of 4.8-mm twine) was 5.1%, compared with 3.8% for the control (Table 2). There was no significant difference in the catches of silver hakes and flatfish between the two nets (*P* , 0.05; Table 2; Figures 5C, 6C). The Kolmogorov2Smirnov test indicated differences in the length frequencies of silver hakes retained by the control and experimental nets (Table 3), though a comparison of the length frequencies showed overlap (Figure 7C).

Experimental panel 4 versus control.-Based on 10 alternate-paired tows over the period September 10-23, 1995, the catch of regulated groundfish in nets with experimental panel 4 (a light-orange large-mesh panel constructed out of 4.8-mm twine) was 4.3%, compared with 5.7% for the control (Table 2). There was a significant difference (*P* , 0.05) in the catches of silver hakes and flatfish between the two nets (Table 2; Figures 5D, 6D). The Kolmogorov2Smirnov test indicated no dif-

TABLE 2.-Extended.

Species	Panel 3 Control	Panel 3 Experimental	Panel 3 P	Panel 4 Control	Panel 4 Experimental	Panel 4 P
Silver hake All	345.77	219.15	0.053*	519.57	227.05	0.014**
flatfish	58.22	40.87	0.262	104.12	58.85	0.017**
Regulated fish	33.1	29.08	0.634	84.13	37.16	0.050*
Butterfish *Peprilus triacanthus*	109.39	85.96	0.407	212.88	183.31	0.474
Spiny dogfish *Squalus acanthias*	20.4	28.23	0.442	44.41	20.00	0.18
Herring (*Clupeidae*)	1.79	1.01	0.467	1.89	1.58	0.851
Goosefish *Lophius americanus*	17.4	5.49	0.233	32.76	47.73	0.369
Hakes *Urophycis* spp.	125.62	81.37	0.192	163.86	159.68	0.944
Skates *Raja* spp.	125.89	63.9	0.126	175.4	125.38	0.050*
Longfin inshore squid *Loligo pealeii*	33.13	28.29	0.254	21.22	24.20	0.630
Scup *Stenotomus chrysops*	0	0		9.99	0.95	0.274
Ocean pout *Macrozoarces americanus*	1.08	0.65	0.41	1.58	1.65	0.422
Longhorn sculpin *Myoxocephalus octodecemspinosus*	2.25	1.44	0.599	8.24	5.48	0.046**
% of total catch consisting of regulated species	3.8	5.1		5.7	4.3	

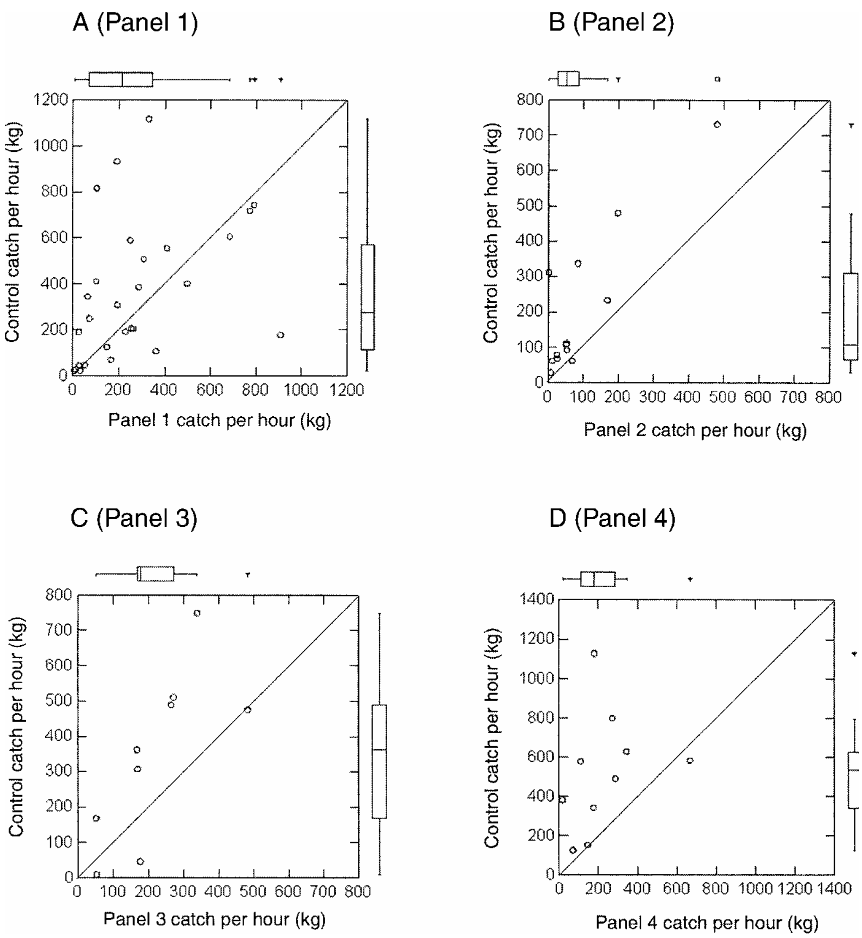

FIGURE 5.-Relationships between catches of silver hakes in control nets and experimental nets with large-mesh panels. The 95% confidence intervals of the data are shown as box plots above the graphs.

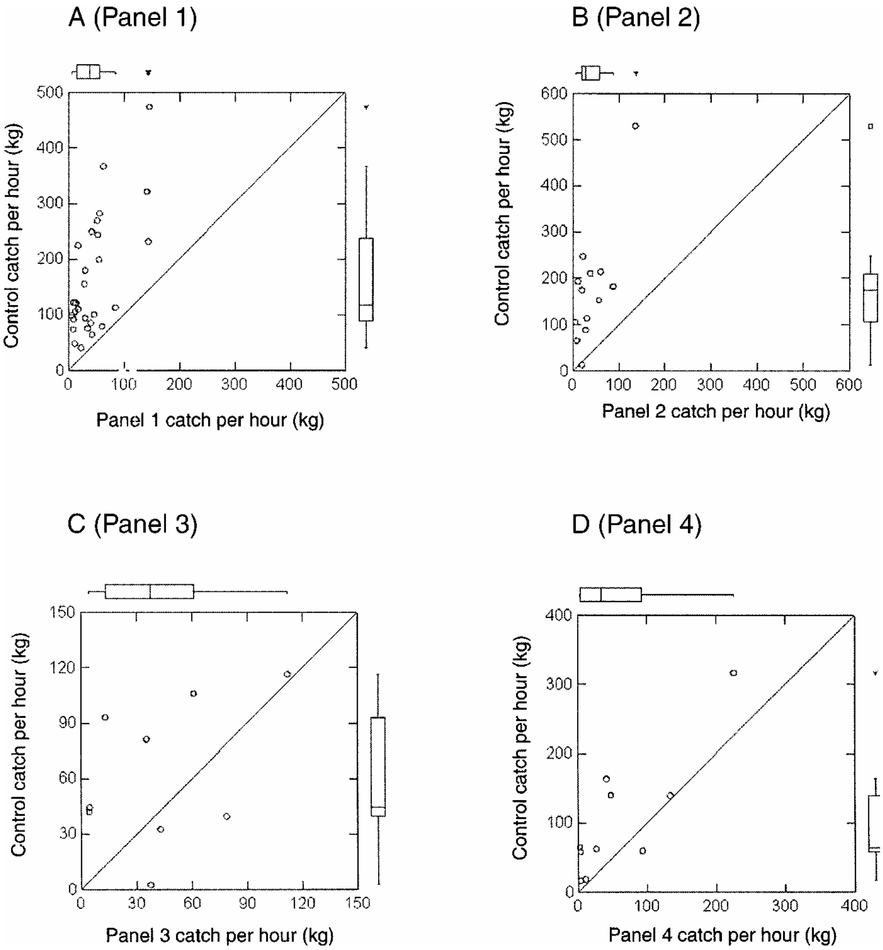

FIGURE 6.-Relationships between catches of flounder species in control nets and experimental nets with large-mesh panels. The 95% confidence intervals of the data are shown as box plots above the graphs.

ferences in the length frequencies of silver hakes retained by the control and experimental nets (Ta- ble 3; Figure 7D).

Discussion

Notes on Experimental Design

The initial experiments compared catches of the orange mesh panel (experimental panel 1) and the control. After completing 12 paired tows and ob- serving reasonable success with this panel, we in- vestigated methods to reduce the bycatch further. A new experimental panel with ropes in place of the 40.6-cm (16-in) mesh was constructed. Testing of the rope panel (experimental net 2) only slightly reduced the catch of regulated species compared with experimental panel 1 and showed an unac- ceptable loss in the catch of the targeted silver hake (Table 2). After this finding, we determined that a test of orange and white large-mesh panels would show what effect the colour of the twine had on the behaviour of silver hakes. We decided to use a heavier twine. Unfortunately, when the large-mesh panel with the thicker twine was dyed, the colour of the twine was light orange rather than the dark orange of experimental panel 1. After 10 pairs it was evident that this panel was not effective in retaining the catch of silver hakes, and the remainder of the study was devoted to testing the original dark-orange panel with the thinner twine against the control net.

Behaviou
r The behaviours of flatfish observed in this study were similar to those described in other studies

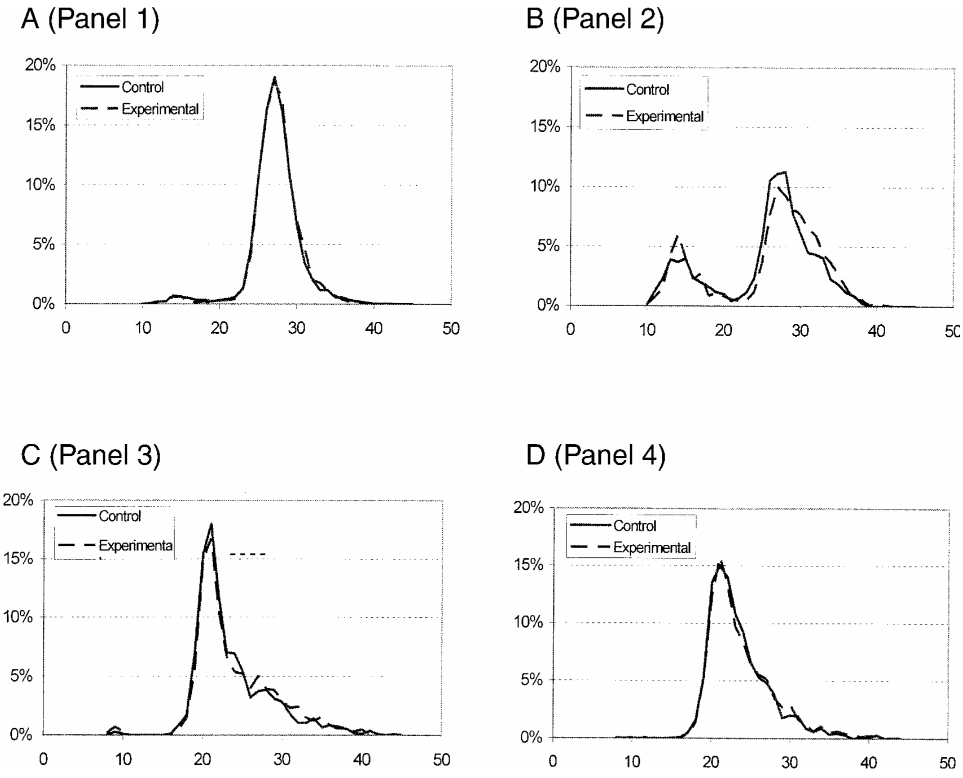

FIGURE 7.-Length compositions of silver hakes caught in the control and experimental nets. In each graph the *y*-axis shows the relative frequencies and the *x*-axis the lengths in centimetres.

(Wardle 1987; Rose 1995; Bublitz 1996). Flatfish generally remained in close association with the seabed as they interacted with a bottom trawl. Initially, they tended to be oriented toward the direction in which the net was being towed (i.e., toward the vessel); then, as they were overtaken by the net, they tumbled back along the lower pan- el into the net. On several observations, this occurred several minutes after the flatfish had been swimming in front of the sweep. As these behaviours have been documented by researchers in other regions with different flatfish species (Wardle 1987; Rose 1995; Bublitz 1996), the large-mesh panel may prove to be an effective flatfish bycatch reduction device in other fisheries in which the targeted species is known to rise into the net when encountering it.

Silver hakes reacted to the sweep by rising, which allowed them to be captured while many of the flatfish were excluded through the experimental panels. If the panel did not provide contrast to the bottom (panel 1), the net retained the silver hakes, confirming the experience of Wardle (1993).

Panel Performance

Experiments were conducted to evaluate different strategies for the reduction of flatfish bycatch in the small-mesh bottom trawl. The experiments were directed at additions of different configurations of escape panels in the lower belly. The escape panels were designed with openings of different sizes and twines (colour and diameter). Of the four modifications tested, only experimental panel 1 (with the 40.6-cm, diamond-shaped meshes constructed of 1.6-mm-diameter orange twine) proved effective in significantly reducing the flat- fish bycatch (73%) while not affecting the catch of silver hakes (Table 2; Figures 5A, 6A).

All large-mesh configurations reduced the catch of flatfish relative to that of the control net. There was an accompanying reduction in the catch of

TABLE 3.-Results of Kolmogorov-Smirnov large-sample tests for differences between the length-frequency distributions of silver hakes retained by four experimental nets. See Figure 4 for panel descriptions. A difference exists when D (the observed difference) is higher than the calculated difference at $D_{0.01}$ or $D_{0.05}$; P , 0.05*, P , 0.01**; NS 5 not significant.

Experimental panel	D	$D_{0.05}$	$D_{0.01}$	Significance level
1	0.0086	0.0240	0.0288	NS
2	0.0867	0.0552	0.0663	**
3	0.0667	0.0559	0.0670	*
4	0.0338	0.0462	0.0554	NS

silver hakes with experimental panels 2, 3, and 4, though the reduction was not significant in the case of panel 3. Experimental panel 1 resulted in no significant reduction in the catch of silver hakes, but overall nets with this panel caught 2,552 kg of fish less than the control net. Although this might lead one to speculate that the control net was actually catching fewer silver hakes, the actual catch data show that the control caught more silver hakes than the experimental net 46% of the time. The reason for the loss of silver hakes in the other experimental nets probably has to do with the contrast of the panel to the sea bottom (Figure 8). As Wardle (1993) suggested, the contrast between the webbing and the seafloor may elicit escape behaviours in certain species of fish.

The analysis of the length-frequency data by means of a Kolmogorov2Smirnov two-sample test showed that both orange panels selected similar size ranges from the population. The results of the test on experimental panels 2 and 3 indicated significant differences in length frequency between the control and experimental nets (Table 3). These differences may be an artifact of the small sample sizes and the test itself, however. Examination of the length-frequency plots (Figure 7) reveals that there is good symmetry between the length frequencies of the silver hakes caught in each comparison.

Experimental panel 1 provided the least amount of contrast to the bottom and thus did not stimulate the silver hakes to escape. Nets with panel 2, which had the most contrast to the bottom, only retained 44% of the silver hakes retained by the control net. Therefore, in designing an escape panel for reducing the catch of flatfish, it is important to consider both the retention of the target species and the reduction in the catch of the bycatch species. In this case, the mesh size of the escape panel had to be sufficiently large to allow for the passive

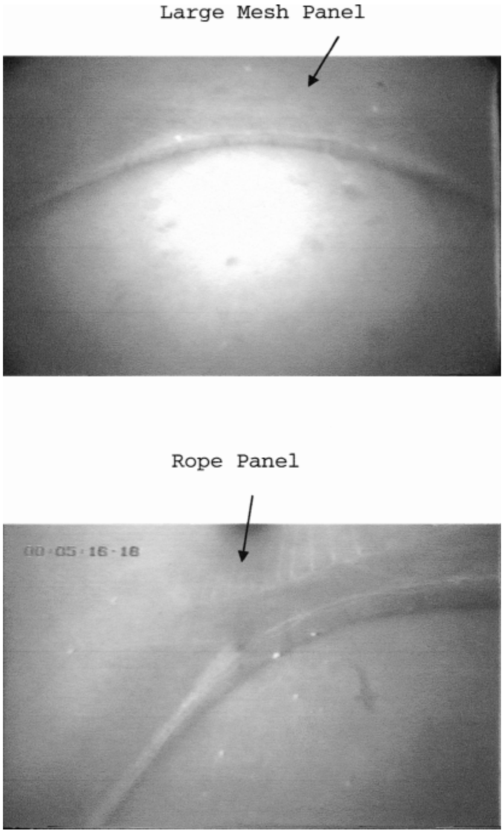

FIGURE 8.-Video images of showing the transparency of the orange mesh panel (upper portion of the figure) and the contrast of the white ropes to the seabed (lower portion of the figure).

escape of the flatfish, while the twine colour had to mask the presence of the escape panel to the actively swimming silver hakes.

In the evaluation of a bycatch reduction technology, there are two critical tests that must be met simultaneously. The first is that the technology must not result in an unacceptable reduction of the target species. The industry will only accept the technology if there is no significant difference between the catch of the target species in the control and experimental nets. The second test is the effectiveness of the new technology in reducing by- catch. If there is not enough reduction in bycatch, the technology needs to be redesigned. In this study, although the numbers of replicated paired tows used in the evaluation of panels 2, 3, and 4 were minimal, they were sufficient to demonstrate that these were ineffective in retaining the target species; as a result, the comparison was terminated.

After 28 paired tows, panel 1 was unable to demonstrate a significant difference in the catch of the target species but clearly demonstrated a significant reduction in the catch of flatfish.

The study has clearly demonstrated that the addition of an orange-coloured, large-mesh escape panel can reduce the catch of flatfish while not affecting the catch of silver hakes. Managers might consider this bycatch solution as an alternative or a supplement to the raised footrope trawl. Furthermore, researchers might investigate this by-catch device in other fisheries in which the bycatch of flatfish is a problem.

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Working Document:

A Lumilux exit grid for the shrimp fishery (Abstract).
Haraldur A. Einarsson and Ásta Hrönn Björgvinsdótti

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A Lumilux exit grid for the shrimp fishery

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On the shrimp fishing grounds where this study was conducted, regulations require the use of a grid with 22 mm bars in the trawl. In October 2003 small trial was conducted to test if fish would swim through a “glowing grid”. A four-panel shrimp trawl was used with an additional lumilux exit grid positioned in the trawl in the side panels. The grid was plastic, 1800 x 1000 mm in size, with 98 mm between the bars and painted with lumilux paint to make it glow. A cover bag over the regular grid sampled all fish that entered the trawl but did not swim through the glowing grid. A total of 8 hauls were completed with the lumilux grid used in every second haul. The idea was to see if fish would swim through the glowing grid with relative large bar spacing to avoid eventual mortality as a consequence hitting the grid or meshes. The results showed no fish escaping through the glowing grid. The concept of using lumilux paint on grids or any other trawl components is interesting, but more knowledge about the reaction of fish to light is needed.

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Annex 3 Report on Efficiency and productivity in fish capture operations

by

Bjarti Thomsen, Andrew Revill, Dominic Rihan, Ole Eigård

Terms of reference

'Efficiency increases in the fish capture process is a continual and incremental process generally stimulated by an economic drive to increase the profitability of fishing operations'

It was proposed at the 2003 ICES-FAO FTFB working group meeting in Bergen, Norway that the following work be undertaken for presentation and discussion at the 2004 meeting of the FTFB working group.

1) Identification of advances and practices, which increase fishing efficiency
2) Quantify such advances wherever possible
3) Review work undertaken in this field

Justification

Increases in the technical efficiency of fish capture processes are not currently accounted for in estimates of fishing effort. Such efficiency increases may therefore undermine management protocols, which utilise estimates of fishing effort as a management tool.

SUMMARY OF THE WORK

The role of ICES as an advisor to its clients on the utilisation of fish stocks is about to change from short term predictions of stock status and recommended F levels to longer term management and strategic planning. There is likely to be an increased emphasis on effort control and advice will be on target F in the future.

One aspect of these new procedures will be to estimate technological efficiency increases in order to optimise and maintain F.

The terms of reference are addressed in the body of this report and include a summary table and breakdown of studies previously undertaken in this field.

Appendix 1: This work gives an overview of the concept of production efficiency in fishing operations and lists the major causes of variations in efficiency and productivity. Technological innovations are identified as responsible for many of these changes, although not all such technologies have such an effect. The drivers for technological innovation are described. The effect of differing fisheries management regimes and incentives to improve efficiency / productivity are described.

Appendices 2, 3 and 4: Case studies undertaken on fleet sectors from the Faroe Islands and Ireland.

The work done by the authors of the report was presented and discussed in a topic group at the FTFB meeting in Gdynia, Poland on 20 April 2004. Following the discussion the report was rearranged and minor alterations made. The topic group participants were:

Bjarti Thomsen, Faroe Islands
Andrew Revill, UK
Dominic Rihan, Ireland
Ole R. Eigård, Denmark
Barry O'Neill, Scotland
Stan Kotwicki, USA
Ken Weinberg, USA
Alessandro Luccnetti, Italy
Mats Ulmestrand, Sweden
Arill Engås, Norway
Hallvard Godøy, Norway
Gérard Bavouzet, France

Terms of reference 1: Identification of advances and practices which increase efficiency

Table 1. Factors that affect the production efficiency of fishing operations.

Biological
Species
Abundance
Distribution
Availability for capture
Susceptibility to capture

Fishing grounds
Location of the fishing grounds
Meteorological conditions
Oceanographic conditions
Seabed topography

Propulsion and Hull
Hull dimensions
Main engine power
Auxiliary engines
Power take offs
Fuel type
Hull design
Propeller design
Gear box reduction
Bollard pull
Fuel efficiency

Bridge electronics
Position location systems
Radar
Sonar
Fish finding
Echo sounders
Charts and plotting
Fishing gear sensors
Autopilots
Integration of instrumentation

Fishing gears
Zone of influence
Herding efficiency
Capture efficiency
Retention efficiency
Retention capacity
Construction materials used
Drag
Number of gears deployed
Duration of deployment
Stowage space required onboard

Deck machinery
Power blocks
Net drums
Net haulers
Net flaking machines
Auto winch control

Catch processing and preservation

Skipper and crew effects
Skills and experience
Quality of life
Safety

Lost fishing time
Maintenance time and costs
Durability
Inactive fishing gear

Port infrastructure and support
Company support
Investment
Market facilities
Processing facilities
Transport
Preservation facilities
Storage facilities

Market
Demand for produce
Price
Elasticity’s

Fisheries management
Regulations
Enforcement
Rule circumvention
Subsidies

Fishing technique used

Terms of reference 2 and 3: Quantification of technological advances and review of work undertaken in this field

Existing Studies on Production Efficiency and Production Frontiers

Numerous quantitative and qualitative studies have been undertaken, many of which are described in 0. Examples of the main methods used in these studies are:

1) Maximum production frontier studies and the relative position of vessels to frontiers
2) Analyses of variance in fishing operations
3) Cost-benefit analyses of fishing operations
4) Catch per unit effort (CPUE) / Fishing mortality (F) relative to reference vessels
5) Catch per unit effort (CPUE) / Fishing mortality (F) relative to stock indices
6) Fishing mortality (F) relative to fishing effort

Studies using reference points

Various studies use reference points (see below) as a baseline to contrast changes in efficiency and productivity, i.e.

1) Indices of stock / abundance
2) Reference vessels (vessels that have changed little over time)
3) The most efficient vessels in the fleet

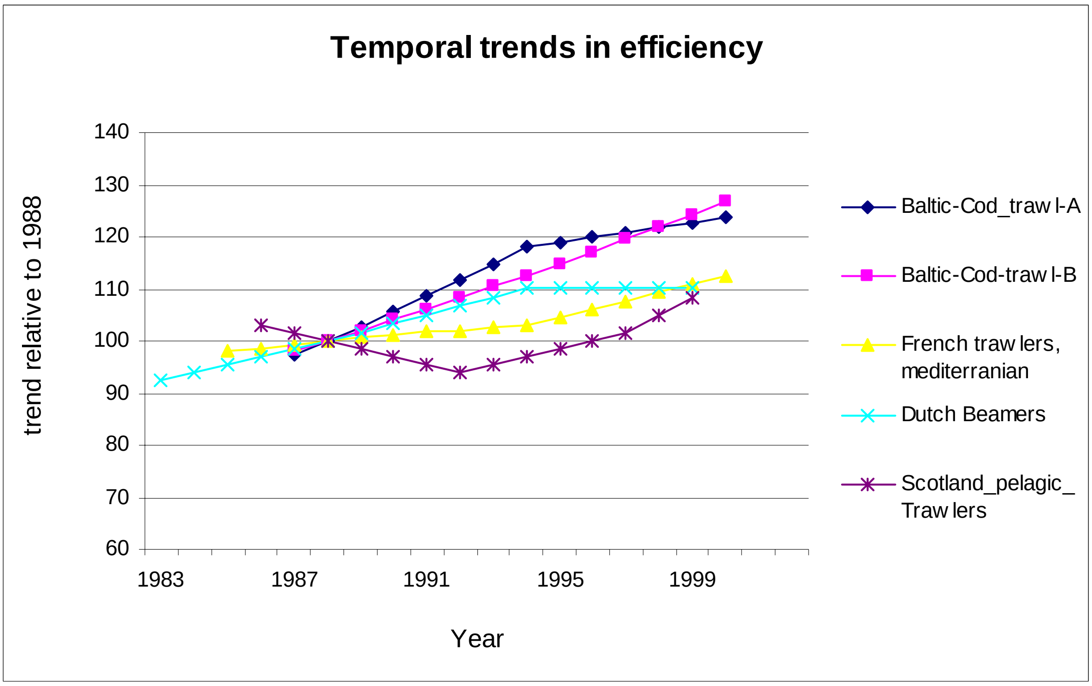


Figure 1. The temporal trend in overall trawl vessel efficiency change relative to 1998 for five different fisheries: Baltic-Cod_trawl-A, French trawlers_Mediterranian, Dutch Beamers and Scotland_pelagic_Trawlers (Banks *et al.* 2002). Baltic_Cod-trawl-B (Marchal *et al.* 2001). Note that the efficiency trends plotted are not necessarily measured on the same scale for all fisheries.

Figure 1 summarizes the results from some of the reviewed literature where quantifications of the total increase in vessel efficiency (as opposed to partial efficiency increase caused by individual technologies as the introduction of the GPS, the twin trawling, etc.) are reported. The results almost uniformly display increasing trends with the values for the average annual increase lying between 0.4 and 2.0%. As mentioned in the figure text it should be noted that the scale on which efficiency is measured is not the same for all fisheries and that the fisheries compared differ very much with respect to their target species and to the management regimes they are placed under.

Table 2. Studies on efficiency and productivity.

Reference	Type of outcome	Methodology and parameters	Fishery	Results (Efficiency / productivity)	Management regime	Source data	Main technical issue	Comments
Anon 'TECMEC' EC 5th Framework project QLK5-CT-1990-01295	Quantitative	Two methods used. 1. Stochastic production frontier models 2. Data envelope analysis	UK Channel (93–98) N.Sea (90 – 00)	Beam trawling (0%) Otter trawling (-5 to +1%) Dredge (+4%) Seine (-15%) *Nephrops* trawling (+6%) Gillnetting (0%) Potting (traps) (-7 to +2%) Long lines (+2%)	Catch quota	Official logbook Economic survey	Skipper skills identified as very important	Technical efficiency found to be more important factor in mobile fisheries than for static fisheries
Banks *et al.*. 2002 (Dutch Beam trawl fishery)	A) Qualitative analysis of technological innovations B) Quantitative analysis of yearly increase in productivity (revenue/effort)	A) Interview programme giving a description and classification of new technology. B) Econometric analysis involving the estimation of a production function.	Dutch Beam trawl fishery for flat fish (targeting sole and plaice) in the North Sea 1983–1998. Data from 52 vessels analysed in the study. The total fleet represented ca. 200 vessels in 1998.	I. Period 1983 – 1990 showed an annual increase of 1.5–2.0% in technical change II. in the period 1991–1998 the increase was 0%	ITQs for Sole and Plaice, Capacity restrictions by horsepower licences (1985) and GT restrictions (1998). Effort regulation by days at sea limitations.	A) Technology data compiled through interviews and literature reviews B) For the quantitative analysis official logbook, and costs and earnings data of the vessels were used	Improvements in boat design and propeller efficiency accounted for most of the increase in pulling power and catching efficiency	

Table 2 Continued.

Reference	Type of outcome	Methodology and parameters	Fishery	Results (Efficiency / productivity)	Management regime	Source data	Main technical issue	Comments
Banks *et al.*, 2002 (Danish trawl fishery for cod in the Baltic Sea)	A) Qualitative analysis of technological innovations B) Quantitative analysis of yearly increase in productivity (revenue/effort)	A) Interview programme giving a description and classification of new technology. B) Econometric analysis involving the estimation of a production function.	Danish trawl fishery for cod in the Baltic Sea. A sub fleet consisting of 23 trawlers with historical catches of cod in February were examined in the period 1987 - 1999	Overall average is 1.8% per annum I. Period 1987 to 1993 annual increase of 2.8% II. Period from 1994-1999 had an annual increase of 0.08%.	Quota rations, capacity restrictions	A) Technology data compiled through interviews and literature reviews B) For the quantitative analysis official logbook, and costs and earnings data of the vessels were used	No technology is singled out, but lay out conversions, electronics, engine, propeller s and gear developments are mentioned. The investment in increasing catching power has been suppressed by the quota rations	
Banks *et al.*, 2002 (Gulf of Lions trawl fishery)	A) Qualitative analysis of technological innovations B) Quantitative analysis of yearly increase in productivity (revenue/effort)	A) Interview programme giving a description and classification of new technology and fisheries. B) Econometric analysis involving the estimation of a production function.	Detailed data covering 1984 to 1999 were sampled for 20 trawlers grouped by 3 different strategies. 1) Demersal trawlers 2) Demersal + pelagic trawlers and 3) Pelagic trawlers	Overall increase of 1.07% per annum from 1985–1999 I. The period 1985 to 1993 had an average increase of 0,7% per annum II. From 1994 to 1999 it was 1.5% per annum	Licensing system	A) Technology data compiled through interviews and literature reviews B) For the quantitative analysis official logbook, and costs and earnings data of the vessels were used	GPS, route tracers, sonar, net sounders and other electronic innovations are the main drivers of the observed technical change	
Bishop *et al.*, 2000	Quantitative analysis of increase in fishing power as a result of new technology but also a methods paper on the applicability of GEE models to fisheries data	Generalized estimating equations (GEE) is applied to factors of stock abundance, fishing power (swept area/hour and vessel + crew skills) and technology	North Australian trawl fishery for prawn (NPF). Analysis covering 1988-1996 with data from app. 240 trawlers yearly	Hull type, Kort nozzle and GPS each affected efficiency by an important amount of the order of 4-7%	??? - Assumed from Robins *et al.* 1998: Restricted fleet size, Licensed fishery, net restrictions, seasonal and temporal closures, no quota restriction, no effort control	Commercial fishery logbook data collected from trawler skippers. Only data covering the main season from august to November were analysed	Gear size and the vessel A-unit (GRT+HP) accounted for most of the efficiency variation. Skipper skills showed no effect.	

Table 2 Continued.

Reference	Type of outcome	Methodology and parameters	Fishery	Results (Efficiency / productivity)	Management regime	Source data	Main technical issue	Comments
Dichmont *et al.*, 2003	Quantitative analysis of changes in fishing power. Particularly important here, because no survey data are available for stock estimation – only commercial catch and effort data	Two step additive modelling 1. statistic estimates of fishing power parameters 2. catch predictions over time by application of parameters to a standard abundance and effort situation before comparing to a standard vessel.	Northern Prawn Fishery (NPF) in Australia. Estimates from dataset for March to November from 1970-2002. All trawlers targeting tiger, banana and endeavour prawns.	1970–1985 (+7% per year) 1985–2000 (+1.7% per year)	Restricted fleet size, licensed fishery, net restrictions, seasonal and temporal closures were introduced in 1986. No quota restriction, no effort control	Augmented dataset used for stock assessment based on data from official logbooks and landings returns	Major innovations Period 70 –85 autopilots, sonar, radar, satnav and try-gear Period 85 – 00 GPS, plotters and TED's* (*Which reduced efficiency	
Eggert, H. 2001	Quantitative	Stochastic production frontier model	Swedish *Nephrop*s trawlers 1995	Vessels found be averaging at 66% efficient	Catch quota		Older vessels less efficient	
Galbraith and Stewart 1995	Qualitative review	Discussion paper	Focuses on Northern Europe	Authors indicate some important historical technical advances in gear efficiency	Not stated but mostly catch quota	Review / discussion paper	Authors highlight importance of advancements in gear technology as a component of overall efficiency	
Hilborn and Ledbetter 1985	Quantitative analysis of differences in catch rates between vessels in the same fishery	Analyses of variance explained by vessel attributes (length, GRT, Horsepower, year built and estimated value) and skipper/crew skills	British Columbia Salmon Purse Seine Fleet fishing in the Juan De Fuca area and Johnstone Strait in the years 1973–1977. App 125 vessels are examined	Vessel attributes account for less than 10% of the difference in the catches and Skipper/crew skills for 20-24%. 66% is unexplained	? (License and effort regulated?)	Official register data of vessel attributes combined with data from mandatory sales slips giving information on weight, number and value of landings together with vessel ID and landing area	Skipper and crew skills are a major drivers of difference in efficiency between vessels	

Table 2 Continued.

Reference	Type of outcome	Methodology and parameters	Fishery	Results (Efficiency / productivity)	Management regime	Source data	Main technical issue	Comments
Kirkley *et al.*,	Quantitative analysis of vessel efficiency in the economic meaning of technical efficiency, which is the vessels ability to produce maximum output with a given set of inputs and technology	Econometric analysis involving the use of a stochastic production frontier	A sample of 10 very physically homogenous vessels fishing for Sea Scallop in the Mid-Atlantic in the period from 1987 to 1990. The vessels are not very representative of the entire fleet	Owners and captains only partly compensate for changing resource conditions through the use of labour and fishing effort	Protection by MLS and since 1994 the fishery has been regulated by limited entry, gear restrictions, days at sea regulations crew size limits and vessel tracking system requirements	Production activity data were obtained from official trip level cost and earnings statement. Resource information for the period was obtained from a resource-monitoring programme.		
Kirkley *et al.*, 2004	Quantitative analysis	Stochastic production frontier model Standard econometric (PC – TSP)	Sete trawl fishery Mediterranean France (1985–1999)	+ 1% per year (Technical efficiency)	Effort	Detailed data from 19 vessels Official LPUE data		
Mahevas 2003	Quantitative, total efficiency increase measured as change in catch per unit effort	GLM + index of abundance from CPUE of reference vessel only having by-catches of species in question	25 French bottom trawlers (Bay of Biscay) targeting anglerfish (1983 – 1998)	I. 1983 – 1991a reduction in overall efficiency – 0.5% II. 1992 – 1997 rise to -0.2% relative to first year	Not specified	Official logbook data on catch and effort. Interviews on gear and vessel development	Partial contribution, Engine power: 58% Twin trawl: 30% Head line: 28% Skipper: 2%	Weak assumptions and not very causal construction of model or interpretation of results

Table 2 Continued.

Reference	Type of outcome	Methodology and parameters	Fishery	Results (Efficiency / productivity)	Management regime	Source data	Main technical issue	Comments
Marchal *et al.*, 2001	Quantitative analysis of temporal development in overall fishing power of two fleets	An index of fishing power for a fleet (IVFP) is derived based on the ratio of CPUE between the fleet and a group of standard vessels with constant fishing power. Makes use of General Linear Models (GLM)	Two vessel groups fishing cod in the Baltic sea are analysed for the period 1987 -1998. I. Trawlers using 105-120 mm mesh size and II. Gill netters using 105-159 mm meshes	The results show a yearly increase in Fishing Power from 1987 to 1998 of 2% for the trawlers and of 6% for the gill-netters.	Not described (quota rations and various technical measures?)	Commercial catch and effort data from official registers and The Danish Institute for Fisheries databases as well as international survey data from ICES covering the examined period	At vessel level the increase is assumed caused by skipper effects and better technology use. On a fleet level either decommissioning of less efficient vessels or recruitment of modern vessels can explain the increase	
Marchal *et al.*, 1999	Quantitative. Comparison of three methods	1. IVC. Changes in catchability and fishing effort 2. IVFP. Changes in CPUE compared to standard vessels 3. IVTE Stochastic production frontier model of economics related to fishing activity	Dutch North Sea beam trawl fishery (1995–1997). Up to 30% of fleet examined	Different methods gave different results. Method 1 and 2 indicated a slow decline in efficiency. Method 3 indicated an increase in efficiency	I.T. catch quota	Official logbook database on catch and effort (DAFIST). LEI cost and earnings database.	Introduction of mesh size regulations reduced efficiency by -19%. Plaice box increased efficiency of small beam trawlers (<221kW) by +14%.	

Table 2 Continued.

Reference	Type of outcome	Methodology and parameters	Fishery	Results (Efficiency / productivity)	Management regime	Source data	Main technical issue	Comments
Marchal *et al.*, 2002	Quantitative analysis	Three different methods used IFP1. Fishing mortality compared to fishing effort IFP2. CPUE of vessels compared to reference vessels IFP3. CPUE compared to abundance data from fish surveys	Northern Europe Demersal fisheries Norway (1980–1998) UK (1989–1998) Denmark (1987–1998) Netherlands (1991–1998)	Danish flatfish fleets (+ 12-27%) Dutch beam trawlers (<300HP) (+ 22%) Norway long liners, gill netters, small saithe trawlers (+ 18 – 44%) Norway small cod trawlers (+ 11%) Danish large otter trawlers and seine netters (+ 4 – 9%) Dutch sole beam trawlers (> 300HP) (+ 6 – 8%) Norway haddock gill netters and medium trawlers (+ 6 – 8%) Norway medium / large trawlers cod and saithe (+ 2 – 10%)	Catch quota	Official logbook data and IBTS (International groundfish surveys)	Paper describes and contrasts three different methods to assess increases in technical capture efficiency. Indicates relative merits, limitations and assumptions associated with each method	A comprehensive study proposing alternative methods to assess technical efficiency. Does not use economic data.

Table 2 Continued.

Reference	Type of outcome	Methodology and parameters	Fishery	Results (Efficiency / productivity)	Management regime	Source data	Main technical issue	Comments
Millischer *et al.*., 1999	Quantitative analysis of the development of fishing power in three industrial fleets of Brittany	By the use of GLM Fishing Power estimates are derived from catchability quantifications based on fishing mortality coefficients (F) as calculated by VPA	Catch per vessel data for three homogeneous Brittany Fleets targeting Gadoids in ICES area VIa and VIIf,g,h. Main target species are saithe, cod, whiting and haddock from 1983 to 1994	From 1983-1994 the fleets on average showed a 15% decrease in fishing power for haddock and 25% for whiting. Opposite for saithe where fishing power increased with 15%. For cod no changes.		I. Official vessel logbook information compiled to catches by stock and year and total nominal effort per area and year for each vessel. II. Fishing mortality data from ICES working groups on stock assessment	The observed changes are assumed to be mainly driven by strategic choices of the fishermen	
Pascoe *et al.*, 20001	Quantitative analysis	Stochastic production frontier model	Netherlands beam trawl fleet (1980–1997)	Overall efficiency of the fleet was fairly stable during study period, but fluctuated up and down throughout (linked to the various management interventions)	ITQ Plaice box Gear restrictions	LEI Dutch economic Database, Dutch beam trawl surveys, N.Sea stock assessment	ITQs increased efficiency Newer larger vessels more efficient Gear restrictions and TAC's reduced efficiency Plaice box increased efficiency by dispersing effort	Paper describes the effect of management regulations on technical efficiency
Pascoe and Robinson 1996	Quantitative	Artificial data set subjected to stochastic variation. Method uses catch and stock data as main inputs to model.	Artificial data set, but method tested on English Channel sole fishery also	Method can detect changes in efficiency	Not applicable	Artificial data sets with stochastic variation	Paper describes a methodology	Method appears to work

Table 2 Continued.

Reference	Type of outcome	Methodology and parameters	Fishery	Results (Efficiency / productivity)	Management regime	Source data	Main technical issue	Comments
Prawitt 1996	Quantitative, total efficiency increase measured as landings weight	Relative fishing power (Gulland 1956), length, GRT, vessel age, beam width, towing speed, engine power	German brown shrimp beam trawlers. 34 trawlers analysed in a two year period (1994–1995)	No significant effect from any of the analysed input variables.	Licensed fishery, Restricted HP < 221 KW. No quota restriction No effort control	Fishing logbooks, Voluntary gear scheme for the study, official statistics	Very similar vessels, No effect from input variables.	Observed differences in landings thought to be due to skipper skills. (From +43% to -24%)
Rahikainen and Kuikka 2002	Methods paper adopting the concepts of fish stock assessment into an assessment of the herring trawl population in the Baltic sea	Application of a population model (VPA type) to data of lifetimes, sizes and numbers of trawls sold as according to the manufacturers	All trawls used on Finnish trawlers fishing herring in the Baltic in the period from 1980-2000	The results indicate that the average gear size of the Finnish herring trawls has nearly tripled in 20 years.		Data obtained from relevant gear manufacturers producing herring trawls as well as data from interviews with skippers on app. 100 vessels. The data covered the period 1980–2000	Only the increase in trawl size is examined and it shows approximately a three times increase in 20 years	
Revill, 2003	Qualitative, describes sources of technical change	Mostly qualitative with some quantitative specific examples of technological advances	Northern European focus but with some global reference	Largely qualitative and descriptive	Varied	Literature review	Describes many trends in technological advancement and the related consequences to unintentional mortality and environmental impacts	Excellent piece of work, well worth the read
Robins *et al.*, 1998	Quantitative, CPUE changes with time as a result	GLM with inputs of boat length, head rope, GPS, Plotters. Assumptions of continuous recruitment, spatial and temporal heterogeneity	North Australian trawl fishery for prawn (NPF). Analysis covering 1988-1992 with data from circa. 200 trawlers yearly	1998 – 1993. GPS and plotter was estimated to cause an increase of 12% in fishing efficiency	Restricted fleet size, Licensed fishery, net restrictions, seasonal and temporal closures No quota restriction No effort control	Official logbooks and landings returns and official yearly gear records.	Year 1 7% increase in fishing power Year 2 9% increase Year 3 12% increase	The potential of the GPS and plotter was only exploited fully by the vessels after three years of experience:

Table 2 Continued.

Reference	Type of outcome	Methodology and parameters	Fishery	Results (Efficiency / productivity)	Management regime	Source data	Main technical issue	Comments
Squires *et al.*., 2002	Quantitative	Stochastic production frontier models	Malaysian artisinal gill net fishery	Most vessels are highly efficient	Effort control through licensed access		Skipper skills important in many regions	
Squires 1994	Quantitative	Ratio of economic inputs: outputs Inputs: Labour, capital, energy Outputs: Quantity of fish landed and revenue	US Pacific coast ground fish trawl	1981–1989 Total productivity growth averaged at 2.8% over the period but with sharp swings (+28%, -12%)	ITQ and effort control	Official statistics Company records	Most important advancement was probably the adoption of electronics	
Valdermarsen 2001	Qualitative / descriptive	Descriptions of technical changes and observed trends	Global view	Qualitative	Global and varied	FAO and scientific literature	Holistic view of trends in technological advancement	Gives an overview of major global technical changes that have occurred in recent decades
Viswanathan *et al.,*	Quantitative	Stochastic production frontier model	Malaysia trawl fishery		Effort control through licensed access	126 skipper interviews	Efficiency linked to: Skipper ethnicity Season Vessel tonnage	

Appendix 1: Production efficiency considered to be industrial production units, which produce a product (the fish catch). Each production unit (fishing vessel) has a finite maximum production capacity with a certain level of production efficiency associated within the production process. A fishing vessel will be fully efficient if production (fish catch) lies at the point of maximum possible production. In a single species fishery, a simple linear production model (0) depicts the point of maximum possible production.

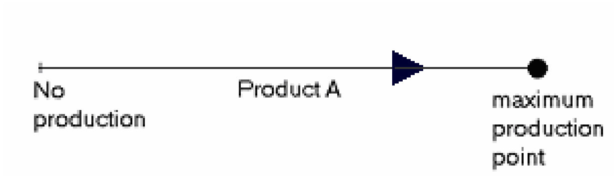


Figure 2. Linear production model depicting maximum production point of a single product (Product A).

In mixed fisheries, the vessel can produce (catch) more than one species. 0depicts the maximum possible production frontier for a two-species fishery (species A and B). The optimum economic point along that frontier will depend upon factors such as the market price, costs of capture etc. With more species in a fishery, the frontier becomes multi-dimensional (i.e. 3-dimensionsal for 3 species) and progressively more complex as more species are involved. The skills of the skipper can be fundamentally important in directing the vessel's productivity towards the optimum economic production point.

The production efficiency / inefficiency of fishing vessels can be compared, relative to each other and also relative to the maximum possible production frontier (0). The production efficiency of a fishing vessel is dependant upon many factors such as the vessel type, propulsion, technology, skipper skills, gear used etc. (0).

New technologies can increase efficiency and /or increase the overall quantity of production possible. In the latter case, such technologies outwardly expand the potential maximum production frontier (0). A sustained outward expansion of the production frontiers may eventually result in an unsustainable level of production beyond that of the sustainable carrying capacity of the exploited natural resource (fish stocks) (0).

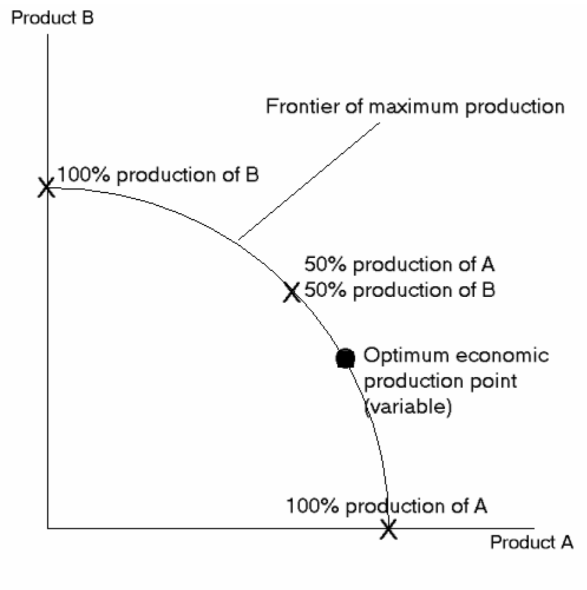


Figure 3. Maximum production frontier associated with dual production options.

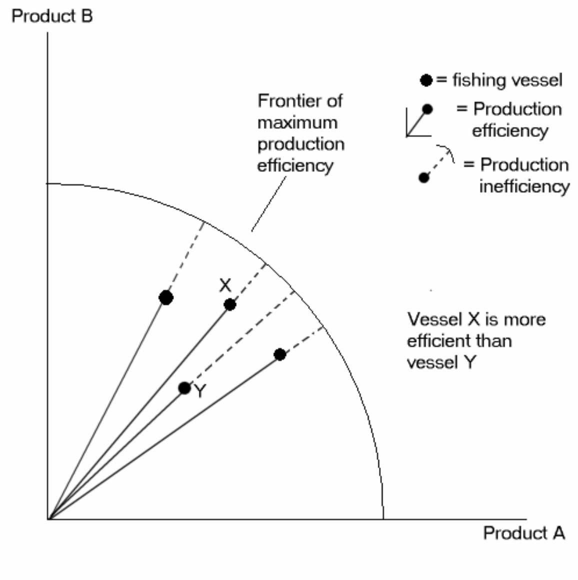


Figure 4. Chart depicting the production efficiency of fishing vessels in a fleet relative to each other and the maximum production frontier

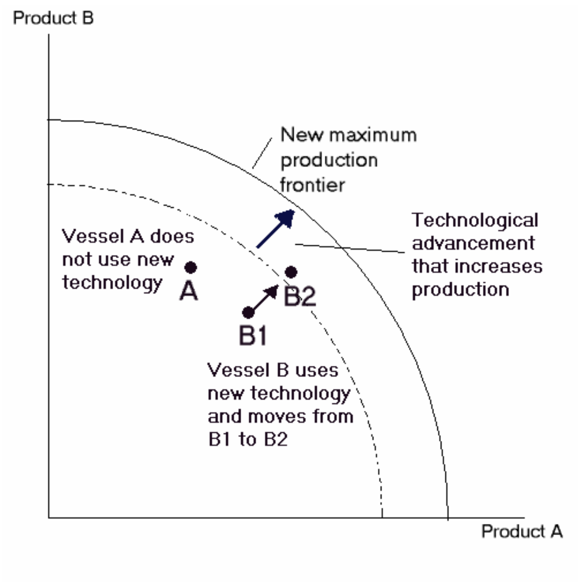


Figure 5. The potential of new technologies that increase production efficiency and /or expand production frontiers.

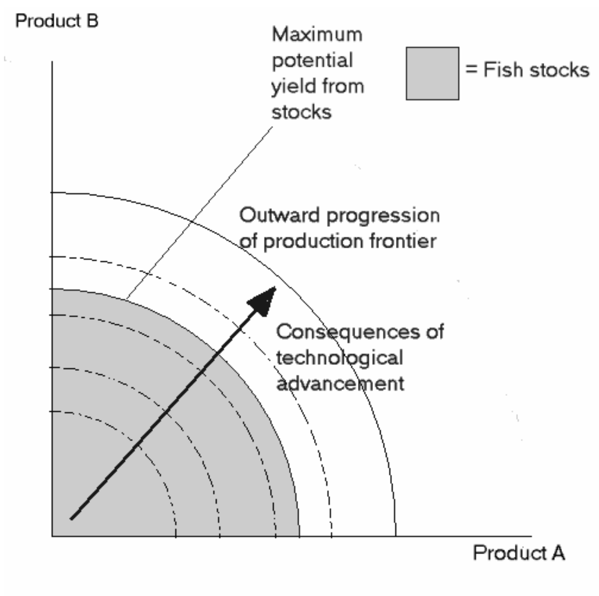


Figure 6. Technological advances that increase productivity and the expansion of the maximum production frontier.

Introduction: Technological Advancement

Many factors can affect the production efficiency and maximum possible production capabilities of fishing vessels, not least advances in technology (0). Historically, technological advances have been developed and adopted by the capture fishery industry on a continual and incremental basis. Not all technological advances however necessarily lead to increased efficiency or outward expansions of maximum production frontiers. For instance, some new technologies may reduce production costs without increasing production (i.e. by reducing fuel costs or crew requirements). Some technologies may decrease production and efficiency (i.e. many selectivity devices).

It is useful to consider the drivers of technological advancement and to differentiate their relative effects upon efficiency and maximum production potentials.

The Drivers of Technological Advancement

Capture fishing is an economic activity, and simple economic forces primarily drive participation in the industry. The four main drivers for technological advancement in the fish capture industry can be considered to be:

A. The need/desire to maintain or increase profitability
   I. Reduce the costs of production (fish capture)(0)
   II. Increase revenue
      i) Catching more fish (+)
      ii)Adding value to catch (0)

B. Concern about stock sustainability / environmental impacts of fishing (-)

C. Negation / circumvention of restricting management policies (+)[1]

D. Improve the quality of life onboard a fishing vessel (0)

Legend:

(+) = Increase production efficiency and outwardly expands maximum production frontiers

(0) = Usually no effect upon production efficiency or maximum production frontiers

(-) = Usually negative effect upon production efficiency and maximum production frontiers

[1] *If consequences result in more fish being caught.*

Fisheries Management Schemes and the Associated Incentives for Fishers to Increase Efficiency and Productivity

The type of fisheries management regime governing a fishery can create incentives or disincentives for participating fishers to increase production efficiency and increase production potentials.

a) Open access / competitive fisheries / unregulated fisheries.

Incentives exist to maximise efficiency and expand production frontiers as fishers try to get as much fish as quickly as possible.

b) Fishing effort regulated fisheries

Incentives exist to maximise efficiency and expand production frontiers within restrictive effort limitations. Incentives may also exist to negate / circumvent restrictive management interventions.

c) Catch regulated fisheries

Disincentives exist to increase efficiency and expand production frontiers beyond the constraints of the total permissible catch.

d) Fisheries that permit transferability of quotas (catch or effort)

Incentives exist for quotas (catch or effort) to consolidate into the hands of the most efficient and productive fishers. Incentives exist to maximise efficiency and productivity.

e) Fisheries with policies to maximise efficiency and productivity

Incentives exist for fishers to maximise efficiency and expand production frontiers. No of participating fishers will continually contract as efficiency increases

f) Fisheries with policies to maintain efficiency and productivity at a sub-optimal level

Direct restrictions exist to limit efficiency and productivity to a desired level. Incentives may exist for fishers to develop strategies, which negate / circumvent the effects of efficiency / production restrictions.

What Data is Required to Assess the Production Efficiency and Productivity

The type of management regimes in place may largely dictate the data requirements on efficiency and productivity. Fisheries are most usually managed using biological reference points such as the maximum sustainable yield (MSY) etc. In such fisheries, two basic types of data are required to monitor efficiency and productivity:

1) Catch per unit of fishing effort
2) Indices of abundance of the exploited fish stocks

In fisheries where production efficiency and productivity are desirable, information detailing the causality of changes in efficiency / productivity may not necessarily be required. Management may choose to grossly adjust quotas (catch or effort) to maintain sustainable stock exploitation rates and allow internal transfer. Consolidation of the quotas to the most efficient and productive vessel operators usually results in fisheries operating under such management schemes.

In fisheries where management aim to restrict production efficiency and productivity at sub optimal levels, knowledge detailing the specific causality of changes (or potential changes) in efficiency / productivity may be desirable. In such cases, specific focussed studies are probably the best mechanism to achieve this.

The identification of the causality of changes in efficiency or productivity of fishing vessels may also be useful for management to justify to fishers any related interventions made

In fisheries where economic performance criteria and targets underpin management policy, continuous based assessments of both the economic and biological efficiency and productivity of vessels and fleets are likely to be of considerable importance.

Case Studies

Case Study 1: Efficiency change in Faroese pair-trawler fleet

Two types of marine resource management regimes can be identified, one output controlled (catch quotas) and one input controlled (effort limitations). In an output controlled system the effect from vessel efficiency increase or creeping is self adjusted, whereas in an input controlled system a range of input variables that are not readily controlled can result in an efficiency increase that will undermine the management regime. An example of an input controlled system is the Faroese fishing days management system. In this system it is of utmost interest to know whether the efficiency of single vessels change over time or not. In the following text data from a particular fleet working in the Faroese area will be examined to identify possible efficiency changes over time.

The Faroese management regime

The economy of the Faroe Island is totally dependent on the fisheries. The most important demersal fish species in Faroese waters have been cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and saithe (*Polaccius virens*) of which a total of between 43,676 and 119,441 tonnes have been harvested each year since 1990, Figure 1.

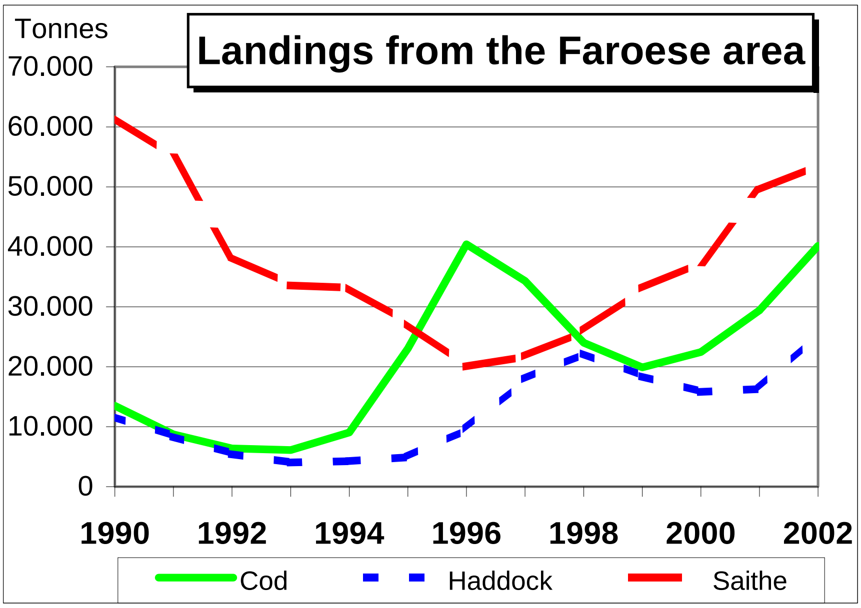


Figure 1. Landings of cod, haddock and saithe from the Faroese area 1990-2002 (data from the Faroese Fisheries Laboratory)

The Commercial Fishery Act from 1994 regulates the harvest from marine resources in the Faroe Island. The main objective is to secure biological and economical sustainability, but also socio-economic factors are considered. To achieve the main objective one aim is that a maximum of 33% on average in numbers is taken from each stock every year.

The fish stocks are harvested by a wide variety of fishing vessels using different fishing gear technique. The fishery is a mixed fishery where cod and haddock are mainly taken by longline and trawl, while saithe is mainly taken by pair-trawl, Figure 2.

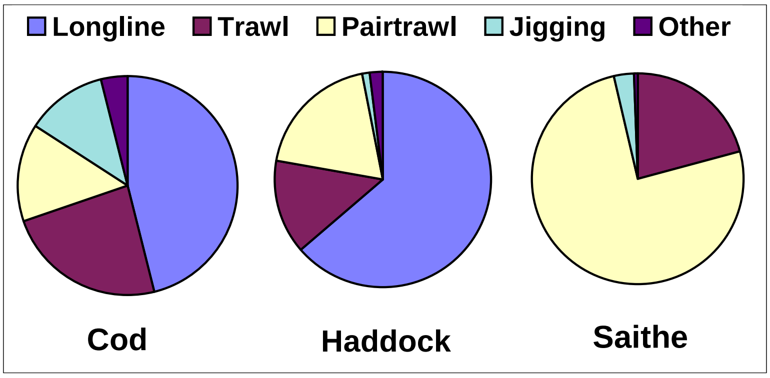


Figure 2. Catch by gear of cod, haddock and saithe in the Faroese area 2000-2002 (data from the Faroese Fisheries Laboratory)

In addition to technical measures such as minimum mesh size and closed areas the fishing activity is controlled by quotas given as fishing days to various groups of fishing vessels and for larger vessels to single vessels within the groups. The system, which has been in effect since June 1st 1996, was originally based on an assessment of the fishing power of each vessel group according to a data series from 1985-1994. The Committee on Fishing days advises the Minister on the number of fishing days to be allocated for each fishing year, which runs from September 1st – August 31st. The Fisheries Laboratory also advises the Minister on the state of the stocks and on adjustments of fishing effort. One question that arises every year when the fishing days are allocated is whether the efficiency of a single fishing vessel has increased over time or not. If the efficiency has increased the fishing days should be decreased accordingly to maintain the same pressure on the stocks. Since the introduction of the system in 1996 the number of fishing days has been reduced by 16-17%.

In their advice for 2003-2004 the Fisheries Laboratory refer to ICES that has estimated the pressure on the cod, haddock and saithe stocks at present to be 42%, 33% and 29% respectively and that due to precautions against low recruitment and low growth suggest a more correct pressure for the three stocks to be 27%, 20% and 22% respectively. The recommendation therefore was a 25% reduction in fishing days over the next 2-3 years.

The Committee on Fishing days on the other hand did not recommend any further reductions on fishing days this year.

Questionnaire survey

As a first attempt to address the question on efficiency change within the Faroese fisheries the Faroese Fisheries Laboratory conducted a questionnaire survey among 200 skippers in 2000. The results are summarized in appendix 2.b. in 7.13 below (Reprint from Jákupssovu *et al.*, 2001). The answers give an overview of when changes have been made to fishing vessels and gears and opinions from individual skippers on the related efficiency change. As the number of answers for each item are limited and the numbers given are opinions rather than facts the results should only be taken as indicative.

Pair trawler data

One of the largest vessel operators working in the Faroes area is the company BETA. In the late 1970's this company invested in three sister ships with steel hulls 37.7 meter long and had 1200 horsepower engine. The eight vessels operated as single trawlers for a couple of years and were then converted into 4 sets of pair-trawlers.

The company has been very keen to keep track of all statistics concerning landings (catch) as well as economics. Also information on all technical changes during the 25-year working period is available. Agreement has been made with the vessel owner to computerize all these data for future scientific analysis. In addition to the records kept by the vessel owner, logbooks from the vessels have been handed in to the authorities. As these logbooks, together with the information from the vessel owner, is thought to be a valuable data series, the Faroese Fisheries Laboratory has made an extra effort to validate and upgrade the logbooks from these vessels. This has resulted in a high quality logbook database with variables on single hauls, such as towing time, position, depth, weather and skippers estimates of catches per species. Unfortunately, despite a special effort, the logbook data does not fully cover all activities of the vessels. The vessel owner has catch records from 1979 to present, while the logbook database has data from 1985 onwards. From 1985 to 1995 the logbooks corresponds to 80%-100% of the catches whereas from 1995 the logbooks corresponds well to the total catches recorded by the company.

For the years 1985 to 2002 the database holds 45,986 records on individual hauls taken by the eight sister vessels. When hauls outside the Faroese area and hauls with low quality data were excluded (no towing time, no catch reported etc.) 38,721 records could be used for the present analysis. In 28,062 records the catch was more than 60% saithe. As the data from the vessel owner is not fully computerized yet, the following analysis is mainly based on the logbook database, but with some input from the vessels owner.

Conversion to pair-trawl

Following the dramatic increase in oil prices during the 1970's many Faroese trawler operators converted their vessels from single trawling to pair trawling as this seemed to be an economical advantage. During the period 1/3-1981 to 10/1-1983 all eight BETA trawlers converted from single trawl to pair-trawl. The 107-120 foot 'box' trawl used while single trawling was replaced by a 250-foot 'ballon' trawl used for pair-trawling. As part of a 'Nordforsk' project (cooperation between institutes in Nordic countries) on 'Energy and fishing', the fuel consumption before and after conversion to pair-trawling was systematically recorded. Fuel consumption per vessel decreased from more than 3000 litres per day to 2000 litres per day, figure 3.

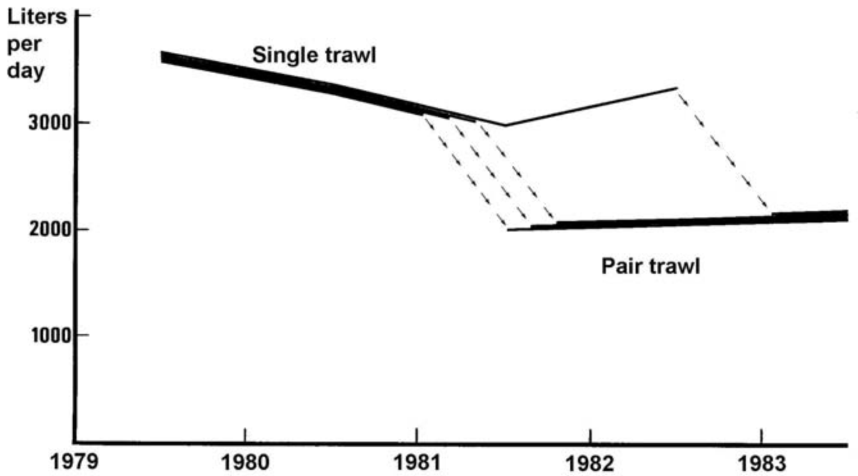


Figure 3. Fuel consumption per vessel before (left) and after (right) conversion to pair-trawling (Reprint from Nyt om OLIEFISK-projektet, Nr. 15, juni 1984, Bogi Hansen).

The conclusion from the vessel owner was that they kept the same landings, but saved 40-45 per cent on fuel. By getting rid of the trawl doors there was a reduction of about 15 per cent on fishing gear expenses.

Converting from single trawl seems to be an example of an efficiency increase that improves the economics of the fishing operation without exerting more pressure on the fish stocks.

The saving in oil was more than should be expected, most probably because pair-trawling at that time was conducted with lower speed than single trawling. The vessels have increased the towing speed during the 1990's (see below). This invites to an analysis (kg fish/litre fuel) on how the economics has changed and how the impact on the fish stock has changed.

Catch, CPUE and stock

The total landings from the eight sister vessels are shown in figure 4 (left) and the CPUE (kg/hour) per pair is shown in Figure 4 (right).

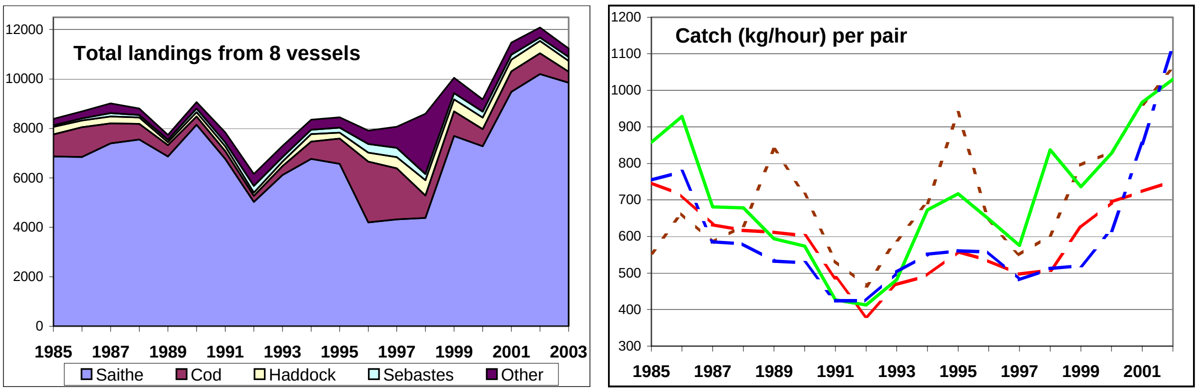


Figure 4. Total landings from all 8 vessels (left) and CPUE as kg/hour per pair (right).

Saithe is the most important fish species for all 8 vessels. In the mid 1980's and especially in 1996-1997 the vessels had increased landings of cod. In 1998 one pair made a few trips targeting argentines.

The CPUE has changed dramatically over the period. From 1985 to 1991 it nearly halved but has increased to record high in recent years.

One way to express the efficiency of a fishing vessel is to compare the CPUE to the stock size of the relevant fish species. In figure 5 the CPUE of saithe (left) and cod (right) divided by the respective spawning stock size is plotted per year.

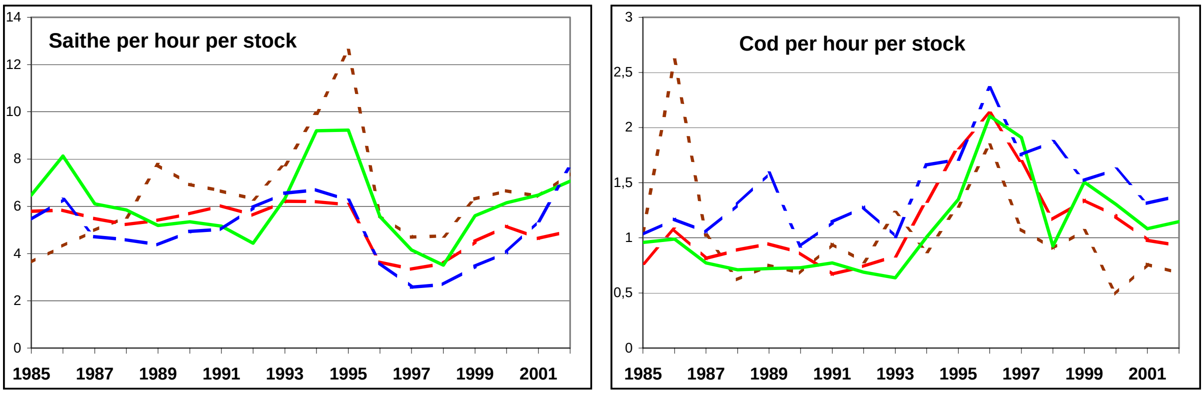


Figure 5. Saithe (left) and cod (right) catches per hour related to spawning stock size.

The efficiency on saithe went up in mid 1990's and then down below previous levels. Last 3-4 years the efficiency on saithe has reached the same level as it was in the late 1980's. The efficiency on cod increased in mid 1990's and has decreased since, but is still above the level in the late 1980's.

The pair that is most efficient on saithe is less efficient on cod and vice versa.

Tow duration and trawling hours per day

A fishing day can be divided into time when towing and time when handling the gear. To increase fishing efficiency the towing time should be maximized while the handling time should be minimized.

The average time length of a tow and the time between tows are shown in Figure 6.

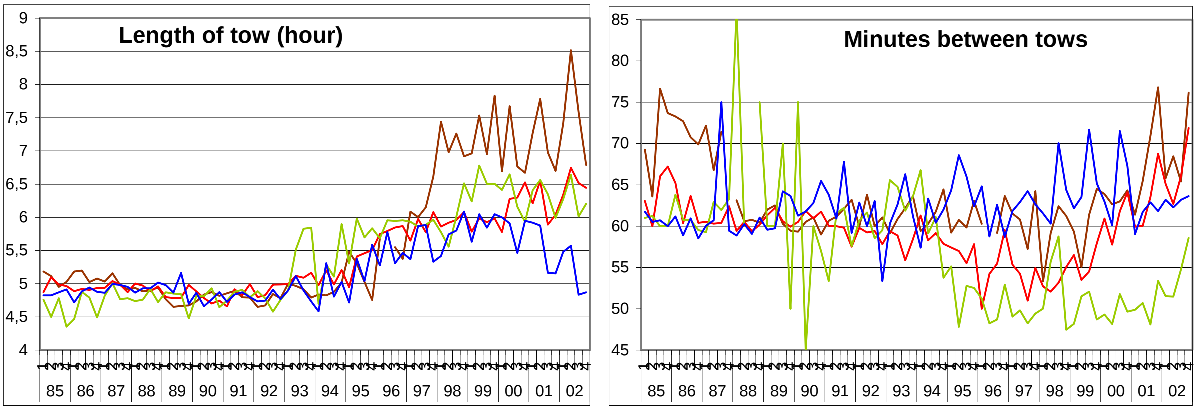


Figure 6. Tow length in hours (left) and time between tows in minutes (right).

The vessels have increased their tow lengths systematically since the early 1990's. One limiting factor in tow length is the trade of between tow length and fish quality.

The time between tows has stayed around one hour, but since mid 1995 one pair has succeeded in lowering the handling time by approximately 10 minutes. One explanation can be a lower wire/depth ratio.

In 1988 pair 1 and pair 2 installed new trawl winches. It is stated by skippers that this reduced the hauling time considerably. This is partly verified by logbook data.

To increase the towing time from 5 hour to 7 hour per tow and keeping the time between tows at 1 hour increases the effective fishing time per day from 20 hour to 21 hour or by 5%.

Change in trawl gear and trawl speed

When pair-trawling started in the early 1980's the gear used was a 250-foot (76m) headline length 'ballon' trawl with a circumference of 645x200 mm meshes. In the mid 1990's most vessels converted to a 'Bacalao' trawl with circumference of 630x160 mm. The headline and footrope length is approximately the same, which means that the meshes are more open. The fishing efficiency seems to be similar, but the tearing of the net is much less.

In the early 1990's the groundgear changed from rubber half-bobbins to rockhopper types.
The weight (in air) of the groundgear has increased gradually over the years from 20-30 kg/m to 80-100 kg/m. The weight of the chains in the front of the wings has increased gradually from 5 kg/m to 22 kg/m and the weight (clump) at the bridle end (instead of trawldoor) has increased from 600 kg to 1600-1800 kg.

According to skippers the towing speed used in the early 1980's was less than 3 knots, in the early 1990's it had increased to 3.5 knots and it has increased further up to 4 knots nowadays. An increase from 3.5 to 4 knots in towing speed corresponds to a 14% increase in swept area per hour. The higher speed does not only affect the swept area, but will possibly increase the efficiency of the trawl towards fast swimming fish species such as saithe. Although the logbook data includes (from 1995 onwards) information on position (latitude, longitude) at start and stop of a tow it has not been possible to verify any changes in towing speed. The reason for this may be that only end positions are available and most of the tows are not strait lines.

Symmetry sensors

It is indicated in the questionnaire survey (Appendix 2.b. in 7.13) that electronic aids is expected to improve the efficiency in the catching process. It appears that GPS and plotters can increase the fishing power of a fleet by 12% (Robins et. al., 1998). According to the vessel owner the electronic aid that has been installed in recent years the Scanmar symmetry sensors on the trawl seems to have the greatest impact on the success of the fishing. The four pair of trawlers got these sensors on 17/11-2000, 3/8-2001, 20/10-2001 and 29/10-2001 respectively. As there is almost a year from the first to the last installation a possible effect on the fishing might be seen while comparing the efficiency between pairs. In figure 7 an index for the catch per hour for one pair against the catch per hour for the three other pairs is plotted.

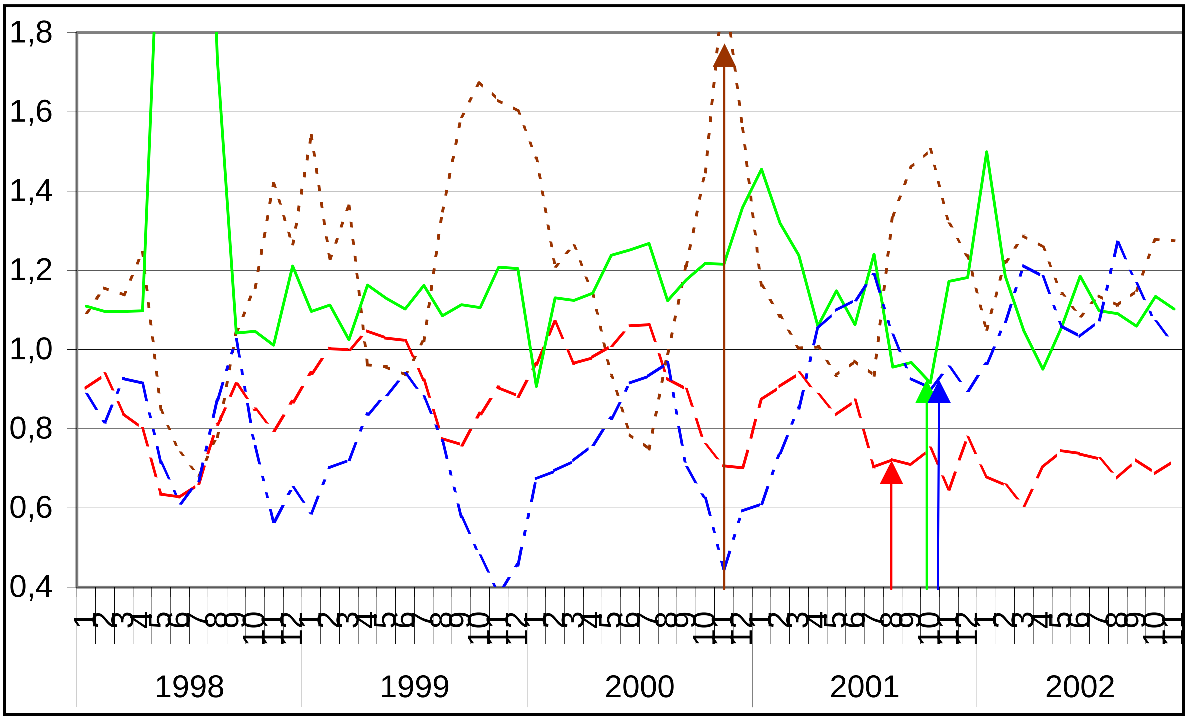


Figure 7. CPUE index calculated as CPUE of one pair divided by the CPUE of the three other pairs. Vertical arrows indicate when pairs introduced symmetry sensor on the trawl.

Pair 1 installed the sensor almost a year before the other three pairs, but in this period the relative efficiency does not improve, rather the opposite.

From the index comparisons some other interesting aspects can be seen. Pair 4 generally increases it relative efficiency during the last three years, while the efficiency of pair 2 decreases in this period. By comparing pair 1 and 4 it can be seen that there is a systematic seasonal variation, as pair 1 increases its efficiency towards the end of the year while pair 4 decreases its efficiency simultaneously.

New vessels

Under the new Faroese management regime vessel owners are allowed to renew their vessels, but new vessels should have similar or lower fishing power than the old vessels that are replaced. The BETA trawlers have a substantial age and the owner has prepared a renewal scheme for the vessels. The company has made an agreement with the authorities where four old pairs (8 old trawlers) can be replaced by three new pairs (6 new trawlers) of slightly larger hull size and engine power. In the discussion on how to compare the old and new vessels it has been argued, that the product of tonnage and engine power should be kept unchanged while changing from old to new vessels. Another argument is that it is the square root of the two that should be compared. Table 1 summarizes the details of the old and new vessels and the conversion calculations.

Table 1. Old and new vessels comparison.

	Old vessels	New vessels	Factor	8 old vessels	6 new vessels
Number of vessels	8	6			
Length oa.	37.70 m	37.96 m			
Engine power	1200 HP	1305 HP			
Tonnage	388 Bt	464 Bt			
Engine*Tonnage	465,600	605,520	1.30	3,724,800	3,633,120
Square root	682	778	1.14	5,456	4,668

According to the product of engine and tonnage the new vessels have 30% more efficiency, whereas with the square root method the increase is only 14%.

Two new vessels have been in operation for one year. Table 2 summarizes the results from the new vessels compared to two old pairs in 2003.

Table 2. Results from old and new vessels in 2003.

2003	Old pair A	Old pair B	New pair	New/Old A	New/Old B	Average
Trips	32	32	45	1,41	1,41	1,41
Days	215	251	326	1,52	1,30	1,41
Days/trip	6,7	7,8	7,2	1,1	0,9	1,00
Tonnes	2770	2726	5684	2,05	2,09	2,07
Tonnes/day	12,884	10,882	17,436	1,35	1,60	1,48
Tonnes/trip	86,563	85,188	126,311	1,46	1,48	1,47

The catches per day and per trip for the new vessels are 47-48% higher than for the old vessels. The new vessels had 41% more fishing days than the old vessels. The total yearly catch for the new pair is twice the catch of the old pairs.

With respect to fishing power the new vessels are superior to the old vessels in many aspects. The bollard pull of the old vessels is approximately 12 tonnes whereas the new vessels have a bollard pull of 19 tonnes or 58% higher. The new vessels spend less time in harbour for repair. The holding rooms in the new vessels are arranged with bigger boxes that are much faster to discharge than on the older vessels. Ice machine onboard saves time when preparing for a new trip. The new vessels can also conduct fishing in rougher weather than the older vessels.

Conclusions

In a mixed fishery it is difficult to calculate the creeping of the pressure on single fish stocks due to efficiency change in a particular vessel as the fishing strategy does change according to the availability (and probably price) of the different fish species.

Efficiency increase based on improved economics does not necessarily result in an increased pressure on the fish stocks.

Efficiency increase based on improved catches can be obtained either by increasing the catch per hour or by in increasing the hour fished. The latter seems to have been more present during the last decades in the Faroese pair trawler fleet.

The fishing power can be increased dramatically when investing in new vessels. No simple formula such as the product of tonnage and engine power can be used to predict the fishing power of a new vessel.

References

Jákupsstovu, S.H., Olsen, D. and Zachariassen, K., 2001. Effects of Seismic Activities on the Fisheries at the Faroe Islands. Fiskirannsóknarstovan, Box 3051. Tórshavn, Faroe Islands.

Robins, C.M., Wang, Y. and Die, D., 1998. The impact of globalpositioning systems and plotters on fishing power in the northern prawn fishery, Australia. Can. J. Fish. Aquat. Sci. 55: 1645-1651

Appendix 2.b. Innovation questionnaire

Results from a questionnaire survey among 200 skippers in 2000. Reprint from: Jákupsstovu, S.H., Olsen, D. and Zachariassen, K., 2001. Effects of Seismic Activities on the Fisheries at the Faroe Islands. Fiskirannsóknarstovan, Box 3051. Tórshavn, Faroe Islands.

Question:
"In any fishery, it is an ongoing process to make changes in the gear and the handling of the gear with the aim to improve fishing efficiency. Fish-finding equipment and other electronic equipment are also continuously improved. In the table below, could you please list some of the more recent innovations by main gear type and indicate when these innovations were introduced on the vessels you were on and to what extent they improved the efficiency (%)."

Gear	Innovation	Year	Improvement %

Answers:

Larger single trawlers (Group 1)

Innovation	Answered *	Year	Impr. %	Avg. Impr. %	Comments
Trawl sonde	12 (8)	89 – 92	0 – 50	18	
Scanmar	9 (6)	81 – 91	0 – 50	13	
Rock hopper	12 (7)	89 – 92	0 – 50	36	
Doors sensors	1 (1)	99	5	5	
Doors	1 (0)	99			
Double trawl**	2 (2)	94 – 95	50 – 100	50	

* The numbers in brackets indicate the number of answers indicating improvement in%. Some of the skippers say that it is impossible to give a percentage. The reason is that the fishery is affected by too many factors.
**Double trawl is not used in the Faroese area. Double trawl is used in the shrimp fishery.

Pair trawlers (Group 2)

Innovation	Answered *	Year	Imp. %	Avg. Impr. %	Comments
Trawl sonde	13 (6)	92 – 98	0 – 40	14	
Scanmar	16 (6)	85 – 94	10 – 40	23	
Rock hopper	31 (14)	90 – 95	1 – 50	15	
Double trawl	2 (2)	98	50 – 90	70	Used for 2 months
Better trawls	2 (1)	97	10	10	
Kitler chain	1 (0)				
Symmetry sensor	2 (1)	96	10	10	
Others	5 (1)	97	10	10	

* The numbers in brackets indicate the number of answers indicating improvement in %. Some of the skippers say that it is impossible to give a percentage. The reason is that the fishery is affected by too many factors.

Smaller single trawlers (Group 4)

Innovation	Answered *	Year	Impr. %	Avg. Impr. %	Comments
Trawl sonde	2 (1)	89 – 97	0	0	
Rock hopper	10 (6)	88 – 98	10 – 40	23	
Kitler chain	1 (1)	92	100	100	For monkfish
GPS	1 (0)				Nav. instrument
Trawl doors	1 (0)				

* The numbers in brackets indicate the number of answers indicating improvement in %. Some of the skippers say that it is impossible to give a percentage. The reason is that the fishery is affected by too many factors.

Larger longline vessels (Group 3)

Innovation	Answered *	Year	Impr. %	Avg. Impr. %	Comments
Automatic baiter	18 (9)	78 – 93	0 – 30	16	Per vessel
Skewed hooks	17 (14)	90 – 96	5 – 50	21	
Stability tanks	10 (5)	91 – 99	5 – 30	13	
Swivel line	17 (14)	92 – 96	10 – 50	34	Better for e.g. haddock
Snood line	5 (3)	92 – 96	10 – 20	13	
Line tec	3 (0)	97 – 99			
Others	1 (0)	91			

* The numbers in brackets indicate the number of answers indicating improvement in %. Some of the skippers say that it is impossible to give a percentage. The reason is that the fishery is affected by too many factors.

Smaller longline vessels (Group 4)

Innovation	Answered *	Year	Impr. %	Avg. Impr. %	Comments
Automatic baiter	6 (0)	96 – 98			Per vessel
Skewed hooks	23 (15)	93 – 98	3 – 40	17	Better for e.g. haddock
Swivel line	29 (23)	10 – 50	10 – 50	28	
Snood line	7 (3)	98 – 99	0 – 10	3	
Others	2 (0)	90			

* The numbers in brackets indicate the number of answers indicating improvement in %. Some of the skippers say that it is impossible to give percentages. The reason is that the fishery is affected by too many factors.

Smaller longline vessels (Group 5)

Innovation	Answered *	Year	Impr. %	Avg. Impr. %	Comments
Automatic baiter	7(4)	90 – 99	0 – 50	22	Per vessel
Skewed hooks	19 (15)	87 – 99	0 – 50	16	
Swivel line	32 (26)	94 – 99	0 – 50	19	
Snood line	6 (2)	89 – 96	0 – 5	3	
Others	5 (0)	97			

* The numbers in brackets indicate the number of answers indicating improvement in %. Some of the skippers say that it is impossible to give percentages. The reason is that the fishery is affected by too many factors.

Jigging vessels (Group 4)

Innovation	Answered *	Year	Impr. %	Avg. Impr. %	Comments
Automatic Jiggers	17 (11)	82 – 88	0 – 50	35	
Electric Jiggers	2 (2)	96 – 97	40	40	
Skewed hooks	9 (4)	94 –96	10 – 15	12	
Nav. equipment	1 (0)				GPS and plotter
Others	1 (1)	97	20	20	

* The numbers in brackets indicate the number of answers indicating improvement in %. Some of the skippers say that it is impossible to give percentages. The reason is that the fishery is affected by too many factors.

Jigging vessels (Group 5)

Innovation	Answered *	Year	Impr. %	Avg. Impr. %	Comments
Aut. Jiggers	20 (11)	87 – 98	0 – 50	33	
Electric Jiggers	5 (4)	95 – 97	20 – 50	38	
Skewed hooks	10 (5)	92 – 95	10 – 50	18	

* The numbers in brackets indicate the number of answers indicating improvement in %. Some of the skippers say that it is impossible to give percentages. The reason is that the fishery is affected by too many factors.

Gill-net vessels

Innovation	Answered *	Year	Impr. %	Avg. Impr. %	Comments
Smaller meshes	1 (0)				
Floating line	1 (1)	97	20	20	For monkfish
New gear	1 (1)		100	100	same type

*The numbers in brackets indicate the number of answers indicating improvement in %. Some of the skippers say that it is impossible to give percentages. The reason is that the fishery is affected by too many factors.

Pelagic trawlers

Innovation	Answered *	Year	Impr. %	Avg. Impr. %	Comments
Lighter material	2 (1)		20	20	
Bigger trawl	2 (2)	70 – 99	35 – 100	68	
Bigger engine	2 (2)	77 - 99	100 – 150	125	
Trawl sonde	1 (0)	89			

*The numbers in brackets indicate the number of answers indicating improvement in %. Some of the skippers say that it is impossible to give percentages. The reason is that the fishery is affected by too many factors.

Purse seine vessels

Innovation	Answered *	Year	Impr. %	Avg. Impr. %	Comments
Better asdic	3 (1)	87 – 99	5	5	
Bigger seine	3 (1)	- 99	100	100	
Bigger meshes	1 (1)	93	10	10	
Others	1 (0)				

* The numbers in brackets indicate the number of answers indicating improvement in %. Some of the skippers say that it is impossible to give percentages. The reason is that the fishery is affected by too many factors.

Have there been any changes in the planning of the fishery since the fishing-day regulation was introduced, e.g., planning the trips differently, using more longline, more concern about weather conditions, etc?

Yes/No **98/45**

Please, could you elaborate a little.

Group 1.
Group 1 is not regulated by fishing days, but by a quota system.

Group 2. Yes/no **27/2**
The "yes" answers specified:

23 answered: In bad weather, they do not wait for better weather at sea, but return to the harbour to land the catch in order to save fishing days.
16 answered: Do not have any dead time at sea.
3 answered: Buy fishing days from others.
6 answered: Try to do some trips in the outer fishing areas, which yields 3 days of fishing for 1 "fishing day".

The two respondents who answered "no" stated that they buy days if they have problems.

Group 3. Yes/no **15/1**
The "yes" answers specified:

11 answered: Do not fish in bad current conditions.
11 answered: In bad weather, they do not wait for better weather at sea, but return to the harbour to land the catch in order to save fishing days.
2 answered: Fish in worse weather than previously.
15 answered: Do not have any dead time at sea.
1 answered: Save days. They have gone from 295 fishing days down to 240 fishing days.

Group 4. Trawl. Yes/no 12/0
The "yes" answers specified:

1 answered: Fish in worse weather than previously.
8 answered: Do not have any dead time at sea.
2 answered: Only start a trip if the weather forecast is favourable for more than two days.
8 answered: Are aware of trying to use their fishing days optimally.

Group 4. Longline and jigging. Yes/no 33/11
The "yes" answers specified:

26 answered: Are aware of trying to use their fishing days optimally.
19 answered: Use more longline.
21 answered: Are more aware of weather and current conditions.
19 answered: Try not to have any dead time at sea.
1 answered: Buy and sell fishing days.
33 answered: Are generally more aware of the fishing days.

Of the 11 "no" answers, many are skippers on jigging vessels. The jigging vessels get two days at sea for one "fishing day"

Group 5. Longline and jigging. Yes/no 11/31

The “yes” answers specified:

2 answered: Are more aware of weather and current conditions.
8 answered: Do not have any dead time at sea.
6 answered: Use more longline
6 answered: Save fishing days.

If there is something else you would like to add, or if some of the questions need a comment, please write it below.

46 had comments and 122 had no comments.

Case Study 2: A Comparison of Twin-Rig Trawling and Single Rig Trawling in terms of Relative Fishing Efficiency. Dominic Rihan, BIM, Dublin, Ireland

Background

Under the Irish Government's Whitefish Renewal Scheme's of 2000 and 2002 a number of new demersal vessels have entered the Irish fleet. These programmes are the most significant targeted investment in upgrading and modernising in the history of the Irish State and were brought to fruition despite the backdrop of wholesale cuts being proposed by the EU under MAGP VI. It was considered vital at this time, to upgrade the Irish whitefish fleet in order to enhance competitiveness, safety and operational efficiency, as the average age of the Irish fleet prior to the Scheme was in excess of 30 years. To date a total of forty-four new and modern, secondhand vessels have been introduced replacing old and inefficient units.

The introduction of these vessels has, however, raised a number of questions in that while overall tonnage and horsepower has not increased above permitted EU levels, the overall fishing efficiency and also the effort required to maintain viability has more than doubled. In particular the use of twin-rigs for species such as *nephrops* and demersal species such as monkfish and megrim by these new vessels has attracted many critics, who say it is too effective and indeed a wasteful form of fishing. This method was first introduced in Ireland in the mid-1980's. BIM and *nephrops* fishermen in the Irish Sea, who saw the benefit of increasing the effective swept area of a trawl, pioneered it. It has proved so effective that many trawlers have converted to this method, including most of the new whitefish vessels. It is fair to say it's development has been one of the most significant developments in demersal trawl fisheries in the last 20 years and recently the use of triple and even four nets has now been tried in other countries, particularly in fisheries for deepwater shrimp (*Pandaleus borealis*) and some Irish fishermen are indeed looking closely at the triple-rig for species such as *nephrops*.

The "over-efficiency" arguments against the use of multi-rigs are well documented, and in Ireland due to increasing operating and gear costs and also a chronic shortage of qualified crew some of the bigger operators who have been working twin-rigs for mixed whitefish species, have begun to investigate the possibility of returning to fishing with a single trawl to reduce costs. In order to ascertain whether this assumption is correct, BIM have carried out an assessment using two vessels as a case study as part of a much more detailed assessment of the success of the Whitefish Renewal Schemes.

Objectives

The overall aim of this study was to ascertain whether by returning to traditional single-rig trawling that economic viability could be maintained, by offsetting a reduction in fishing efficiency with a reduction in operating costs. A secondary objective was to estimate the relative fishing efficiency through the use of gear monitoring systems and operational parameters of single rigs as opposed to twin rigs.

Fleet Métiers

Table 1 summarises the profile of the twin-rig sectors of the Irish fleet by length of vessels as taken from the Irish Fleet Register, 2003.

Table 1 A Breakdown of the Irish Twin-Rig Fleet in 2003

Vessel Type	12-17.99m	18-23.99m	24m+	Total
Twin-rig Whitefish		14	5	19
Twin-rig *Nephrops*	5	31		36
Twin-rig Whitefish/*Nephrops*	12	16	1	29
Total	17	61	6	84

Available data suggests that the *nephrops* and *nephrops*/whitefish "dual-purpose" twin-riggers do not have a viability problem at present, and a return to single-rigging for most of these vessels was not considered a viable option by the owners on discussion with them. Thus for this study the sector containing the 19 twin-rig whitefish vessels were considered, as the vessels in this sector are reportedly operating on a high gross earnings/high operating costs basis and in recent years on diminishing profits put down to increase fuel costs and lower fish prices. This sector has increased in importance since the mid-1990s with the number of vessels having increased since 1995 and the combined horsepower has over doubled. The nineteen vessels currently involved are modern, of around 20-22m in length, 650hp-850hp/485kW-635kW and targeting monkfish and megrim off the south, south-west and west coasts of Ireland. They tend to work 7-10 day trips fishing from the 100m depth contour out to depths of 600m-700m and work up to 280 days per year. The gear used is typically either twin scraper trawls or double bosom trawls with long combination rope bridles and heavy doors and clump weights. Scraper trawls used tend to be small mesh with long, slow tapering wings, straight gable ends and light rubber footropes of plain rubber discs or small rockhoppers. These nets have a low headline height and consequently there is very little bycatch of roundfish. The double bosom trawl design was developed in Scotland originally primarily for catching *nephrops* and is characterised by having a “tongue” section in the centre of an extended bosom section. Weight is taken on this tongue section via bridles leading to the wingends of the trawl. This tongue then divides the wide bosom into two smaller sections giving increased ground coverage. This net design is now widely used by Irish vessels when targeting monkfish, although bycatch of other species tends to be lower than with more conventional trawl designs.

With the introduction of the new whitefish vessels it is fair to say that the size and weight of the gear being used has increased dramatically since 2000. Previously where vessels had fished with 2 x 60m trawls, now boats are working 2 x 100m+ trawls. This has almost certainly been because the new vessels are more efficient and can tow much bigger, heavier gear and which fishermen have equated with increased catch rates. In reality the use of larger gear has really only compensated in an overall reduction in catch rates for increased effort and increased operating costs.

Interestingly the economic viability of the Irish twin rig fleet is mirrored by the continuing viability of the Scottish twin-rig whitefish fleet and similar questions have been raised about this fleet as well. The vessels in this sector are very similar in size and operate in the North Sea and West of Scotland, and fishing mainly in areas IVa and VI on 7-8 day trips. According to the SFIA Economic Survey[2] of the UK Fishing Fleet, between 1998 and 2001 the average income for this fleet reduced by almost £400,000 stg, a fall of 40%. During the period fuel costs have been a major factor in the reduced profitability of this sector. Fuel costs increased by 77% from 1998, and accounted for 59% compared to 29% in 1998 of total fishing costs. Conversely total vessel owner costs were found to have decreased by 23% since 1998 as a result of reduced expenditure on repairs and gear costs as margins become tighter.

Case Study

The following case study describes the differences in fishing or catching efficiency, fuel consumption and overall profitability of reverting from twin-rigging to single rigging observed on two Irish vessels. The mfv’s “Cu na Mara” and “Boy Jason” are typical examples of the craft in this métier and indeed these owners would freely admit that since acquiring their new vessels they have increased the size of gear used from their previous crafts. With increasing costs they have questioned the logic of this and experimented with single rigs and the results from work with these vessels form the basis of the findings of this study.

[2] Martin A., and Watson J. 2002. 2001 Economic Survey of the UK Fishing Fleet. Sea Fish Industry Authority Report June 2002.

The main specifications of these vessels and the fishing gear used are as follows:

MFV "Cu na Mara" S 224

Skipper/Owner:	Kevin Deasy
Built:	Concarneau, 2000
Registered Length:	21.79 m
Breadth:	8.0 m
Draft:	3.90 m
Hull Design:	Steel, Full Shelterdeck, Transom Stern
GT:	233GT
Engine:	Caterpillar 825hp/615kW
Main Fisheries:	Twin-rig Whitefish winter/spring/autumn; Tuna summer
Fishing Gear:	Twin-Rigging - 2 x 120 m Scraper Trawls; 600 x 80 mm Wings and cover sheet in 80 mm x 4 mm; Bellies and baitings 100 mm x 3 mm; Codend 100 mm x 6 mm; Roped on 20 mm combination with 8" deepwater floats Doors – PF10 Morgere 3m x 1.8m/1100kg and 1200kg Morgere Clump Weight Bridles – 60 fm x 32 mm combination or 40fm x 40 mm combination Single-Rig – 1 x 140 m Scraper Trawl 700 x 100 mm; Wings and Cover sheet in 160 mm/120 mm x 3 mm twine; Bellies and baitings 100 mm x 3 mm; Codend 100 mm x 6 mm; roped on 18 mm combination with 8" deepwater floats Doors - PF10 Morgere 3 m x 1.8 m/1100kg Bridles – 120 fm x 40 mm combination and 20fm rubber legs

MFV "Boy Jason" S 41

Skipper/Owner:	Ebby Sheehan
Built:	Concarneau, 1990
Registered Length:	22.25 m
Breadth:	7.2 m
Draft:	3.84 m
Hull Design:	Steel, Full Shelterdeck, Transom Stern
GT:	123GT
Engine:	MAN 629hp/469kW
Main Fisheries:	Twin-rig Whitefish winter/spring/autumn; Tuna summer
Fishing Gear:	Twin-Rigging - 2 x 100 m Double Bosom Trawls; 500 x 80 mm Wings and cover sheet in120 mm/80 mm x 15/24; Bellies and baitings 100 mm x 3 mm; Codend 100 mm x 6 mm; Roped on 18 mm combination with 8" deepwater floats Doors – PF8 Morgere 2.8 m x 1.6 m/800 kg and 900 kg Morgere Clump Weight Bridles – 60 fm x 32 mm combination Single-Rig – 1 x 150 m Dual Purpose Trawl (later reduced to 140 m; 750 x 100 mm; Wings and Cover sheet in 120 mm x 2.1 mm magnet twine; Bellies and baitings 100 mm x 2.1 mm/3.1 mm; Codend 100 mm x double 4 mm; roped on 18 mm combination with 79 x 8" deepwater floats Doors - PF8 Morgere 2.8 m x 1.6 m/800 kg replaced with PF 2.9 m x 1.7 m/900 kg Bridles – 150 fm x 38 mm combination

Discussion of Results

The figures presented were provided from the "Boy Jason" in 2001 and the "Cu na Mara" in 2003. For the purpose of this study, the assessment of twin-rigging against single rigging has been expressed as a function of fuel efficiency; catch in terms of daily earnings and relative gear performance. Other factors such as gear costs, crew and other operating parameters have also been referred too. Costs of repayments, insurance, harbour dues, commission and other levies and dues have not been factored in as these will remain largely constant whether the vessels fished with single or twin-rig gear.

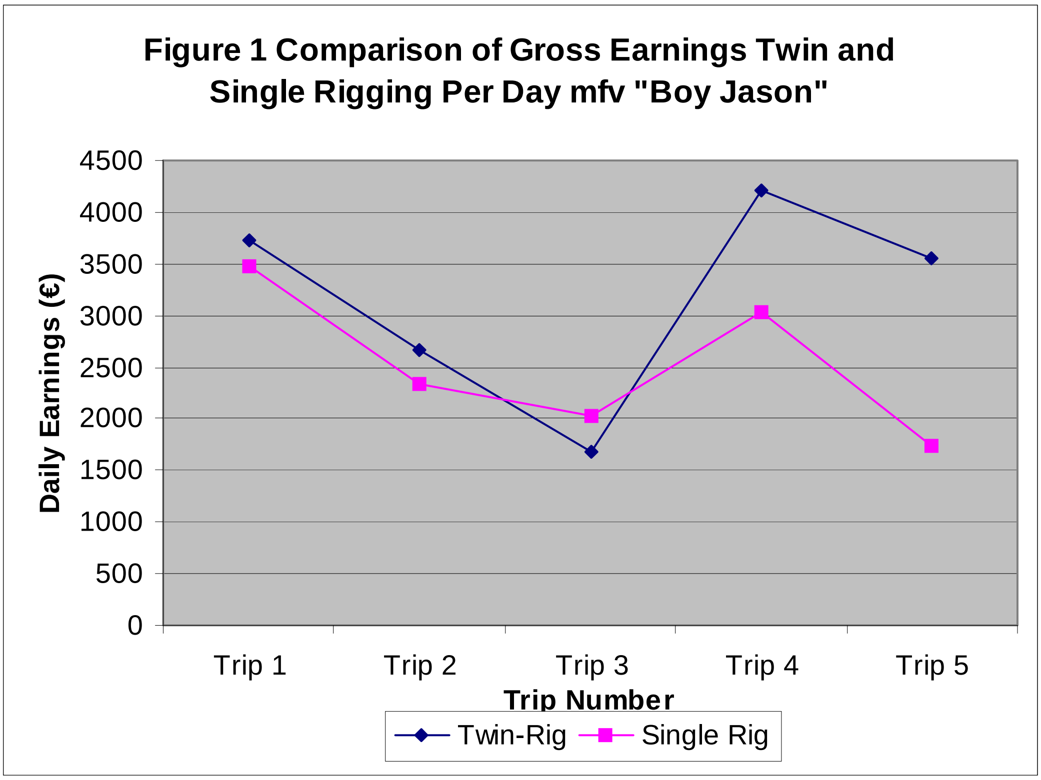
Table 2 summarises the average earnings and fuel costs per day obtained during the trial periods on the two vessels. This amounted to10 trips totalling 74 days on the "Boy Jason" over the period September – December 2001 and over 20 trips totalling 134 days on the "Cu na Mara" from March-June and October-December 2003.

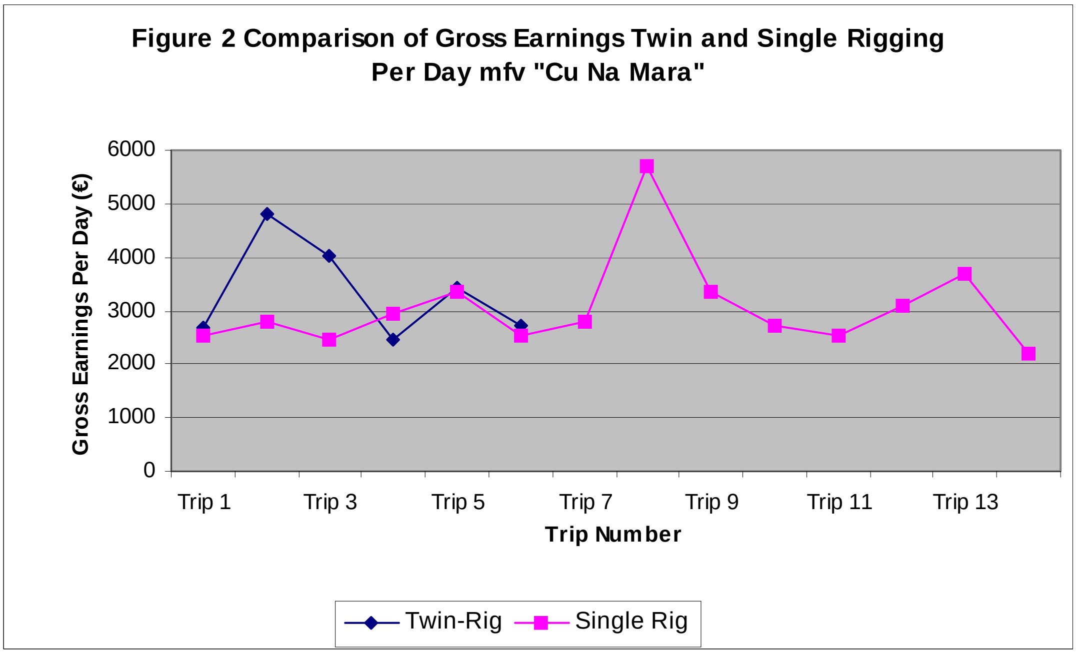
Table 2 Summary of Operational Parameters with both gear types.

	"Cu na Mara"		"Boy Jason"	
	Twin Rig	Single Rig	Twin Rig	Single Rig
No. of Trips	6	14	5	5
Average No. of Days per Trip	7	7	7	8
Average Earnings/Day	€3,181	€2,973	€3,381	€2,525
Average Fuel Costs/Day	€1,096	€954	€583	€530
Average Earnings as % of Fuel Costs	34%	33%	18%	22%

Average Earnings/Day

As catch rates fluctuated greatly from tow-to-tow with both gear types, it was decided to use daily earnings to compare the relative efficiencies of the two gear types. This is also the measure of performance used commonly by fishing skippers. As would probably be expected both vessels found that there was a reduction in gross earnings per day using a single trawl compared to the twin-rig. Both vessels had similar daily earnings when twin-rigging ranging between €1,682-€4,822 with an average of €3,281. When single trawling daily earnings between €1,739-€5,694, with an average of €2,749. For the "Cu na Mara" this equated to a reduction of 7% and for the "Boy Jason" it was in the order of 25% per day. Figures 1 and 2 show the difference in daily gross earnings by gear type over the number of trial trips on each vessel.

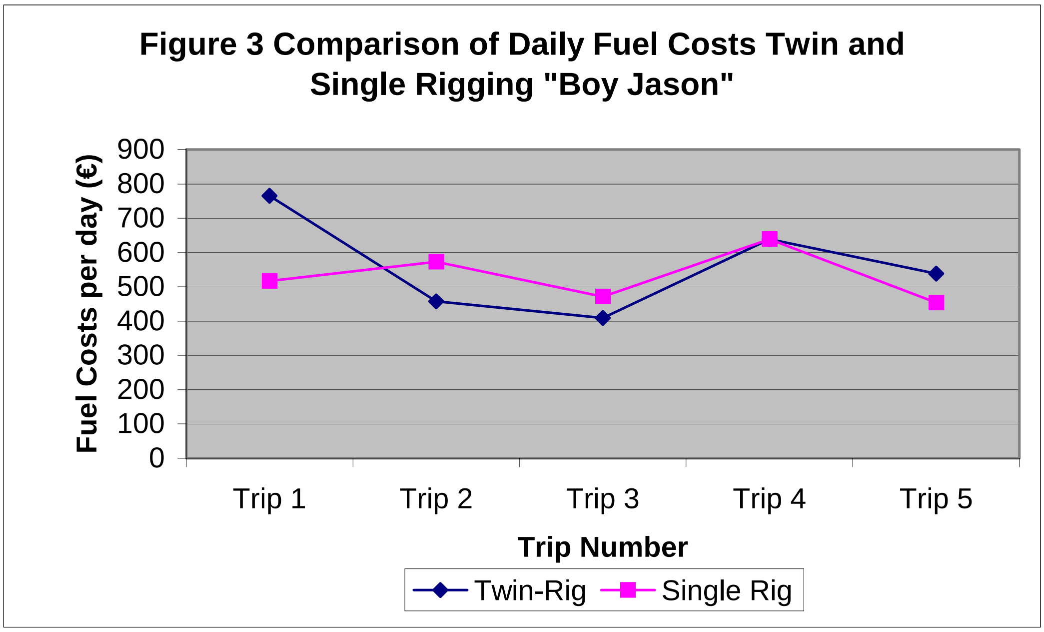


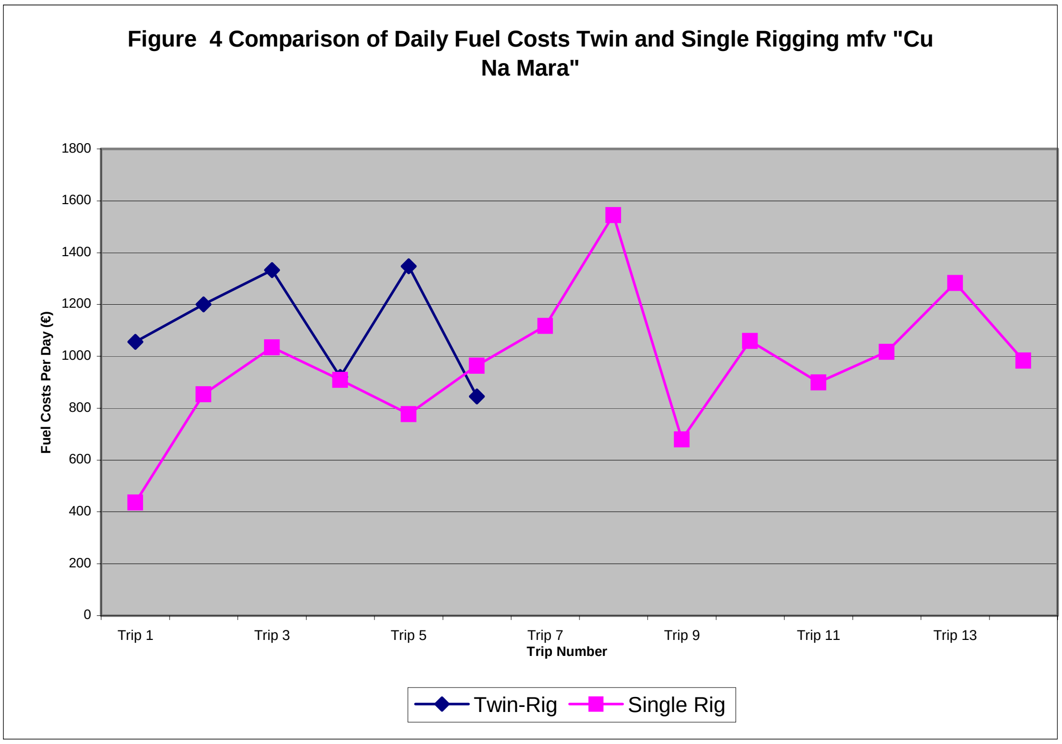


Extrapolating from these figures using a 280 day fishing year, this would give a reduction in gross earnings over the year of around €62,000 for the "Cu na Mara" and €236,000 for the "Boy Jason". The difference in earnings between the two vessels is as a result of a number of factors, including the fall in average fish prices for monkfish and megrim from 2001 in 2003 and also the vessels employing different tactics when reverting to the single-rig. The "Boy Jason" tended to target similar grounds with a slightly different net design with a higher headline height to catch more hake and roundfish, while still catching monkfish and megrim. The "Cu na Mara" targeted harder ground areas than could normally be worked with twin-rig gear, resulting in a wider catch composition comprising smaller volumes of high value species, as well as monkfish and megrim.

Fuel Consumption

Both vessels found by reverting to a single trawl that fuel consumption reduced, as shown in Figures 3 and 4. In the case of the "Cu na Mara", the skipper reported a reduction from an average of 3,800 litres/day, with the twin-rig gear to 3,000 litres/day with a single trawl, equating to a reduction in fuel consumption of approximately 21%. In monetary terms this equated to a 13% reduction in fuel costs per day. On the "Boy Jason" the difference was around 10% with a reduction from 3,100 litre/day to 2,800 litres/day, equating in monetary terms to a 9½% reduction. It is interesting to note, however, that during 2001 fuel prices were around 19 cents/litre compared to 28 cents/litre in 2003. This shows that as fuel prices increase the savings from reduced fuel consumption become more pronounced.





Again extrapolating from these figures for a 280 day fishing year this would give a fuel saving over the year of approximately €39,760 for the "Cu na Mara" and €14,840 for the "Boy Jason".

Gear Parameters

Door, wingend spread, headline height and towing speed information was recorded from Scanmar Gear Monitoring equipment fitted to both types of gear on board the "Cu na Mara" on separate trips in 2003. These results are summarised in Table 3.

Table 3 Recorded Gear Parameters for Separate Trips with Single and Twin Rig Gears on the "Cu na Mara" (* Indicates based on data from one net recorded)

Recorded Parameters	Single Rig (140m Trawl)	Twin Rig (2 x 120m Trawls)
Av. Net Speed (knots)	3.0	2.5*
Warp Length (m)	412	412
Depth (m)	190	201
Bridle Length (m)	256	110
Warp/Depth Ratio	2.17	2.05
Av. Door Spread (m)	156	146
Av. Wingend Spread (m)	51	37.5*
Av. Headline Height (m)	1.95	1.5*

From the data gathered fitted to both the single and twin-rig gear an estimate was made of the relative fishing efficiency in terms of swept areas and volumes, defined as follows:

- Swept Area Net = Wingend spread * speed
- Swept Volume Net = Wingend spread * headline height
- Swept Area Doors = Door spread * speed
- Mouth Area = Wingend spread * headline height

The results are summarised in Table 4 below.

Table 4 Estimates of Relative Fishing Efficiency with Single and Twin Rig Gear (** Indicates based on data from one net multiplied by 2).

	Single Rig	Twin Rig	% Difference
Swept Area Net (m^2)	76.5	97.5**	-32%
Swept Volume Net (m^3)	149.2	146.25**	+2%
Swept Area Doors (m^2)	234	190	+19%
Mouth Area (m^2)	99.5	112.5**	-12%

As can be seen, the effective swept area of the trawls is increased with the twin-rig by around 32%, with a corresponding reduction in swept door area of 19% when compared to the single-rig. It was also found that the vessels were able to cover more ground single-rigging due to being able to tow one net at an average speed of 3.0 knots at the same engine RPM required to tow two nets at 2.5 knots, and hence covering a bigger area per tow. It is also interesting to note that over the course of an average 7 day trip, the vessel "Cu na Mara" found that it was possible to tow for 3 hours per day longer with the single-rig. This time was as a result of the reduction in hauling time with one trawl as opposed to two nets. Over the course of a 7 day trip, the time thus gained is estimated at around 18 hours per trip, equivalent to 4½ x 4 hour tows extra per trip.

These results should be treated with caution as they are based on trials over a short time period and do not necessarily equate to optimum catch rates with either gears, although at these values the nets are fishing with similar bridle angles of 12º-14º.

Other Factors

According to the skippers interviewed, reverting to single-rigging had a number of other potential benefits aside from the improved fuel efficiency and only slight differences in gear efficiency found.

The gear expenses associated with twin-rigging have become increasingly prohibitive as reported by both skippers. Reverting to single rigging effectively means that a vessel does not need a clump weight, warp for the middle wire in a twin-rig system and only one set of bridles. At current prices this equates to a saving of around €16,000. Other gear expenses made up mainly of chandlery e.g. (shackles, hammerlocks, chain etc.) are also reduced, and during this study equated to on average between €500-1,000 per trip. Labour costs of mending nets ashore were also reduced by around €1,500 per month due to a reduced need to leave nets ashore to be repaired during trips. This is common practice for Irish twin-rig vessels as gear damage has increased as new grounds have been attempted to be opened up and is now accepted as an added cost to these vessels. This represents a saving per year of approximately €30,000-36,000 in gear and repair costs. The skipper of the "Cu na Mara" also reported an added benefit of the single-rig was that he did not have to use the Auto Trawl System other than to shoot and haul the gear. This dramatically reduced, not only wear and tear on the warps on the vessel but also on the vessels hydraulics.

As discussed single-rigging also allows the vessels to work much harder ground, working along the edges of banks and on stony ground. This resulted in a different catch composition comprising small volumes of high value species such as John Dory, lemon sole and red mullet, along with monkfish and megrim. With the single-rigs landings contained around 45-55% monkfish, in comparison to landings with the twin-rig gear, which was made up of 85%-95% of monkfish. The over reliance on one species for the majority of a vessel's earnings is a cause for concern of many of the skippers in the twin-rig sector and small catches of high values species are seen as one way to supplement earnings. Should monkfish quotas in particular come under further pressure or, as has been the case in the last 2 years, prices for monkfish and other "Spanish" species drop further, the economic viability of Irish twin-rig vessels is further in question.

The "Boy Jason" also found crew numbers could be reduced by one man at least with the single-rig gear, due to the less time spent hauling and shooting and a reduction in gear damage. Working with one less crew would represent a saving of around €25,000 per year for one of these vessels. The "Cu na Mara", however, has maintained the same crew size as the vessel tended to work harder crew and incurred significant gear damage, although with one net the crew can cope with this level of damage without downtime at sea. Whether single rigging ultimately will allow a reduction in crew numbers is therefore based very much on the fishing tactics employed.

Conclusions

The findings suggest that, for this sector of the Irish fleet a return to single-rig trawling has some obvious advantages, particularly in terms of fuel and other cost savings but there will be a corresponding loss of earnings, which from the results from these two vessels averages out at 16%.

Extrapolating from the fuel savings and the indicative reduction in gear and crew costs, showed the reduction in gross earnings to be almost negated on the "*Cu na Mara*". This vessel has remained single trawling. Results from the "*Boy Jason*" showed savings not as high compared to the reduction in earnings, due largely to lower fuel costs and higher prices for monkfish at the time of the first part of the study. The owner of this vessel was less convinced about the benefits of single trawling at the time and the vessel reverted back to twin-rigging at the beginning of 2002. Subsequently the vessel switched to single trawling during the summer months in 2002 and 2003 when monkfish are generally less prolific on the grounds and intends doing the same in 2004, targeting megrim and hake which currently have less quota restraints.

The differences in earnings also reflect the different strategies adopted by the vessels when reverting to single-rig trawling, and in this respect there is no doubt that when monkfish are the main target species the twin-rig has a significant advantage over the single rig. The over reliance on this species, however, raises serious questions and it is fully accepted by all of the operators in the twin-rig sector that there is a need to diversify to other species.

In terms of relative fishing efficiency twin-rig gear has an advantage in terms of swept net area but again this is largely counteracted by the fact that much longer bridles can be worked with a single net, giving a larger swept door area. Towing one net also had the added advantage of increasing the effective fishing time by up to 3 hours per day, equivalent to 4 complete tows a trip.

This study was not designed to be a full economic analysis of the profitability of twin-rigging compared to single rigging for the entire sector, but more as an indication to the skippers involved in this sector to examine closely their current operations and assess whether there is a need to consider other options for their vessels, including looking at returning for part or all of the time to single trawling. In this respect it has raised a number of interesting points.

Case Study 3: Efficiency change in the Faroese long line fishery. Ole Eigård, DIFRES, Denmark

In order to describe temporal trends in efficiency in the fish capture process of long line vessels two terms are essential: 1) the temporal change in "true" capacity/effort and 2) the temporal changes in catch per unit of effort (CPUE).

In the following, some aspects of these two terms will be examined and attempted quantified by analysing a set of catch and effort data covering the period 1986 to 2002 for 5 Faroese long line vessels. This data set holds approximately 15.000 observations with, among other variables, the individual catch weight of 5 species (cod, haddock, ling, blueling and tusk), the weight of the total catch, and the number of hooks set, being given for each day fished in the 17 year period.

The 5 vessels ranging from 30.7 meters to 38.6 meters in length all belong to the same management defined vessel group "larger long liners". In total nineteen long line vessels larger than 110 GRT from the Faroes are placed in this group, which means that our data material covers app. 25% of the capacity in this vessel group. In Figure 1 below it can be seen that long line vessels (large + small) caught a little less than 50% of the cod and somewhat more than 50% of the haddock landed in the period 2000-2002. In the present fisheries policy on the Faroes it is a management objective that the group of larger long line vessels should be responsible for 23% and 28% respectively of all cod and haddock catches.

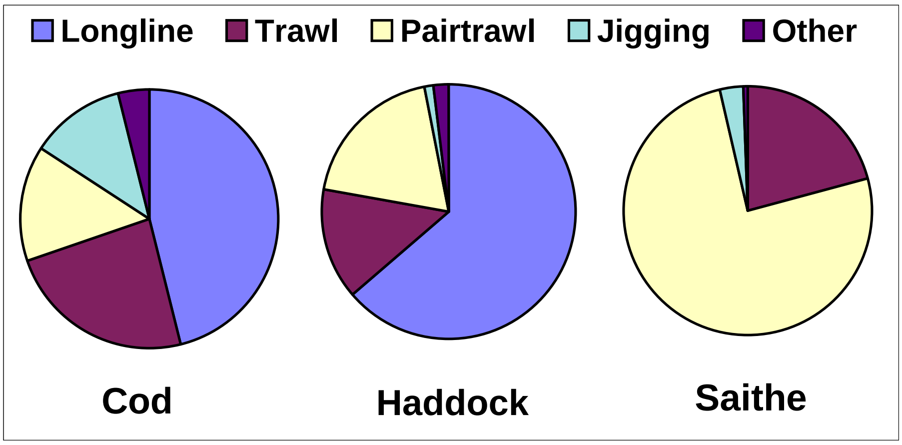


Figure 1. Catch by gear of cod, haddock and saithe in the Faroese area 2000-2002 (data from the Faroese Fisheries Laboratory).

In addition to a general questionnaire survey from 2002, covering all the different vessel groups that the management system operates with on the Faeroes, a more specific interview programme was conducted by the Faroese Fisheries Laboratory in 1997. This programme was targeted at identifying new technology purchased by vessels belonging to the group "larger long line vessels". The interview reports from telephone interviews with the skippers of the 5 long line vessels described above were kindly made available to this analysis by the Faroese Fisheries Laboratory.

These 5 interview reports together with the official catch and effort data for the same 5 vessels form the basis of the following analyses.

Temporal trends in fishing effort

In most management regimes concerned with monitoring and adjusting fishing capacity in the commercial fleet, Gross Register Tons (GRT) or Horsepower (HP) is used as a nominal measure of the fleet capacity. Neither is however very suitable scales for monitoring efficiency increases in the capture process of all the many different vessel types in commercial fishery. This is acknowledged broadly and several other capacity measures have been discussed. It is obvious that HP is a more suitable capacity measure for trawl fishery than for vessels deploying passive gears as gill nets or long lines. Even so changes in HP is not always a good approximation for changes in efficiency of trawl fishery and suggestions have been made that e.g. bullard pull should substitute HP as this measure is much more directly linked to trawl size, which in turn obviously is seen as a very important component of trawl efficiency.

The same discussion of appropriate measures applies to effort terms. The most broadly used term of nominal effort is fishing trips per year or in some instances fishing days per year as in the present Faroese management regime. When aiming at clarifying the biological impact from the fish capture process in the long line fishery, the temporal development in annual fishing days is however not the most appropriate measure to describe the temporal efficiency development in the fleet. In the Figure 2 below the annual number of fishing days for the examined 5 vessels as reported to the logbooks are displayed.

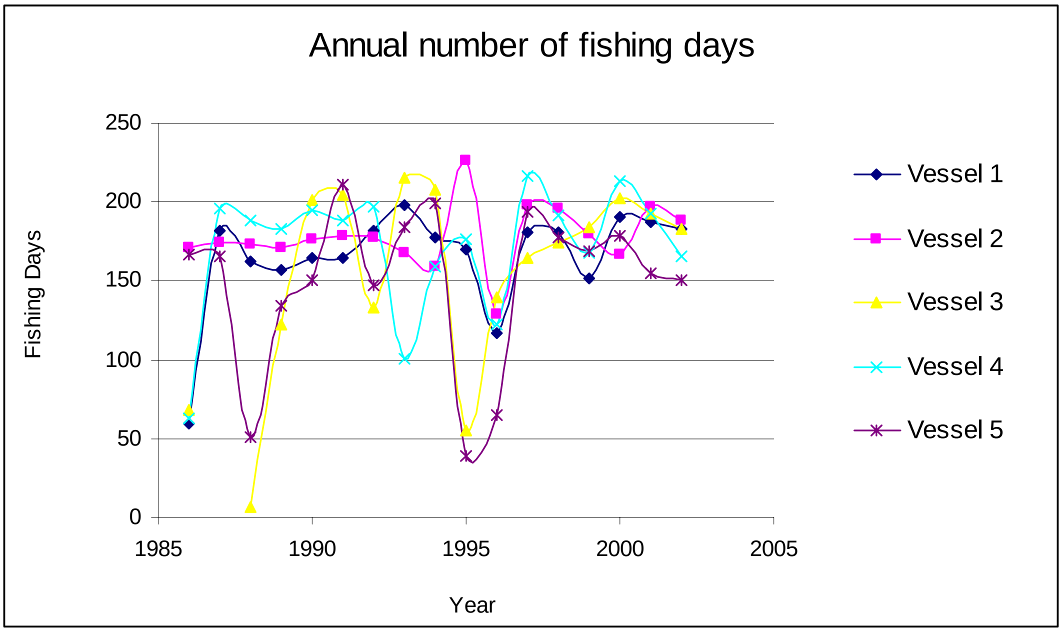


Figure 2. The trend in annual number of fishing days for 5 long line vessels larger than 110 GRT.

Figure 2 shows no increasing trend in the annual fishing days per vessel and as such the effort of the long line fleet seems to have been relatively stable throughout the last 20 years. In the case of the long line fishery we find it however more suitable to apply the number of hooks set per day as a truer measure of effort.

The first half of this paper deals with the quantification of the part of the long line efficiency change with time that is caused by an increase in true effort, measured as the number of hooks set per day.

Methods

In order to describe variations in number of hooks fished per day between years, seasons and vessels in our set of observations from the logbooks we have set up the following multiplicative model:

hooks/day = fishing year * fishing month * fishing vessel

The model is logarithm transformed and thus made additive:

ln (hooks/day) = fishing year + fishing month + fishing vessel

The following explanatory variables are included in the model:

Fishing year, 17 classes (1986 – 2002)
Fishing month, 12 classes (1 – 12)
Fishing Vessel, 5 classes (Vessel 1 – Vessel 5)

The dependent variable in the model “hooks/day” was calculated for each of 878 monthly observations in the final data set, as the number of hooks fished per day averaged over a month.

Parameter estimates were derived by applying the GLM (General Linear Model) procedure of SAS to the data set.

Results

In our case the main parameter estimates of interest are the ones for the 17 categories (1986-2002) of the class variable “year”. These estimates are plotted on a time axis in Figure 4 below and give a reasonable linear fit with a slope of app. 1.5% for the analysed period of 17 years this corresponds to a total increase in number of hooks set per day of 25%.

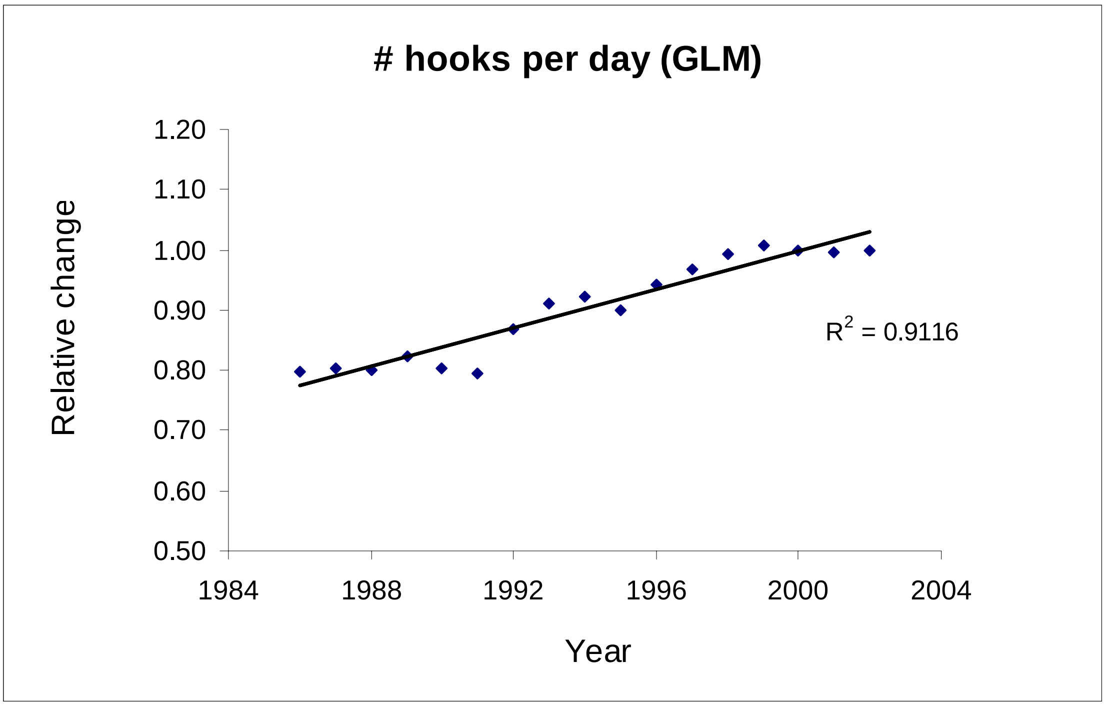


Figure 3. Plot of parameter estimates from model 1 showing the temporal trend in number of hooks set per day in the Faroese long line fishery for vessels larger than 110 GRT.

Based on the individual parameter estimates and their levels of significance relative to the 2002 estimate (table 1), the model output should perhaps rather be interpreted as a non linear development of three major periods: Two rather stable periods separated by a third period of marked annual increase of app. 4% from 1991 to 1996.

Table 1. Parameter estimates of the yearly change in number of hooks set per day relative to the year 2002.

Year fished	number of hooks/day relative to 2002	level of significance
1986	0.80	<.01
1987	0.80	<.01
1988	0.80	<.01
1989	0.82	<.01
1990	0.80	<.01
1991	0.79	<.01
1992	0.87	<.01
1993	0.91	<.01
1994	0.92	<.01
1995	0.90	<.01
1996	0.94	0.05
1997	0.97	0.21
1998	0.99	0.84
1999	1.01	0.77
2000	1.00	1.00
2001	1.00	0.88
2002	1.00	.

Discussion

The time period of major increase in effort from 1990 to 1996 is covered by the interview programme conducted by the Faroese Fisheries Laboratory in 1997. No technological innovations directly connected to the process of, baiting, shooting or hauling the lines (e.g. automatic baiters) could be identified in the interview reports. However one innovation that could have had indirect influence on the ability to increase the effort was introduced on all vessels during the period 1992 to 1995. The global positioning system might have played a role by shortening the time spent locating the spot to set the line and the time spent to relocate the gear upon hauling. These navigational improvements might have liberated some time for setting additional hooks.

Some indications of what technologies might have contributed to the observed increase in effort can be obtained from the 2002 questionnaire survey results for the group “larger long line vessels”. According to the answers four new technologies with an impact on efficiency were broadly introduced during the time period in question: I) Skewed Hooks (1990-1996), II) Stability tanks (1991-1999), III) Swivel line (1992-1996) and IIII) Snood line (1992-1996). Of these four technologies possibly the stability tanks could directly influence the vessels hook capacities, whereas the three others might indirectly have some effect on effort (e.g. skewed hooks being easier for the automatic baiter to handle)

Another characteristic for the period is the introduction of a TAC system in 1994 and it is possible that this marked increase in effort is also somehow behaviourally induced by the sudden limitations of a resource that was previously freely available. The introduction of the fishing day regulation in 1996 has for sure induced an effort increase as evident from the questionnaire survey from 2002, where a majority of the skippers from the group small long line vessels informed that they had responded to the effort regulation by using more long line. The skippers on the larger long liners did not inform about any increase in the length of long line used as a direct response to the effort regulation. But it seems highly likely that it has taken place - also on the larger vessels.

Temporal trends in CPUE

The temporal trend in CPUE for the long line vessels is much more difficult to quantify by employing the same data set that allowed for the quantification of effort changes. This is due to the fact that expected yearly changes in CPUE are induced by a combination of technological introductions and of fluctuations in availability of target species, with the latter presumably having the largest impact. A break down of the combined effect into two separate factors requires the inclusion of an availability variable (maybe approximated by yearly stock assessment numbers) in the data set and this lies been beyond the scope of the present investigation. It is however something to be considered for future work and the analyses carried out in this investigation of the Faeroes long line fishery form a good basis for an elaborate analyse including some kind of availability variable.

Impact of global positioning systems, swivel lines and skewed hooks on CPUE

What might li.e. within the immediate scope of the present investigation is the quantification of single event changes in CPUE induced by individual technologies introduced prior to 1997. In other words it might be possible to identify some partial contributions from single technologies to the overall changes in CPUE. This could be done by combining the data set previously used to identify the temporal development in numbers of hooks set per day and combining this data set with the technological observations of more qualitative nature arising from the 1997 interview programme.

Qualitative Technology data

As mentioned previously an interview programme was conducted in April 1997 by the Faroese Fisheries Laboratory. The reports from these interviews allowed us to get some information on the new technologies that have been introduced in the Faroese long line fishery. The interview programme was directed at collecting information of technological introductions prior to 1997 on the five previously mentioned larger long liners. These vessels were picked out for the interview programme based on a positive evaluation of the reliability of their logbook reporting on catch and effort data.

The logbook data cover the period 1986 to 2002. This means that the overlap in time between the qualitative technology data from the interview programme and the quantitative data from the logbooks exists for the period from 1986 to 1996.

Three technological innovations with significant influence on the capture efficiency (as estimated by the skippers) were introduced on all of the vessels in the time period covered by both quantitative and qualitative data: 1) Global Positioning System, 2) Swivel lines and 3) Skewed Hooks. The swivel line (SL) and the skewed hooks (SH) were introduced almost simultaneously on the individual vessels and are treated as one technological innovation (SL+SH) in the following analyses. The Global positioning system (GPS) was also introduced on all 5 vessels during the ten year period, but unfortunately the time of introduction was not mentioned in the interview report for one of the vessels. Therefore the qualitative and quantitative data for this vessel are not included in the following analysis, leaving us with data from 4 vessels or app. 20% of the fleet.

Two additional problems with achieving a correct dating of the introduction of the technologies are 1) none of the introductions were identified to the exact date, only the year of introduction was given and 2) The SL-SH were not purchased as single discrete events but were gradually introduced over typically 1-1½ years.

We chose to solve this problem by introducing a category for transience in addition to the two categories “yes” and “no” for the variables GPS and SL-SH in the interview data set. This transient category “per” (perhaps) covered the time periods where we were uncertain of whether (and for SL-SH to what degree) the vessels had introduced the GPS and the SL-SH.

This resulted in the following categories being applied to each observation of catch and effort data in the logbook data set depending on the year of the observation. Observations before 1990 were of course assigned a “No” for both GPS and SH-SL and the years after 1996 were assigned a “Yes” for both variables.

Table 2. The period and pattern for the introduction of the Global Positioning System (GPS) and the Swivel line+Skewed hooks (SL-SH) on board four long line vessels.

		1990	1991	1992	1993	1994	1995	1996
Vessel 1	SL+SH	No	No	No	Per	Per	Yes	Yes
Vessel 2	SL+SH	No	No	No	No	Per	Yes	Yes
Vessel 3	SL+SH	No	No	Per	Yes	Yes	Yes	Yes
Vessel 4	SL+SH	No	No	No	No	Per	Yes	Yes
Vessel 1	GPS	No	No	No	No	Per	Yes	Yes
Vessel 2	GPS	No	No	No	No	Per	Yes	Yes
Vessel 3	GPS	No	No	No	No	Per	Yes	Yes
Vessel 4	GPS	No	No	Per	Yes	Yes	Yes	Yes

SL+SH = Swivel line + skewed hooks
GPS = Global Positioning System

One concern regarding the robustness of the data was the relative low temporal contrast in the observations as visualised in Table 2. Put simply we are comparing the catches of one vessel with SL-SH with the catches of three other vessels without – or partly without - SL-SH over a period of maximum three years. The same comparative basis applies for the data for the introduction of the GPS. Fortunately the vessel (vessel 4) that purchased the GPS as the first vessel was not also first to purchase the SL+SH, which adds some substance to the window of contrast.

Methods

Bearing in mind the lack of accuracy and the low contrast value on the temporal scale in the data, a GLM analysis was carried out to establish if the two technological innovations identified had any significant effect on the CPUE. The following additive model was applied to the observations in the logbook dataset merged by year with the variables GPS and SL-SH containing the classes "Yes" "Per" and "No":

ln (CPUE) = fishing year + season + vessel + area + GPS + SL-SH

To account for spatial differences in the abundance of target species an area effect was included. This explanatory variable, Fishing area, was fairly easy to include in the analysis as each observation in the log book database is assigned to the ICES square where the lines are set. This resulting data set was a mixture of information from the logbooks and the interview programme with the following explanatory variables included in the model:

Fishing year 17 classes (1986 – 2002)
Fishing month 12 classes (1 – 12)
Fishing Area 116 classes (ICES squares around the Faeroes)
Fishing Vessel 4 classes (4 larger long line vessels)
Global positioning system (GPS) 3 classes (yes, per, no)
Swivel line + skewed hooks (SW+SH) 3 classes (yes, per, no)

The dependent variable in the model "CPUE" was calculated for each of 10658 daily observations in the final data set as the catch weight of each of 5 species - as well as various combinations of these species – per hook.

Some difficulties arose in the process of choosing the appropriate measure of catch. That is whether to run the model with the response variable being the total catch in weight (cod, haddock, ling, blue ling and tusk), only include the main target species cod and haddock in the catch or maybe even choose some third species combination. One problem with the latter options is that they would exclude between 5 and 10% of the observations because many of the older logbooks only reported the total catch - not the distribution among species.

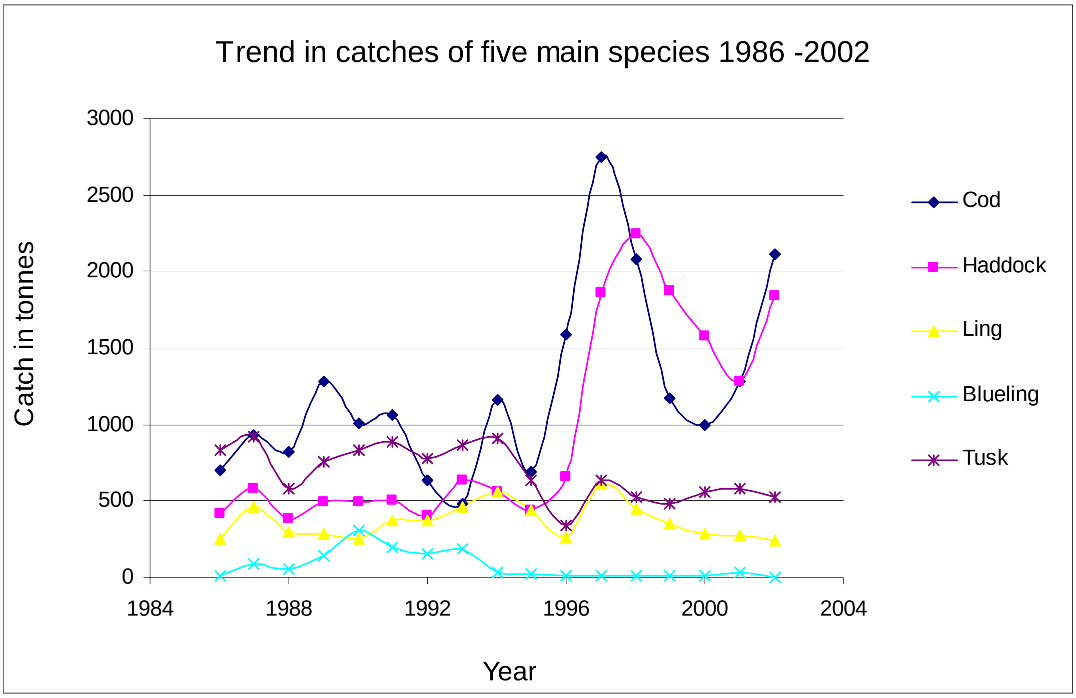


Figure 4. Catch composition in the total landings from 4 long line vessels for the period 1986 to 2002.

Based on the temporal pattern of the catch composition shown in figure 4 above, we decided to run the model with the three presumed main categories of catch: I. total catch (haddock, cod, ling, blue ling and tusk) II. Main target species (cod and haddock) and III. Main bycatch species (ling, blue ling and tusk).

Parameter estimates for each of these three categories were derived by applying the GLM (General Linear Model) procedure of SAS to the dataset.

Results

The parameter estimates from the GLM analysis are shown in Table 2 below.

Table 2. Parameter estimates and level of significance for the impact of GPS and SL-SH on the CPUE of the vessel group "larger long line vessels".

		Total Catch		**Cod and haddock**		**Ling, blueling and tusk**	
		% increase	Significance	% increase	Significance	% increase	Significance
GPS	No	0	-	0	-	0	-
	Per	8	<.05	31	<.05	-14	<.05
	Yes	9	<.05	76	<.05	-14	<.05
SL+SH	No	0	-	0	-	0	-
	Per	4	0.22	23	<.05	1	0.05
	Yes	-1	0.89	71	<.05	-18	0.90

The figures in Table 2 display some rather dramatic – but in most cases significant - results from the GLM analysis. The results for the effect of the GPS contradict each other across the three different categories of catch composition chosen for the model runs. The most conspicuous discrepancy being the GPS causing an increase in CPUE of 76% when modelled for the target species cod and haddock but inducing a decrease of 14% when modelled for the bycatch species of ling, blue ling and tusk.

For SL-SH the parameter estimates show an increase of 71% when modelled for the target species and no significant effect when modelled for the bycatch species.

When the model is run with the catch being composed of both target and bycatch species (total catch) the result can be interpreted as a kind of means between the two other results.

Discussion

The results from the GLM analysis of the effect from global positioning systems and Swivel lines + skewed hooks should be treated with large reservations. It goes without saying that a 1.75 * 1.75 increase in CPUE being exclusively a result of the acquisition of both the technologies on a long line vessel is a bit unrealistic. Previous findings on the effect of GPS in the fishery for northern prawn in Australia show a 12% increase in CPUE (Robins *et al*. 1998) and another investigation in the same fishery report a 4-7% increase (Bishop *et al*. 2000). Probably the obtained results should be interpreted in the light of a high degree of temporal overlap between the recruitment of some very large year classes of cod and haddock in the fishery (Jakupsstovu *et al*.) and the introduction in the fleet of the two investigated technologies. Serious bias from the fluctuations in the stock availability in the examined period should however have been avoided by the inclusion of the year effect in the model. But probably the temporal and spatial scales of the data (years and ICES squares) have not had detail enough to counter the availability effect on the CPUE.

Also undermining the reliability of the parameter estimates is the previously discussed low robustness of the qualitative technological data that had only little temporal contrast and precision.

One result giving a little credit on the validity side is that the transient category "per" displays values placed nicely between the category yes and the category no for practically all the significant results. The reliability of the parameter estimates is also strengthened by the seemingly contradictory result of the cod and haddock CPUE being positively influenced by the GPS and the ling-blueling-tusk CPUE being negatively influenced by the same technology. It might well be expected that new technology improving the precision/selectivity in the fish capture process – like the GPS - would increase the proportion of the target species and minimize the proportion of bycatch in the total catches.

When it all sums up we find the results for the parameter estimates highly debatable and hesitate to conclude further than: That both the GPS and the SL-SH seems to have had significant impact on the CPUE of the target species and seemingly none or insignificant impact on the CPUE of a combination of bycatch species (ling, blueling and tusk)

Some of this general picture is recognized in the answers from the questionnaire survey, where the majority of the informants from the long line fishery replied that the Swivel line and skewed hooks had significant effect on efficiency for especially haddock. The answers in the questionnaire reported efficiency increases varying between 10 and 50%.

Future work

Achieving a higher degree of precision in the Repeated and very focused technology interviews to achieve robust and precise data

Treating the logbook and interview data as the result from a controlled experimental fishery by isolating observations from vessels with technology and vessels without technology with exact overlap in time and space (same ICES square and date) and comparing their catch and effort data.

A GLM on the logbook data with an availability variable added (Stock assessment index)

Conclusions

1) With respect to the analysis of the temporal trends in fishing effort (number of hooks set per day) the GLM analysis of logbook data showed an annual increase in effort for the larger Faroese long liners of 1.5% annually for the period 1986 to 2002. This development should however rather be interpreted as two rather stable periods from 1986-1990 and from 1997-2002 separated by a third period of marked increase from 1991 to 1996. The introduction of GPS and stability tanks in the fleet and the enforcement of a quota system and especially the fishing days regulations could very well be the main factors responsible for this development.
2) We did not attempt to quantify the overall temporal trends in CPUE for the long line fishery. In this investigation we limited ourselves to exploring the partial contribution to the CPUE trends from two single technological innovations: the GPS and the Swivel line in combination with skewed hooks. The results obtained for the GPS and the SL-SH are however subject to very large uncertainty and are most likely heavily biased by both high availability of cod and haddock coinciding with the period of technology introduction and from low temporal precision and contrast in the qualitative data. We therefore hesitate to conclude anything other than that the analysis indicates that the introduction of the GPS and the SL-SH have had a significant positive effect on the CPUE of the main target species cod and haddock.

We also conclude that the existing data material for the Faroese long line fishery is a good foundation for quantification of both partial and total temporal changes in CPUE if extended, combined and analysed in the manner discussed above.

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Annex 4 Mitigation Measures against Seabed Impact of Mobile Fishing Gears

Note that this report is a working document and as such is in draft form, any citation must be done with approval of the authors.

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MITIGATION MEASURES AGAINST SEABED IMPACTS OF MOBILE FISHING GEARS

1. Abstract

Bottom-tending mobile fishing gears such as otter trawls, beam trawls and shellfish dredges alter the physical structure of the seabed though their impacts on benthic communities and ecosystems vary with sensitivity and natural disturbance of the seabed, among other factors. While more research is needed to quantify various impacts of different fishing gears used in different fisheries under different fishing ground conditions, technical measures to reduce seabed impacts are encouraged. This report summarizes such measures and ongoing research projects with potential for reducing physical impacts on the seabed as well as negative effect on benthic communities. In general, measures that improve fishing efficiency can reduce fishing time and seabed impacts in strictly-enforced output-controlled fisheries. Also, alternative gears with less seabed contacts may be used instead of traditional bottom-tending gears in some fisheries. Gear modifications which have less seabed effects include measures to reduce seabed contacting area/points of trawl footgears, use of semi-pelagic trawls for shrimps, provision of dropout aft-belly openings in beam trawls, adoption of "sweepless" trawls for whiting, and "wheeled" footgears replacing rockhoppers. Electrical stimuli may be employed in beam trawls to replace traditional heavy tickler chains for some species, and use of electric pulses in scallop dredges has also shown promise. Some novel gears which have potential for reducing seabed impacts include the "Active Trawl" system, the "Auto-trawl" system, and the use of kites and depressors in trawls, though some of these gears are in early stages of development. It should be noted that some technical measures described in the report may have other negative or positive outcomes in additional to potential reduction of seabed impacts. Caution should therefore be taken in recommending or implementing their use in specific fisheries.

2 Introduction

The International Council for the Exploration of the Sea (ICES) Working Group on Ecosystem Effects of Fishing Activities (WGECO) and Working Group on Fishing Technology and Fish Behaviour (WGFTFB) have been examining trawling effects on the seabed for many years. In 1988, Study Group on the Effects of Bottom Trawling under Fisheries Technology Committee was convened in response to Council Resolution 1987/2:7 (ICES, 1988) to collect and review available information and to report on the development on the effect of bottom trawling. More recently, WGFTFB meetings were held in St. John's, Newfoundland in 1999 and in Haarlem, the Netherlands in 2000 to discuss alteration of the seabed caused by towed fishing gears such as bottom trawls, beam trawls and shellfish dredges, and the potential impact of these alterations (ICES, 1999; 2000a). At the same time period, WGECO held a meeting in Copenhagen on wider aspects of ecosystem effects of fishing (ICES, 2000b). Researchers in ICES member countries have independently and jointly taken steps to evaluate fishing impacts and/or to reduce potential impacts of towed fishing gears on the seabed. While physical alterations of the seabed by towed gears are evident in many cases, the effect of such alterations on benthic organisms and recovery rates of the alteration are variable depending on location, depth, and natural disturbance in the area, among other factors.

Several major reviews, books, and comprehensive studies have been completed and many are ongoing concerning potential impacts of fishing with bottom trawls, beam trawl and dredges on the seabed and marine habitat (see Dorsey and Pederson, 1998; Hall, 1999; Kaiser and de Groot; 2000; Linnane *et al*., 2000; NRC, 2002; Sinclair and Valdimarsson, 2003; Lart *et al*., 2003). Natural variations, complexity of benthic communities, variations in gear designs, and methodologies used to evaluating impacts resulted in very few general conclusions regarding the impact of towed gears on the seabed and marine ecosystem (Løkkeborg, submitted). Despite these uncertainties, several papers have proposed technical modifications to lessen seabed impacts of fishing activities (Carr and Milliken, 1998; Rose *et al*., 2000; He and Foster, 2000; van Marlen *et al*., 2001a,b; Fonteyne and Polet, 2002; NRC, 2002; Valdemarsen and Suuronen, 2003; Lart *et al*., 2003; He and DeLouche, 2004). In accordance with the precautionary approach, impacts of fishing on the seabed should be reduced whenever it is feasible to do so. This report continues previous efforts and summarizes recent work on mitigation measurers to reduce impacts on the seabed and benthic communities of mobile fishing gears including otter trawls, beam trawls and shellfish dredges.

3 Terms of Reference

This report was produced by WGFTFB members as a result of the terms of reference for a topic item adopted at the WGFTFB meeting in Bergen, Norway, June 2003. The Terms of Reference were:

> *To evaluate the effect of fishing gears on the seabed with special reference to mitigation measures in mobile gears and the effects of stationary gears on sensitive environment.*

The justification for the Terms of References was:

> *The effect of bottom tending towed fishing gears on the seabed has received considerable attention in recent years. While it is important that the effect be quantified, studies to reduce the effect should be encouraged and strengthened. Members of WGFTFB will summarize and review previous works and discuss current status on the effect of towed gears such as bottom trawls and dredges and will put special emphasis on mitigation measures to reduce the effect through modification of gear designs and operational methods. In addition, the members of WGFTFB will summarize and review possible effects of stationary fishing gears including but not limited to gillnets, longlines, traps and pots on sensitive environments such as coral reefs, sea mounts, near shore communities and mollusc beds and will evaluate current status on the subject.*

This report will focus primarily on aspects related to mobile fishing gears. The effects of stationary gears on the environment will be addressed in a separate report.

4 Participants

The following WGFTFB members participated in discussions on 20 April, 2004 at the Working Group meeting held in Gdynia, Poland and/or contribute text to the report.

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5 Review on the Effect of Mobile Fishing Gears on the Seabed

This section is primarily based on a recent review by Svein Løkkeborg for FAO (Løkkeborg, submitted). More detailed discussion on the subject can be found in that report.

How fishing and other anthropogenic activities may affect the marine environment has always been a concern. More specifically, debate about impacts of towed fishing gears such as trawls and dredges on benthic habitats and organisms has increased over the last couple of decades. The rationale for this concern is that benthic habitats provide shelter and refuge for juvenile fish and the associated fauna comprise food sources for important demersal fish and shellfish species. Severe impacts on benthic communities attributed to trawling disturbances may cause a change in species composition and species diversity. Therefore, knowledge of responses of these communities to impacts from fishing gears is of great importance to ecosystem and sustainable fisheries.

Two methods have been employed to investigate physical and biological effects of mobile gear operations on benthic habitats and communities. One method is to conduct experimental fishing on a site and compare physical and biological parameters of this site before and after the disturbance, and/or with an adjacent and undisturbed control site (Freese *et al*., 1999; Hansson *et al*., 2000; Kenchington *et al*. 2001). The other method is to compare commercial fishing grounds that have been heavily fished with areas that are lightly fished or not fished at all (Engel and Kvitek, 1998; Thrush *et al*., 1998; McConnaughey *et al*., 2000). Experimental methods applied in fishing impact studies should ideally fulfil three basic requirements: trawling disturbance at a spatial and temporal scale representative of commercial fishing, comparison with undisturbed control sites and quantitative sampling of benthic organisms. Many impact studies conducted to date fail in meeting one or more of these requirements, consequently conclusions from such studies should be viewed with caution. Comparisons of the direct mortality caused by various or modified gears represent an exception to these requirements. In these cases, an area of abundant benthic species should be selected and the secondary mortality caused by scavengers should be considered.

Otter trawls, beam trawls and scallop dredges have different catching principles and are thus likely to have different physical impacts on the seabed. Demersal otter trawls are rigged with different types of footgears and bottom doors when targeting fish and shellfish staying close to the bottom. The most noticeable physical effect of otter trawling is the furrows (up to 20 cm deep) created by the doors, whereas other parts of the trawl create only faint marks (Brylinsky *et al*., 1994; Sanchez *et al*., 2000).

Beam trawls and scallop dredges are used to catch species that stay on or are buried in the seabed. Accordingly, many of such gears have tickler chains (beam trawls) or teeth (dredges) designed to penetrate the upper few centimetres of the sediment. Thus beam trawling and scallop dredging cause a flattening of irregular bottom topography by eliminating natural features such as ripples, bioturbation mounds and faunal tubes (Eleftheriou and Robertson, 1992; Kaiser and Spencer, 1996). Marks made by towed fishing gears may last from a few days in tidally exposed areas to many months in sheltered bays (Currie and Parry, 1996; Tuck *et al*., 1998; Fonteyne, 2000).

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 the ground gear (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 declines in the abundance of some benthic species, but trawling disturbances did not produce large changes in the benthic communities. These habitats may be resistant to trawling 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 bottoms (i.e. clay, silt) (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.

Clear evidence of the short-term effects of beam trawling and scallop dredging has been demonstrated in several studies (Bergman and van Santbrink, 1994; Currie. and Parry, 1996; Kaiser and Spencer, 1996). Intensive disturbance has been shown to cause considerable reductions in abundance of several benthic species. Beam trawling disturbance caused no effects in areas exposed to natural disturbances, e.g. wave actions and salinity fluctuations, confirming the general trend that exposed habitats seem to be resistant to disturbances caused by towed gears.

It can be concluded that our knowledge of the impacts of towed fishing gears is still rather rudimentary, and few general conclusions can be drawn on the responses of benthic communities to impacts from fishing disturbances. It is difficult to draw firm conclusions from fishing impact studies due to complexity and natural variability of benthic communities, as well as a lack of comparable pristine control sites. However, it is prudent to take measures to reduce fishing impacts through technical modifications to gear designs and operations in the effort to preserve benthic ecosystem and to sustain fisheries resources.

6 Improving Efficiency to Reduce Effort and Seabed Impact

Seabed impacts and fishing efficiency are closely linked because both are a function of time. In output-controlled fisheries, such as those managed with a Total Allowable Catch (TAC) or Individual Transferable Quota (ITQ) regimes, if effort management is effective, improving the efficiency of fishing operations can reduce the contact time between the fishing gear and the seabed. One path to improving efficiency is developing accurate and detailed maps of the concentrations of target species, especially sessile species such as scallops.

Attempts to limit effort (and efficiency) may prevent the use of technical innovations with less seabed impact. As an example, pair trawling for groundfish is not allowed in the multispecies fisheries in Northeast United States even though a well-adjusted pair trawl would have less seabed impact than an equivalent otter trawl because the former does not use trawl doors. Also, multi-rig trawl systems are illegal for British-registered vessels. Multi-rig trawl systems use smaller and lighter nets to cover the same ground area compared to single trawls, and could reduce the overall fishing impacts.

Below are examples of two effort-controlled scallop fisheries on Georges Bank between Canada and USA and on offshore banks off Nova Scotia. Georges Bank in the Northwest Atlantic is the world’s largest single resource for the sea scallop species *Placopecten magellanicus*. Recent mitigation measures against seabed impacts of scallop dredges on Georges Bank resulted indirectly from increasing efficiency. The area is shared between the US and Canada, and managed under two different schemes. The increased efficiencies and resulting mitigation arose differently in each country. In Canadian waters, the increased efficiency was the result of interpretation of comprehensive multibeam imaging leading to accurate mapping of scallop beds. In combination with individual transferable quotas, bottom time of dredges was reduced by more efficient fishing. In US waters, dredging was allowed in areas previously closed to fishing where very high scallop densities were determined high by video imaging. Habitat impact was reduced by reduced bottom time of dredges due to high densities, trip limits, and effort reduction measures.

6.1 Effort and bottom time reduction in the US scallop fishery on Georges Bank

The New Bedford (or “chain sweep”) dredge is the primary gear used on Georges Bank in the sea scallop fishery. The dredges are typically 4.3 m (14’) wide and two dredges are usually towed by a single vessel at speeds of 4 to 5 knots. Unlike dredges used in Europe and in the Pacific, it is toothless. The forward edge of the New Bedford dredge includes the cutting bar, which rides above the surface of the substrate, creating turbulence that stirs up the substrate and kicks objects (including scallops) up from the surface of the substrate into the bag.

The shoes and the bottom of the bag are the primary contacts of the dredge with the sea floor. The turbulence behind the cutting bar also results in suspension of sediment and some smoothing of irregularities. Other physical impacts can occur during setting and hauling but they are minor in comparison to those caused by the shoes, the bag and the cutting bar (Pol and Carr, 2002).

Large areas of the US side of Georges Bank (approx. 50% of the overall) area were closed in 1994 to protect fish populations (Hart, 2001). Scallop fishing was diverted to other areas with declined fishing efficiency and average scallop size. By 2000, survey indices for scallop biomass in the closed areas had increased by twenty times (Hart, 2001). Stokesbury (2002) developed a video camera apparatus to survey scallops in these areas, and measured scallop densities among the highest reported in any Georges Bank survey. The mean densities were between 0.25-0.59 scallops per square meter (NEFMC, 2004). Sea scallops were found to be highly concentrated in beds several square nautical miles in size. Moreover, depletion experiments and underwater photography permitted improved estimation of dredge efficiency and selectivity of commercial dredges.

A fully developed rotational fishery was thus established using high-density scallop beds in the closed areas. Catching efficiency was very high in the closed areas, resulting in less bottom time for the same mount of catches. In addition, landings were limited to 4,540 kg (10,000 lbs) per trip, and vessels were deducted 10 fishing days from their annual allotment for each trip into these areas, although actual trip durations averaged six days. As a result, this programme reduced the annual available Days-At-Sea (DAS) by 2,576 days or about 10%. Total annual fishing time (time towing) was reduced from 408,000 hrs in 1999 to 384,000 hrs in 2000. Reduced bottom time of the dredge resulted in reduced habitat impacts (Howard, 2004).

6.2 Seabed mapping in the Canadian offshore scallop fishery

The Canadian scallop fishery is managed under an individual transferable quota that limits the annual amount of harvest. The fishery is dominated by several large corporations. In the early 1990s, these corporations formed the Canadian Offshore Scallop Industry Mapping Group (COSIMG) and worked with governmental agencies to map seabed characteristics using multibeam technology. They produced 3-D topographic charts overlaid by geological features and sediment characteristics of commercial scallop areas. The resulting three-dimensional maps of bathymetry, sediments, and benthic habitat were used by fishermen to identify scallop beds (areas of “pea” gravel). The locations of the beds were then distributed to vessel captains, who optimized dredge efficiencies by towing directly on those areas. Follow-up research determined that the maps were 94% accurate in identifying the presence of scallops. Because the total catch was limited by quotas, average fishing time per metric ton of scallop meat was reduced from 6.37 hours to 2.41 hours, fuel consumption was reduced by 36 percent, and 74 percent less seabed area was dredged (BIO, 2002).

Two factors make the offshore scallop industry especially well-suited to the technology: 1) Scallops can be mapped reliably because they are relatively sedentary and found in high association with a particular substrate; 2) The industry’s quota system under Canadian Department of Fisheries and Oceans (DFO) assures the industry a secure level of access, thereby providing a strong incentive for the industry to invest in science, such as mapping, and other activities with long-term benefits.

The success of this project has inspired others to attempt to duplicate it. A similar project in Ireland is currently underway, having completed multibeam imaging of important scallop grounds (D. Rihan, personal comm..; Sutton *et al.*, 2003).

It should be noted however that new technologies similar to multibeam seabed mapping could only contribute to ecosystem conservation when accurate stock assessment and output control can be assured. Overestimation of stocks, excessive TACs and inability to control output can result in depletion of the resource with high-resolution seabed maps.

7 Use of Alternative Gears to Lesson Seabed Impact

The Alaskan pollock fishery had been pursued by bottom trawls prior to 1990. Concerns over shellfish (crabs) and groundfish (mainly Pacific halibut) bycatch prompted the North Pacific Fisheries Management Council (NPFMC) to allocate a large proportion of the pollock TAC to the pelagic trawl sector. In an attempt to discourage bycatch, the NPFMC officially distinguished pelagic trawls from non-pelagic trawls by the number of crabs greater than 38 mm carapace width caught by the trawl. Onboard observers, therefore, determine whether the trawl is operating in pelagic or non-pelagic mode and assign the catch against the appropriate TAC accordingly. Because the non-pelagic trawl was assigned only a small portion of the TAC, industry soon adopted the pelagic fishing method to harvest pollock. Ultimately, with industry support, NPFMC banned bottom trawling in the Bering Sea pollock fishery in 1999 (NRC, 2002). While the original concern was bycatch of shellfish and groundfish, the resulting pelagic trawls for pollock probably have benefited the seabed and the benthic ecosystem by reducing or eliminating the contact between the trawl components and the sea seabed. Although the pelagic trawls may still have occasional bottom contacts, they are generally much lighter and less intrusive to the seabed.

8 Gear Modifications to Reduce Seabed Effect

Gear modifications to achieve ecosystem objectives including reducing seabed impact has been discussed by Carr and Milliken (1998), Valdemarsen and Suuronen (2003), Rose *et al*. (2000), and CEFAS (2003). These modifications include reducing weight of groundgear, reducing door bottom contact (e.g. semi-pelagic trawling), using exit openings or drop-out areas for benthos and bycatch species, as well as "sweepless" trawls with drop chains and no groundgear. The following sections describe some recent experiments on mitigation measures in various mobile gears.

8.1 Experiment on lighter groundgear in the offshore shrimp fishery off Labrador

In 1999, 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 (He and Foster, 2000). The project involved in model testing and sea trials to investigate whether seabed contact of the existing shrimp trawl could be reduced through a reduction of the number of footgear bobbins, without significantly altering the engineering and catch performances of the gear. The fishing gear tested was a three-bridle Skjervoy 3600 shrimp trawl with 31 bobbins of 24" and 21" diameter. The full footgear weighed 5,698 kg in air and 2,984 kg in water. The modified 9-bobbin footgear weighed 2,187 kg in air and 1,306 kg in water.

The total area of the contact was calculated from the width and the number of bobbins in the groundgear. The percentage of altered area was defined as the ratio of total contact area to the swept area between the wings. Analysis showed there were no measurable changes in the geometry or stability of the trawl when the number of bobbins was reduced from 31 to 9. The number of tracks left on the seabed by the bobbins was reduced and the total altered area was reduced by 70% when the number of bobbins reduced from 31 to 9.

Sea trials were conducted during a commercial fishing trip of M/V "Newfoundland Otter", a 60-m shrimp factory freezer trawler. A full set of Scanmar trawl monitoring devices including a Trawleye Netsonde were used to monitor gear geometry and seabed contact. The fishing trials were carried out in Shrimp Fishing Area 5 off Nain on the Labrador coast in the northwest Atlantic. Fishing was conducted at depths between 270 m and 367 m.

A total of 17 tows were completed targeting the pink shrimp (*Pandalus borealis*). There were no clear differences in catch rates between the control gear with 31 bobbins and the experimental gear with less number of bobbins. Under good sea and ground conditions, the nine-bobbin rig provided enough weight to keep the groundgear steadily on the seabed. However, on adverse sea and ground conditions, the lightweight experimental gear resulted in poor seabed contact. Although poor seabed contact is generally believed to negatively affect shrimp catch rates, no clear relationship was demonstrated between seabed contact and catch rates during the experimental period. Gear damage occurred in the experimental gear mainly at the location where the seabed was rough and underwater current was strong.

In summary, the number of bobbins on the Skjervoy 3600 footgear of an offshore trawler may be reduced to as few as nine without significantly altering geometry and stability of the trawl. The nine-bobbin rig would only alter as little as 4% of the seabed between the wingends, a five-fold reduction when compared with the area of seabed likely altered by the 31-bobbin control gear. Preliminary sea trials indicate that the footgear with less number of bobbins may result in footgear intermittently off bottom, but this may not necessarily result in catch reduction. The trawl with less number of bobbins was more likely to incur damage, especially on grounds with rough sea and bottom conditions.

8.2 Semi-pelagic shrimp trawling in the Gulf of Maine and off Newfoundland

Bottom trawls were developed for harvesting groundfish species during the turn of the twentieth century. Sand clouds stirred up by the doors and bridles herd fish toward the mouth of the trawl. Shrimps, on the other hand, could not be herded by sand clouds and bridles due to poor swimming ability and inability to react to fast moving trawl components. The mouth area of a shrimp trawl therefore determines, to a large extent, the amount of shrimp caught. Therefore, a trawling system with the trawl doors off bottom and the trawl on the bottom should not reduce the capture efficiency of the gear, but it would reduce the disturbance of seabed by the doors.

Two parallel projects to test feasibility of a semi-pelagic shrimp trawling system were carried out in the Gulf of Maine and in two locations off Newfoundland (He *et al*., 2002; He and Littlefield, 2003; DeLouche and Legge, 2004; He and DeLouche, 2004). In both experiments, the primarily control of the door height off the seabed was achieved through the shortening of warps and monitored through the use of door height monitoring devices. Even though there were reports of the "active" trawling devices which control the height of the trawl through variable thrust vector devices to spread the trawl without doors (Shenker, 1995; 1996; 2004), this technology was not commercially available. High lift coefficient and high lift-to-drag ratio Poly-Ice® El Cazador doors were selected for the project. In the Gulf of Maine experiment with a 55' vessel, a pair of 1.9 m^2 door weighing 240 kg in air was used. In the Newfoundland experiments with 65' vessels, 2.8m^2 (550 kg) and 3.6m^2 El Cazador doors (850 kg) were used.

The height of doors was monitored by height sensors in the real time. When the trawl was towed on a straight track, the doors could be kept off the bottom with shorter warps. However, when the gear was towed in a curved track, one of the doors on the inside of the curve would fall down to the bottom, while the other would be lifted to a higher point in water column. After 38 tows fishing in the Gulf of Maine in 2003, only about one-third of the door shoes were polished, indicating very light and intermittent contacts during turning and depth changes.

In the 2003 season in the Gulf of Maine, the amount of shrimp caught by the experimental trawl operating in semi-pelagic mode was comparable to catches by commercial vessels fishing with regular bottom shrimp trawl on the same grounds. In the 2004 trials, however, tow-by-tow comparisons indicate that the experimental gear had a lower catch rate than the commercial gear. There were a few experimental tows where the experimental gear was not tuned properly for the depth, resulting in very low catches. When properly tuned, the experimental gear with doors off the bottom caught as much shrimp as the commercial vessels with doors on the bottom.

On the west coast of Newfoundland the door spread with the high aspect trawl doors was 17% higher than that of the bottom tending doors. While more tows are needed to quantify the differences, catch rates of three tows using semi-pelagic doors were higher than those of four tows using bottom doors in the west of Newfoundland. On the east coast of Newfoundland, the mean catch rate when the doors were rigged to fish off the bottom was less than those tows when the doors were on the bottom. In the later case, differences in catch rates were probably from a large tow at the end of trials.

Results from both the Gulf of Maine and the Newfoundland experiments were preliminary. It did demonstrate potential of semi-pelagic trawling for shrimps if the door height and the groundgear bottom contact can be better controlled. Semi-pelagic trawling with doors and bridles off the bottom may also reduce herding of fish by these trawl component, resulting in reduced fish bycatch. Further experiments are required to design a more robust semi-pelagic trawling system.

Use of high aspect pelagic trawl doors may also reduce seabed impact even if they are on bottom. Hydrodynamically efficient doors typically have a narrow width and operate at a lower angle of attack, leaving a narrower "footprint" compared with traditional bottom doors (Goudey and Loverich, 1987; McCallum, 2001). High aspect trawl doors also reduce the bottom contact of bridles by keeping a large proportion of them off the seabed.

8.3 Drop-out panels to reduce benthos catch in beam trawls

The Belgium, Dutch and British researchers have been working on drop-out zones and escape belly panels in their beam trawls to reduce catch of benthos and seabed materials in the frame of the EU FAIR project "Reduction of Adverse Environmental Impact of Demersal Trawls (REDUCE)" (van Marlen, 2000; Fonteyne and Polet, 2002; Polet, 2003).

The Belgium tests included escape zones (square mesh, diamond mesh, or opening without netting) just behind the fishing line and square mesh panels (120 mm, 150 mm and 200 mm mesh size) just ahead of the codend (Fonteyne and Polet, 2002). Sea trials were conducted on these designs on board R/V "Belgica". Results showed that escape openings just behind the fishing line were not effective in releasing benthos and an unacceptable loss of commercial catch was experienced. Similar results were obtained in the Dutch experiment on similar designs (van Marlen, 2000). On the other hand, square mesh after-belly panels tested in Belgium beam trawls significantly reduced benthos by 64 to 83%, with larger mesh (200 mm) resulted in larger reduction. For commercial species, the square mesh panels produced a mixed result with some species experienced reduction while other increased in catch.

Studies undertaken in the UK using benthic drop-out panels in the English Channel beam fishery have been conducted since 2002. A variety of square mesh drop-out panels have been evaluated (n=8). Square mesh panels of 140–150 mm full mesh fixed into the belly of a beam trawl just a few meshes in front of the codend joining round, have proven to be the most effective, similar to Belgian findings mentioned above. Around 80% of unwanted benthic invertebrates are typically released from the beam trawls fitted with drop-out panels and escapees exhibited a high survival rate. No loss of target species was observed with this simple technology and the panels have been piloted by one vessel for extended periods on a voluntary basis without technical problems. Fleet trials on a wider scale are to be initiated throughout the Channel beam trawl fleet of the UK.

8.4 Sweepless trawl for whiting in the Gulf of Maine

The groundgear is called the sweep in the northeastern US. In keeping with the established name of "sweepless trawl", the word "sweep" is used instead of "groundgear" in this section.

The "sweepless" trawl was modified from the "raised footrope" trawl which was developed for the Gulf of Maine silver hake *Merluccius bilinearis* to avoid catching flatfish and other bottom-dwelling organisms by raising the height of the fishing line by about 0.5 m above the seabed (Pol, 2003). In the raised footrope trawl, the fishing line was raised by the attachment of a sweep chain equal or shorter than the fishing line by a number of drop chains of about 1 m long. The sweepless trawl, as the name implies, has no chain sweep. Additional weight to replace the weight of the chain sweep was provided either by increasing the link size of the drop chains, or by hanging two chains at each attachment point.

The raised footrope trawl has been very successful. A fishery for silver hake was re-established by mandating the raised footrope trawl, and the gear was popular with the fishing fleet before it became mandatory. However, the sweepless trawl represents several improvements over the raised footrope trawl. It is easier to rig and to enforce because it is a simpler design. It is less likely to become entangled with ghost gears or other debris, which is a major cause of unwanted bycatch when using the raised footrope trawl. Most importantly, the sweepless trawl has less impact on the sea floor, because contact is reduced to a limited number of points, instead of the whole length from one wingend to the other wingend.

Some fishermen have adopted the sweepless trawl because of these advantages. However, voluntary adoption has been limited, partly due to concerns about loss of target species. Quantitative analysis of catch and bycatch between the two types of trawls has been inconclusive due to high catch variability. Nevertheless, analysis of catches of one vessel that adopted the sweepless trawl indicated that it performed as well as or better compared to the reported catches of other vessels using raised footrope trawls.

An outreach programme to encourage voluntary adoption of the sweepless trawl resulted in limited success. Effort is continuing to promote the use of the sweepless trawl. Reduction of sea bottom impact should result from increased voluntary use of the sweepless trawl. However, substantial reduction of the bottom impact of trawl nets in this fishery will only result if use of the sweepless net is made mandatory and is adequately enforced

8.5 Other Developments

Tickler Brushes: A tickler chain is commonly used in the Faeroe Islands flatfish fishery. A project was developed to reduce sea bottom impact of the tickler chain by replacing it with tickler brushes (K. Zachariassen, unpublished). Tickler brushes were made of nylon, cylindrical in shape and 15 cm in diameter. Alternate tows were conducted to compare the tickler brushes with traditional tickler chains. Filming was used to compare bottom impact by the presence or amount of sand clouds behind the brushes or chains. The brushes were found to drastically reduce suspension of sediments while maintaining catches of target species.

Roller Gear: Rockhopper groundgears are typically used in Faeroe Island trawl fisheries. To reduce the bottom impact caused by the rockhopper gear, it was replaced with several different configurations of wheels, or rolling gears (K. Zachariassen, unpublished). The object was to develop modifications that could roll in the towing direction. Several configurations were tested, starting with pairs of rubber disks mounted on an axle and attached to the fishing line at a fixed angle. These pairs of discs tipped over easily due to tidal currents, and were unacceptable. The most successful rolling gear consisted of a single 22 cm wide rubber disk 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 height of the wheels. In this configuration, each wheel can rotate independently, and maintain orientation in the towing direction.

Testing of this rolling gear showed a reduction in target species compared with the rockhopper gear, but it showed clear reductions in sand clouds as documented by video recordings. The design seemed to be workable and practical, and further tests are planned.

Similar experiments on roller groundgears are being carried out in Norway (E. Grimaldo, unpublished).

Weighted Rollers: An experiment was conducted to investigate whether the rubber ground gear or bobbins of an otter trawl could be replaced with a series of weighted rollers (Ball *et al*., 1999). The purpose of the design was to allow the trawl to move over, rather than plough through, the seabed. The action of the rollers appears to stimulate fish to rise off the seabed, eliminating the need for tickler chains. Preliminary fishing trials indicated no reduction in commercial catch. Due to reduced ground fiction, there is potential for a reduction in fuel consumption during trawling.

9 Use of Alternative Stimuli in Beam Trawls and Dredges

Electrical stimuli were tested in the Netherlands for beam trawls targeting flatfish (van Marlen, *et al*., 2001b) and in Belgium for beam trawls targeting shrimp (Polet *et al.*, submitted). The purpose was to reduce the catch of benthos and other discards while maintaining commercial catch. In the US, acoustics and electrical stimuli were investigated as a possible means to modify toothless dredges targeting sea scallops (Pol and Carr, 2002).

9.1 Experiments on electrical stimuli in flatfish beam trawls in the Netherlands

In the Netherlands, four gear tests were carried out in 1999, and a comparative study into direct mortality of invertebrates was conducted in 2000. The 7 m prototype pulse trawl was developed by Verburg-Holland Ltd., and tested thoroughly in 1998 and 1999 (van Marlen *et al*., 2001b). The gear was scaled up to 12 m and re-designed to ease production and to reduce costs in 2000. The experiments are continuing at present with promising results.

The area chosen for the direct mortality study was the Oyster Ground in the North Sea. The methodology is described in Bergman and van Santbrink (1994) and Lindeboom and de Groot (1998). A significantly lower direct mortality of 15 species was found in the 7 m pulse beam trawl compared to the conventional beam trawl. Benthos catches were about 60% in weight compared to the conventional trawl and fewer infauna were caught (van Marlen *et al*., 2001a, b).

The total catches of the pulse trawl for all commercial marketable sized species were about 70% of the conventional beam trawl, but the pulse trawl caught about the same amount of sole. Only about 50% of commercial size plaice were caught in the pulse trawl compared to the conventional gear.

The 7 m pulse beam trawl caught 45% less benthic invertebrates per hour than the conventional 7m tickler chain beam trawl, when all benthic species were added together. Considering individual species, however, only in a few cases was the difference significant, e.g. for whelks and sea mouse. Addition of one tickler chain to the pulse beam trawl increased overall catch of invertebrates. The catch rate of invertebrates was increased from 45% to 76% of the catch with conventional gear. Catches of swimming crabs, hermit crabs, and *Luidia* were significantly higher in the pulse beam trawl, while catches of infaunal species such as sand star and edible crab were much less.

In conventional 7 m trawl tests, invertebrate species showed mortalities from 17% (edible crab) up to 80% (quahog). Hermits, masked crab, prickly cockle, and swimming crab showed short term discard mortalities of 64%, 64%, 32%, and 45% respectively. In catches of the pulse beam trawl, the mortality of hermit crab (without shells) was reduced to 38%, and masked crab to 44%.

9.2 Electric pulses as an alternative stimulus for brown shrimps

A study was conducted to determine the feasibility of electric pulses as an alternative stimulus for brown shrimp (*Crangon crangon*) in an effort to improve the selectivity of the shrimp beam trawl and reduce bottom contact of the groundrope and thus seafloor disturbance (Polet *et al*., submitted).

In a first phase of the project, detailed observation and survival tests were carried out. The results showed that brown shrimps reacted strongly to electric pulses. The optimal pulse amplitude was between 40 and 110V for 50 cm electrode spacing. Both higher and lower voltage has a negative effect on the response of shrimps. Though the pulse frequency had only a minor effect on the maximum response of shrimps, the frequency was closely related to energy consumption of the underwater apparatus. The startle response for small shrimps was slightly lower compared to that of large animals. Both a higher water temperature and a low light intensity resulted in a stronger response. The maximum response was usually obtained within 4 s after the start of the pulses.

Fish and other invertebrates, with the exception of dab and sole, showed weak responses to the pulses. If a reaction was observed, the animal kept staying close to the bottom. This means that, in principle, species selective fishing for brown shrimps should be possible with electric pulses as an alternative stimulus.

The sea trials demonstrated potential for a species-selective and benthos-friendly electro-trawl without loss of commercial shrimps. The raised groundrope design of the electro-trawl created an escape route for most of the discard species regularly caught in shrimp trawls including benthos. The electric field made shrimps tail-flip high enough to be caught.

Future work will include the design of an electro-trawl with a larger net opening to fit longer electrodes and a new type of bobbin rope with less bottom contacts. It seems that electric trawl can be a feasible alternative to the standard shrimp beam trawl and could be an acceptable alternative between the economic interests of the fishermen and the ecological demands of the marine ecosystem.

9.2 Acoustical and electrical stimuli for scallop dredges

Pol and Carr (2002) tested acoustic and electrical stimuli for sea scallop *Placopecten magellanicus* and bay scallop *Argopecten irradians* aimed at reducing dredge weight and penetration of the seabed. The study was initiated to develop an alternative stimulus for catching scallops. Bay scallops were observed swimming up into the water column following the passage of a boat with an outboard engine. Based on multiple observations of this phenomenon, bay scallops and sea scallops, in the field and in captivity, were exposed to selected frequencies, recordings of engines, and the original engine-type that produced the phenomenon.

Testing of reactions of scallops to acoustic stimuli resulted in inadequate reaction to justify further development. Efforts with electric pulses resulted in a workable and safe dredge design. The experiment on the use of electric pulses to stimulate scallop is being continued.

10 Novel Systems in Development

10.1 The “Active Trawl” system and “Auto-trawl” system

The concept of the Active Trawl System was developed by Shenker (1995; 1996) to overcome difficulties in improving performance of trawl doors and active control of the doors. The Active Trawl System expands the trawl by using “variable thrust vector devices” (VTVDs) powered from the ship. VTVDs are based on the “Magnus Effect” - towed rotating cylinders generate side forces perpendicular to the axis of the cylinder. The system can have a “bottom-contour (bottom-hugging) mode in which the VTVD's maintain light contact with the bottom or operate at a set height above the sea bed” (Shenker, 2004). This product is still in the developmental stage. Successful application of this technology may result in a doorless "otter" trawl for certain fisheries. It should be noted however that sand clouds from doors digging into the seabed play a significant role in herding groundfish species.

Similar development using acoustic control of the trawl door's vertical and horizontal positions has been carried out by Scanmar, a Norwegian acoustic gear monitoring equipment company (CEFAS, 2003). This is a part of more comprehensive research and development programme called "Auto-trawl" system. It is reported that the position of doors is controlled by acoustic manipulators fitted onto the doors. Detailed information is not available due to the nature of private industry research.

9.2 Use of kites, depressors and other flexible devices in trawls

The use of kites or other flexible devices as depressors and/or expanders of the trawl has been investigated to reduce weight of the gear and/or eliminate the use of trawl doors (Goudey, 1999). A narrow fabric depressing panel was installed between the fishing line and the footgear. Kites were also installed at various locations in the trawl including the square, and the adjacent side panels, mid belly, and in the rear part of the trawl. Parafoil trawl doors were also tested to replace traditional doors. Comprehensive flume tank tests were performed for various designs, but no sea trials were carried out.

Canvas footgear depressors were seen to function well in tank tests, providing sufficient downward force to keep the trawl on bottom. However, due to the soft material of the depressors, damage would be experienced if they touch rough seabed. The "self-spreading" groundgear being developed by SINTEF and IMR, Norway may overcome this problem (SINTEF, 2004). In this design, a series of rubber plates were hung under the fishing line. In flume tank tests and in half-scale field tests, increased wingspread (15-20%) was observed with this arrangement in comparison with typical rockhopper gear. This increased spread from the ground gear suggests that the 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 be less disruptive to the bottom and may produce less suspension of bottom sediments. Rockhopper gears were observed to react to obstructions more dramatically. A third possible reduction of impact may result from increased efficiency of this gear. Escapement of fish under the rockhopper gear has been observed to exceed 50% in numbers. With the self-spreading groundgear, little or no escapement was observed. While cautions should be taken to evaluate size selectivity of the trawl with the self-spreading groundgear, the observation suggests that in output-controlled fisheries, dramatic reductions in towing time and area swept may be possible using spreading ground gear. Further field testing of a full scale design is scheduled for May 2004 in cod and shrimp fisheries.

11 Conclusions and Recommendation

The following conclusions and recommendations were reviewed and approved by WGFTFB on April 23, 2004.

- Bottom-tending mobile gears have an effect on the seabed. Impacts are poorly understood and documented in many fisheries. Research into fishery-specific impacts on the seabed must continue.
- The group has identified a number of technical measures available or in development, such as semi-pelagic trawls, drop-out windows and electrical stimuli in beam trawls, and ground gear modifications. Many of these offer potentially powerful means of mitigating seabed impact. These research and development efforts should continue with an additional focus on their commercial application.
- The measures identified largely reduce apparent impact but few studies include quantifiable measurements. Seabed impact indicators are needed to help gear technologists to evaluate the effectiveness of mitigating measures. WGFTFB should seek advice and input from other groups such as WGECO to define practical indicators of seabed impact in different fisheries.
- In a strictly-enforced output-controlled management regime, impacts on the seabed can be reduced through the development of methods that improve efficiency, such as detailed mapping and changes in fishing practices.
- Techniques for the mitigation of seabed impacts by mobile fishing gears outlined in this report are intended as a review of the current state of knowledge. Progress in assessment and mitigation of bottom impacts should be evaluated and reported to WGFTFB on a regular basis.

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Annex 2: A Review of the Experimental Work Conducted Concerning the Cod-End Selectivity for Cod in Cod-Ends Made from Netting Turned 90^0

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Introduction

The idea of the Turned-meshes type of codend (Figure 3) originated in Poland (Moderhak, 1997). However, investigations concerning codends with meshes turned through 90^0 have also been carried out in several other Baltic countries. First a Polish and from 1998 on a German-Polish researcher group made experiments with this type of codend. Sweden and Denmark have also tested these types of cod codends in recent years, although to a more limited degree. In Denmark, a model of a codend with meshes turned through 90^0 was made and tested along with model investigations of various cod codends in the DIFTA flume tank in Hirtshals, as will be presented in one of the contributions to this topic today. Investigations of a cod codend with meshes turned through 90^0 and other codend types were carried out during commercial catches in Sweden in 1997 as part of the EU- Bacoma project. However, these experiments were discontinued, despite of a rather positive summary in the first interim report of the BACOMA-project.

To date turned meshes codends have been tested in two configurations:

a) codends (codend and a extension) made entirely of the turned material, directly attached to the end of the belly (Poland, Denmark-codend model),

b) codends with turned meshes attached to an extension made of standard diamond meshes (Germany, Sweden).

A choice of available selectivity data concerning this type of codend has been evaluated prior to last years FTFB-meeting and was presented during this event. The Working Group "noted with interest the positive developments in the use of turned mesh codends". However, the Working Group concluded that did not feel in the position to estimate from the available data an alternative mesh opening to the Bacoma 120 codend and recommended the additional use of commercial vessels, a broader range of mesh sizes, twine thicknesses and meshes in the circumference for further experimental work. A repetition of the evaluation during the next annual meeting was envisaged.

Thus, the terms of reference for the present meeting say: "Unintentional mortality of juvenile cod continues despite the recent increase in minimum codend mesh size to 140 mm for commercial bottom trawling in the Baltic Sea. Experiments on trawls equipped with turned-mesh codends indicate that size selection is more nearly knife-edged and, therefore, like the size selection by the BACOMA- window, easier to control to obtain better escapement of sub-legal fish. Considering the current crisis in the management of Baltic cod, review of the selective properties of turned-meshes codends is critically important"

It would be presumptuous to expect under the current restrictions to carry out experiments that the recommendations of the WGFTFB from summer 2003 could fulfilled completely until spring 2004. This is certainly a more long-term work plan. What could be and has been done is data mining to get together every possible piece of information on turned meshes and the application of more advanced statistical techniques onto the total data collection

Methodology

Amount and Origin of data

Data of 161 hauls in total were collected in a data base comprising 28 experimental conditions and further derived results. The data originate from the period 1998-2003. They were so far collected only on German and Polish research vessels of the sterntrawler type, only in ICES area 24 and only from bottomtrawl catches. A depth range of 21 to 98 m is covered. Towing times vary between 64 and 363 min. The catches of cod in the main trawl vary between 11 kg and 1118 kg with a mean of 187 kg, bycatches of flatfish .between 0 and 521 kg with a mean of 57 kg. Most data originate from PE codends made of single yarn 4 mm. The circumference of the codend is in most cases 90 # or higher. Only the covered codend method was used to determine the selectivity

Evaluation

Before compilation of the data all measured mesh openings were transferred to wedge mesh opening, though most of them had been taken with an ICES mesh gauge. The selectivity parameters stored (L50, SR) are the result of a maximum- likelihood estimation of the best fitting logistic function to the raw data.

Results

A first quick screening of the selectivity factors stored for each of the 161 cases without taking regard to any particular maybe influential variables shows a mean value of 3,65 with a standard error of 0,24 (Figure 4).

A linear regression of L50 against wedge mesh size (Figure 5) measured under the same conditions results in a clear positive correlation and a relatively narrow 95% confidence band. However, due to the unbalanced nature of the data collection (much more data in the lower range of mesh openings) it seemed worthwhile to do a variation component analysis.

This has been done externally by a specialist from the Hamburg University. His detailed statement is given in Annex 1.

Discussion

From this evaluation it becomes first of all clear that principally codends of meshes turned 90° belong to a class of codends which with regard to their selective properties are distinctly positively separated from other codends made of diamond meshes. However, a high variability of the results cannot be neglected if specific influential factors are left out of control or are not optimized. As one would expect from any codend without any strict regulations of specific features. If the interpretation is correct, the statistical analysis described in Annex 1 has identified by the preferable random forest technique the following factors in their order of significance as important:

Wedge mesh opening, Twine size of codend, Yarn Construction, Material of codend, circumference of codend, Material of extension, Mesh orientation of extension, Month year, Depth, tow duration, tow speed, wind force, Total catch. Codend, catch of Cod in codend, Bycatch of flatfish

Only the first seven of them are either quantitatively important enough or controllable to be taken into regard in future investigations. As the first and the second factors are now common to be regulated and the circumference of the codend, too, it can be derived that now material and yarn construction should get prime attention in future experiments. Most recent experiments in the last cruise of the research vessel underline the importance of this statement

A few words to an additional aspect raised during last years meeting. There the importance of performing the experiments on commercial vessels has been stressed to a degree which is debatable. First of all there is no scientific evidence at all, that selectivity results from commercial fishing vessels are distinctly different from those obtained on a research vessel. The recommendation given in the manual for selectivity research is therefore rather weak and not strict as averred during last years meeting. Secondly, research on commercial vessels has usually much more restrictions as it has on research vessels. Being included into the production process of a commercial good means being forced to subsampling with all its inherent error possibilities and leaves no extra time for e.g. having a look on the codend with underwater observation devices. There is no doubt that work on the research vessel should follow commercial catching procedures as closely as possible. And without doubt it is also necessary to check from time to time if the results obtained are still comparable to what one would get on a commercial boat. This has been done over the years with "Solea" again and again and no particular bias for using a research vessel has been found.

One might ask whether there is a real need to continue with this research on turned-mesh codends or if it is a pure academic exercise in account of the fact that now with the Bacoma codend a codend with significantly improved selective properties is introduced. We do believe that this necessity still exists.

- With the decision to introduce the Bacoma codend as sole legal codend a dependency on a monopolist producer was established which with regard to price and minimum purchase is never a favourable economic condition.
- The long-term behaviour of the window material is unknown and, according to an increasing number of fishermen detected with too small window meshes, might be good for a surprise.
- Details of carrying out repairs or attaching sensors or lifting straps which might have an effect on the selectivity of the window have neither been investigated before nor regulated. The EU-Commission is just now trying to fill these gaps.
- Bacoma codends can be manipulated as other selective devices. It is always a challenge for cheating to concentrate the selective parts of a codend in particular sectors. Up until now there are several methods known to suppress the effect of the selective window.

A turned-meshes codend would do away with some of these problems

- It consists of material available everywhere

- From commercial trials undertaken in Poland (see below) there is no evidence for a decrease of better selectivity over time
- The repair technology of diamond netting is well known and if performed correctly will not affect the selectivity
- A turned meshes codend offers escape possibilities over its whole length.

With regard to the applicability of such codends in normal fishing practice the following might be of interest: Since three years the turned meshes codends are tested on two Polish fishing vessels aiming to check: as well the usefulness for commercial fishing as to collect data of undersized cod retention. During about 550 fishing days (more than 6500 hours of towing time) more than 400 ton of cod were caught

According to the participating fishermen and netmaker the wear of the turned codends netting is the same as that of standards diamond codends. The positive selective and protective properties of the turned codends remained the same during the exploitation

Conclusions

- Codends of turned-mesh netting are even after this evaluation an interesting alternative to the presently legal Bacoma codend.
- They have demonstrated their practical usefulness in commercial fishery over a longer period
- The analysis presented has revealed in particular a not negligible influence of material, yarn size and construction which ought to be investigated ceteris paribus in greater detail.
- In account of this a legal introduction should not be hurried but ought to include results of related research

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Annex 1

Regression analysis of E. Dahm's fish selection data

Hennig, C.*

15 April 2004

1 Data used for the analyses

The following data have been used for the analyses: As dependent variable, L50 was used (all variable names as in the file you sent me). As predictors, from our discussion the following variables have been considered:

- Wedge.mesh
- Twine.size
- Construction
- Material
- Meshes.round
- Ext.twine.size
- Material.1
- Mesh.orient.
- Vessel.hp
- Monthyear (only month information has been used)
- Depth
- tow.duration
- tow.speed"
- wind.force
- Totalcatch.Codend
- Cod.codend
- Bycatch. Flatfish

All cases including missing values have been discarded. This reduced the sample size from 161 to 143, which seems to be tolerable (however, an improved analysis could be possible by use of imputation techniques for the missing values). The following variables have been discarded after inspection of the data: Ext.twine.size (because its information is identical to Material.1), Vessel.hp, because its value does not vary in the 143 "clean" cases.

Of the 15 remaining variables, Material and Material.1 have been removed from the linear regression analyses (but not from the other analyses), because of linear dependencies with other variables (presumably Construction and Month). The variables Construction, Material, Material.1 and Mesh.orient. have been treated as factors, not as numerical values (except for the MARS analysis, which does not accept factors). The variables Totalcatch.Codend, Cod.codend and Bycatch. flatfish have been incremented by 1 and the (natural) logarithms have been taken to reduce the influence of the skewness of their distributions.

2 Regression methods

The following regression methods have been compared:

<u>Linear regression/ANCOVA</u> Three versions of linear regression/analysis of covariance have been tried:

- full model, i.e., all 13 variables,
- variables selected by stepwise regression with Akaike's Information Criterion (AIC),
- variables selected by stepwise regression with Bayesian Information Criterion (BIC).

The BIC penalizes the number of parameters more strongly and leads generally to models with fewer variables (AIC 11 variables, BIC 6 variables for the full data). Wedge.mesh, the predictor variable of primary interest, has always been selected.

Regression trees The principle of regression trees is to look for a sequence of splits of the predictors so that all resulting "leafs" are as pure as possible (i.e., minimum variance) with respect to the dependent variable. For example, for the given data, Wedge.mesh is chosen as the first variable and split up at 108.8. Now there are two nodes, one consisting of the points to the right, the other consisting of the points to the left of the cut point. It is now looked for optimal splits (new or the same variables, new cut points) in these nodes. After some stopping criterion is fulfilled, prediction is done by determining the "leaf" (terminal node) for each point and predicting it by the mean of the training data in this leaf. Compared at least with MARS and the random forest, the prediction rules generated by the tree are easily communicated and interpreted. Trees treat factors in a sensible way and are in principle able to cope with missing data without using imputation (I have not done that, though).

Three versions of regression trees have been tried:

- a tree on the full data set (15 variables),
- a linear regression of L50 on Wedge.mesh and a tree (with 15 variables) applied to the residuals of this regression,
- a linear regression of L50 on Wedge.mesh and a tree (with 14 variables, excluding Wedge.mesh) applied to the residuals of this regression.

Random forest A disadvantage of regression trees is that the results (selected variables) are often somewhat unstable in the sense that small variations in the data may lead to a very different tree.

The principle of the random forest is to build a lot of (500, say) restricted trees (only a randomly selected subset of the variables is allowed for each new node construction) and to predict new cases by averaging over the trees. This has been shown theoretically to reduce the variance of the predictions and to improve the precision in many situations. The disadvantage is that the result is no longer that easy to communicate. Three versions of the random forest have been tried:

- a forest on the full data set (15 variables),
- a linear regression of L50 on Wedge.mesh and a forest (with 15 variables) applied to the residuals of this regression,
- a linear regression of L50 on Wedge.mesh and a forest (with 14 variables, excluding Wedge.mesh) applied to the residuals of this regression

Table 1. MSE of all methods over ten times a 10-fold cross-validation.

Method	MSE
Forest(residuals, 15 var.)	2.364769
Forest(full data)	2.526971
Forest(residuals, 14 var.)	2.541065
Tree(full data)	3.218533
Tree(residuals, 15 var.)	3.32208
Tree(residuals, 14 var.)	3.63859
Linear(full model)	3.798893
Linear(AIC)	4.002467
Linear(BIC)	4.126437
MARS	5.076639

Multiple additive regression splines (MARS) MARS estimated a linear model which is made up by piecewise linear variables, which correspond to the original variables and are constant 0 to the right of some cut point and linear in the original variables to the left. Also products of such variables can be added to the model. Optimal variables and cut points are chosen in a stepwise manner similar to the regression tree method. The resulting models are continuous and much more flexible than both trees and linear regression.

All methods are described in Ripley (1996) except of the random forest, for which the standard reference is Breiman (2001a).

3 Comparison of methods

The quality of the regression methods has been compared by ten runs of a 10-fold cross validation. For a single 10-fold cross-validation, the data is split up into 10 parts of equal size. The algorithms are then run ten times, and in every run one of the parts is left out. The resulting model of the algorithm is then used to predict the points that have been left out, and the mean squared error on these points is computed to assess the quality of the algorithm. This procedure has been performed on ten different partitions of the data into 10 parts, i.e., every regression method has been applied on 100 data subsets of 9/10 of the size of the whole dataset. The mean squared errors averaged over all 100 runs are shown in Table 1.

The results can be interpreted as follows: The random forest yields the best predictions. However, the random forest may not be desired because of the difficulty to interpret the result and because it is a “black box method” whose predictions can only be calculated by a computer. Furthermore, the algorithm depends on random selections. Thus, the random forest is only reproducible from the same data, if the same random numbers are used (e.g., by manually setting the “random seed”). Arguments in favour of using such complicated computer models are given in Breiman (2001b). The regression tree also outperforms the linear regression methods clearly. It does not seem to be a good idea to run the random forest or the tree on the residuals from a regression on Wedge.mesh without having Wedge.mesh still in the trees. Wedge.mesh turns out to be still an important predictor for the residuals of its own linear regression (cf. the first column in Table 2). This indicates that linearity is not a well chosen model for the dependence of L50 on Wedge.mesh. An improved prediction quality may be possible by applying trees or forests to the residuals of a suitably chosen nonlinear model for Wedge.mesh. The best forest uses residuals from the Wedge.mesh linear regression, and allows Wedge.mesh also to enter the forest afterward. MARS does not perform well and should not be taken. It is somewhat surprising that the full linear regression model outperforms the results from the variable selection criteria AIC and BIC.

The variability in the results can be assessed in Figure 1, where the 100 MSEs of every single run of the methods are plotted. While there is some variation in the results, the tendency that the forests are better than the trees and that the trees are better than linear regression and MARS seems to be stable. Note, however, that the order of the MSE values in Figure 1 is different for every method. The algorithms attained their best results, e.g., for different data splits. Therefore there is more variation in the ranking of the procedures than the plot might suggest. For example, the full tree has been better than the full forest in 15 runs (out of 100), the full linear regression has been better than the full tree in 36 runs (and in 11 runs even better than the forest), and MARS has been better than the full linear regression even in 50 runs.

4 Results and variable importance

The result of the random forest is too complex to be shown. Figure 2 shows the result of the single tree on the full data. The full linear regression looks like this (the AIC/BIC-results indicate that it is not better to remove non-significant variables):

Coefficients:

	Estimate	Std.Error	t value	Pr(>|t|)	
(Intercept)	70.842666	9.565810	7.406	1.59e-11	***
Wedge.mesh	0.204624	0.041151	4.972	2.10e-06	***
Twine.size	-9.863007	2.122928	-4.646	8.34e-06	***
Construction2	3.286322	0.761501	4.316	3.17e-05	***
Construction3	-0.083877	0.677418	-0.124	0.90165	
Construction4	-4.658508	1.480439	-3.147	0.00206	**
Meshes.round	-0.022678	0.013207	-1.717	0.08839	.
Mesh.orient.2	-2.921083	0.669293	-4.364	2.61e-05	***
Monthyear	0.195608	0.090919	2.151	0.03333	*
Depth	0.057536	0.018185	3.164	0.00195	**
tow.duration	0.001829	0.006921	0.264	0.79201	
tow.speed	-2.624214	1.111739	-2.360	0.01977	*
wind.force	-0.070876	0.048838	-1.451	0.14917	
Totalcatch.Codend	-2.817105	0.867793	-3.246	0.00150	**
Cod.codend	1.727926	0.748931	2.307	0.02266	*
Bycatch.flatfish	0.225886	0.213133	1.060	0.29123	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 1.83 on 127 degrees of freedom
Multiple R-Squared: 0.7367, Adjusted R-squared: 0.7057
F-statistic: 23.7 on 15 and 127 DF, p-value: < 2.2e-16

Table 2 shows some information about the importance of the variables. While the selection numbers indicate a relative stability of the chosen variables of trees and linear regression, the differences between the importance statistics for the different methods is remarkable. However, Wedge.mesh is consistently the most important variable. Note that the %IncMSE of the residuals forest indicates that Wedge.mesh is still the most important variable to explain the residuals from its own linear regression, which should not be the case under linearity of L50 in Wedge.mesh.

Table 2. Some variable importance measures: "%IncMSE" is a measure associated with the solution of the random forest (of the full forest and of the forest on Wedge.mesh residuals with all 15 variables, both applied to the full dataset).

Variable	Full forest %IncMSE	Residual forest %IncMSE	BIC selected variables (100 runs)	Tree selected variables (100 runs)
Wedge.mesh	34.966915	27.680521	100	205
Twine.size	3.345204	7.432533	100	0
Construction	11.092340	8.466366	100	0
Material	7.525938	17.536893	n.i.	0
Meshes.round	10.493189	9.698014	86	0
Material.1	4.754318	8.885725	n.i.	0
Mesh.orient.	12.304545	9.177853	100	74
Monthyear	8.033536	6.737759	96	0
Depth	18.803935	17.242544	100	105
tow.duration	8.928899	5.838670	0	1
tow.speed	7.278886	1.991361	96	4
Wind.force	4.155478	3.539159	59	108
Totalcatch.Codend	15.434296	19.751966	100	26
Cod.codend	8.514939	10.987152	94	14
Bycatch. flatfish	21.234127	18.646008	26	93

It gives the percentage worsening of the predictions if the variable would be left out. The BIC selection numbers show how often the variable is selected by BIC/linear regression in the 100 cross-validation repetitions. Note that Material and Material.1 have not been included in the selection process. The tree selection numbers indicate how often the variable is chosen to split a node in the 100 cross-validation repetitions by the regression tree on the raw data. (Wedge.mesh has always been included at least twice, and no variable has been selected more than three times for a single tree.)

To assess the in influence of concrete decisions of producers or fishermen on the values of certain variables such as construction or depth according to the random forest prediction method, "dummy points" with these values and alternative choices and some default values for the other variables should be constructed, and the forest predictions of L50 for these points should be compared (this is possible as well for the other methods).

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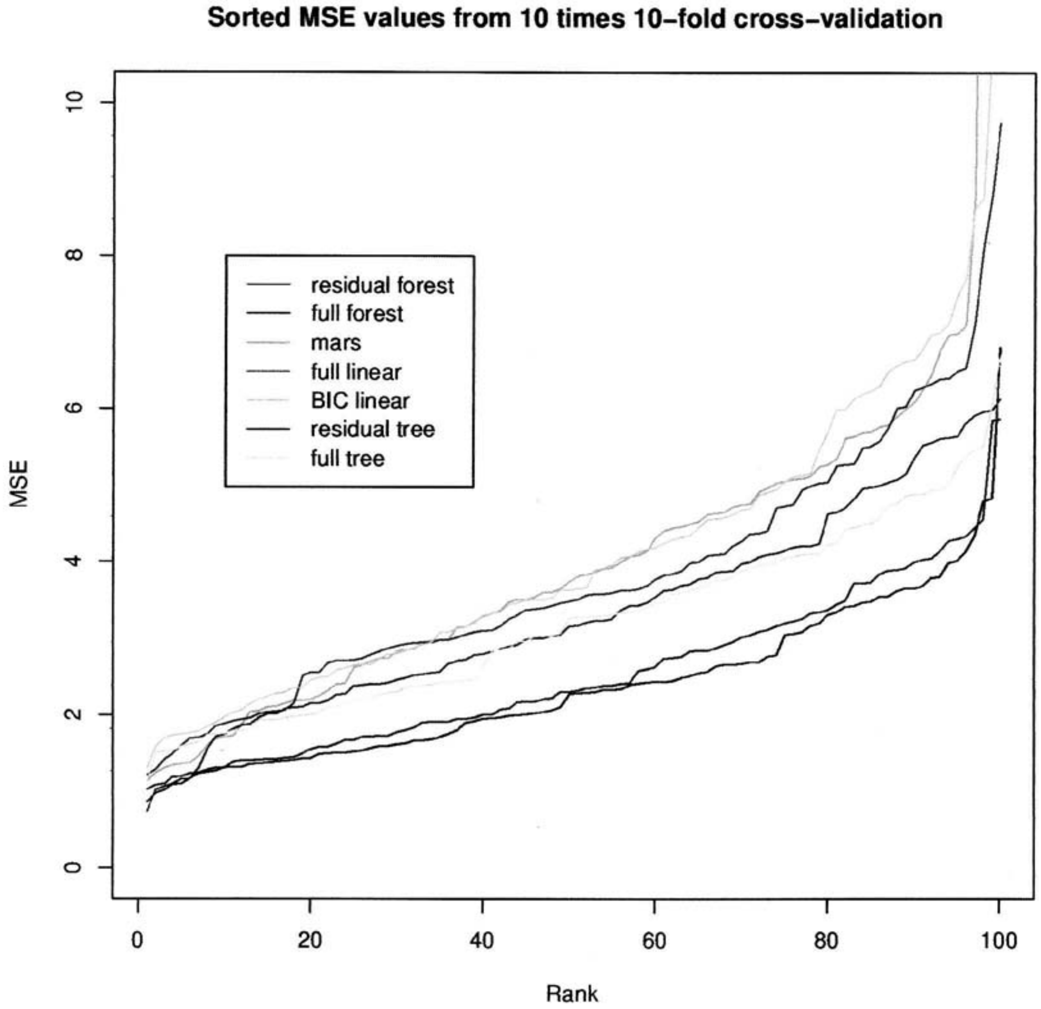


Figure 1: Sorted single MSE values from the 100 cross-validation experiments. Not shown are the forest and the tree on residuals with 14 variables and the linear regression with AIC.

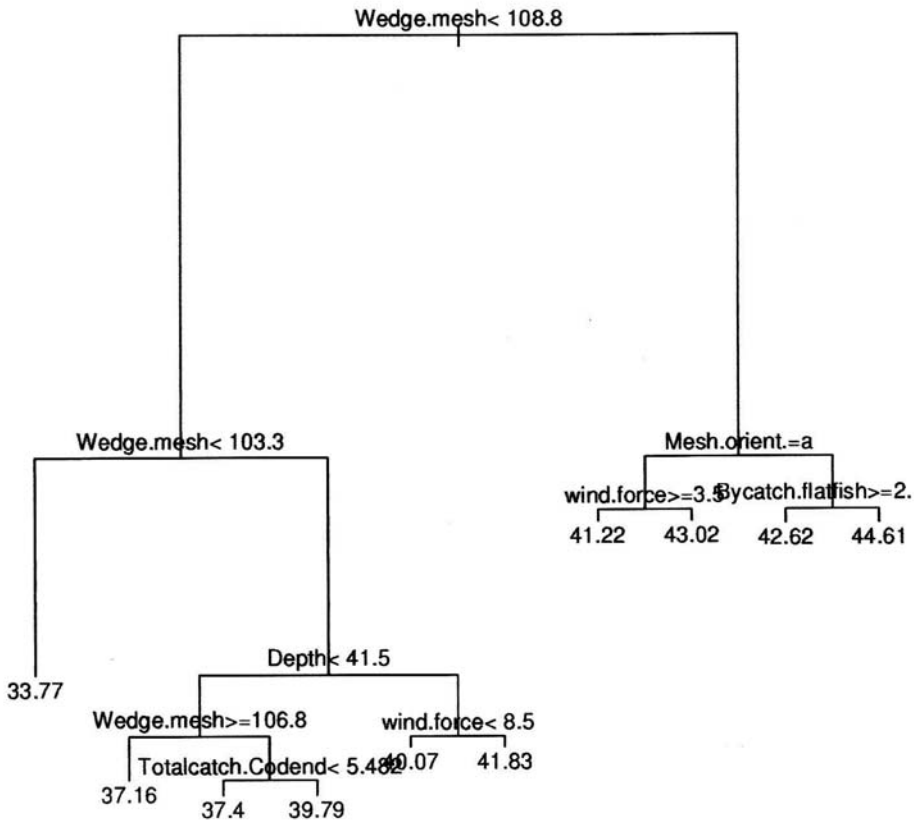


Figure 2: Regression tree on the raw data.

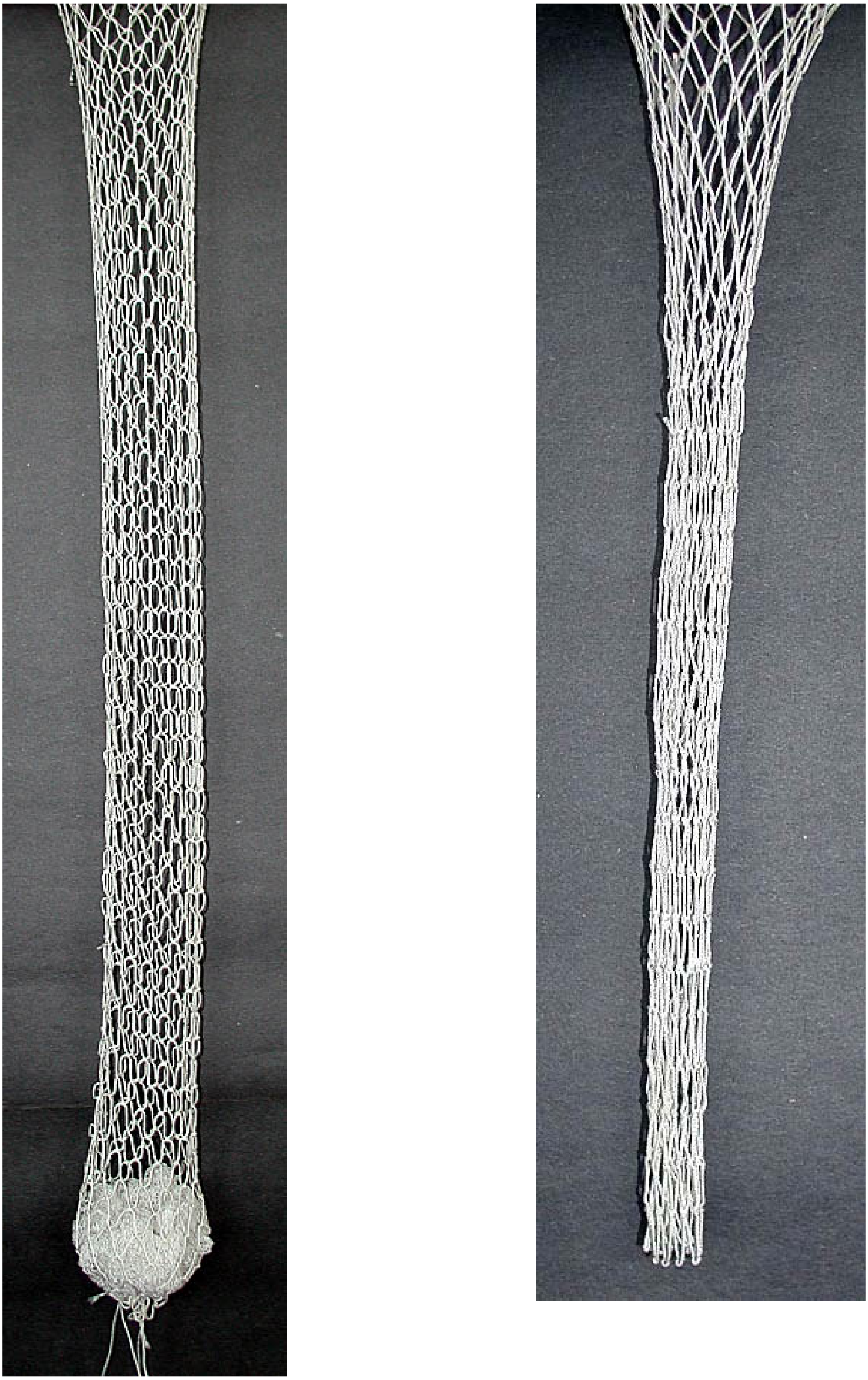


Figure 3. The different shape of a codend of turned meshes compared to one of diamond meshes

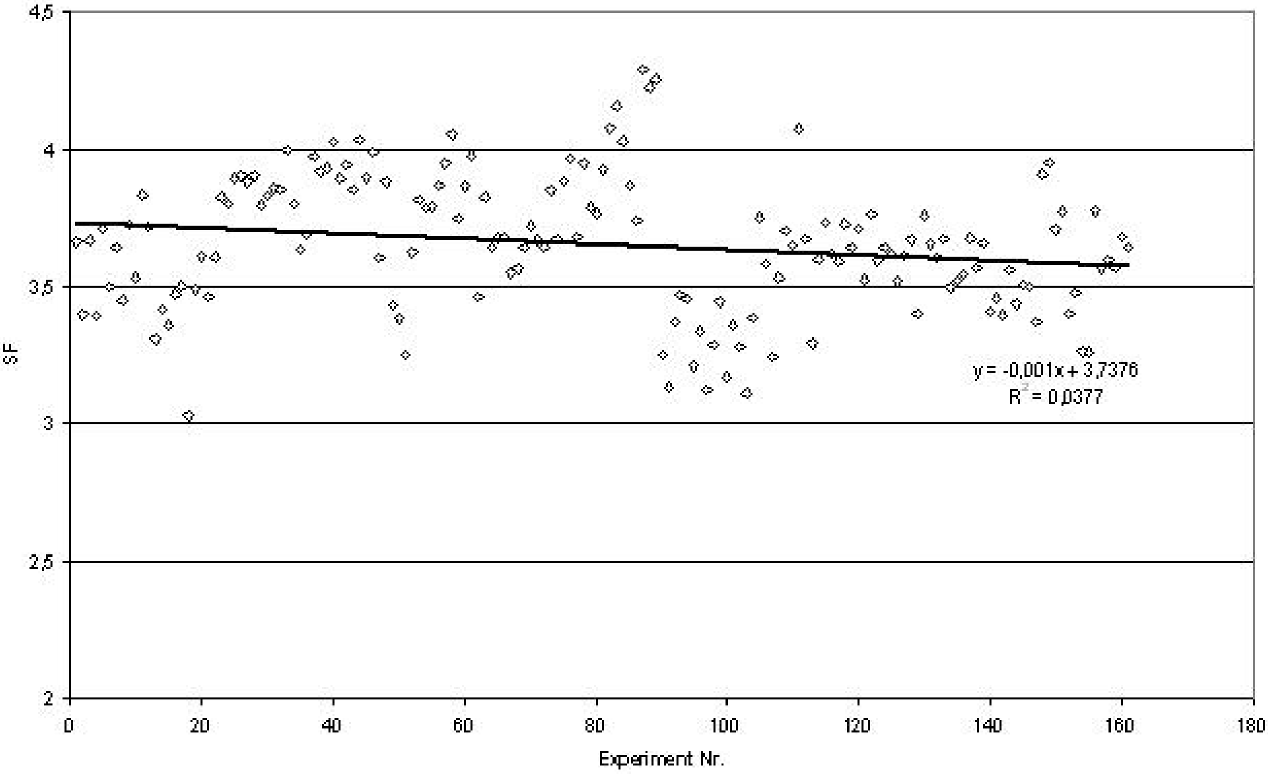
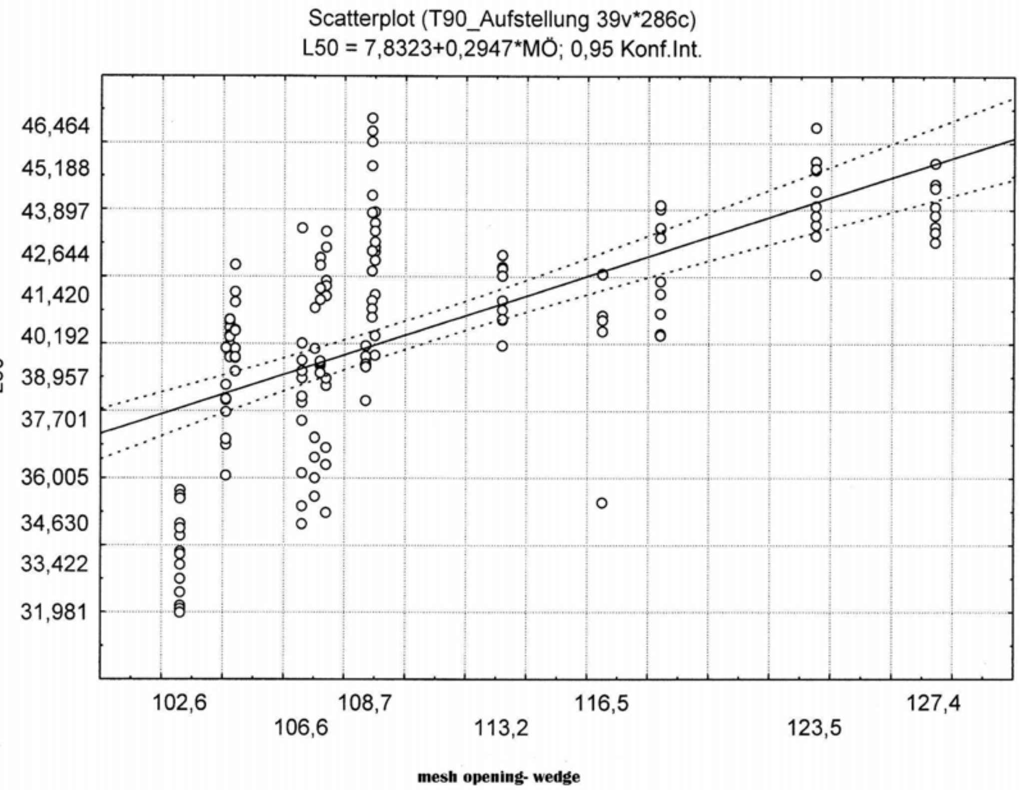


Figure 4. Presentation of selectivity factors encountered during this study


Scatterplot (T90_Aufstellung 39v*286c)
L50 = 7,8323+0,2947*MÖ; 0,95 Konf.Int.
L50
46,464
45,188
43,897
42,644
41,420
40,192
38,957
37,701
36,005
34,630
33,422
31,981
102,6
106,6
108,7
113,2
116,5
123,5
127,4
mesh opening- wedge

Working Document: The engineering aspects of the mesh shape and codends made of turned meshes. Waldemar Moderhak, Poland

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Abstract

Selectivity is mainly defined in an empirical way. Finding proper selective codends construction for particular fish species can be supported by theory. On that way it is possible to adopt some engineering theory to determine faster the proper material and twine of codend netting and construction for protection of fish juveniles. In active fishing, e.g. trawl fishing, the meshes of the codend are subjected to the mechanical and hydrodynamic forces and moments from water moving through the meshes. Depending on the positioning of meshes to the water flow, the hydrodynamic forces act on particular mesh bars to either close or open the mesh, thus decreasing or increasing opening of a meshes and selectivity. All technical phenomenon's taking place during towing of different construction codends with different features bring about their different shape and mesh opening. Those effect in a different selective properties and catch abilities of particular codends construction.

The paper presents technical explanation of different properties of meshes and codends turned 90°.

Mesh bars shape

The mesh shape and mesh opening mainly depend on its construction witch should take into account mechanical properties of the netting it's made of. Today a wide range of mesh twine is produced. These twines have different constructions which determine its elasticity and mechanical strength, therefore shape mechanical properties of the netting's.

Different properties of netting can be achieved by choosing different:

- twine fabrics (e.g. polyamide - PA or polyethylene PE),
- twine construction (e.g. twisted or braided)
- twine diameter.

In fishery we usually use PA or PE twines. There are different construction abilities of twines because of the number and diameter of basic filaments used. In the market there are many different constructions available which enables us to create twines of different mechanical properties which can be used to construct codends. Another opportunity to shape the properties of codends gives us turned 90° netting. Turned meshes have bigger mesh–opening and elasticity.

Brief theory of mesh bars bending

Twines elasticity can be observed while bending twine, after the force is released it returns to its previous position – just like a spring. Stiffness is the product of elasticity modulus (Young's) E and the moment of inertia of cross-section of a mesh bar J. The elasticity modulus defines the elastic properties of twine material and the moment of inertia characterises the size and shape of the cross-section of a mesh bar. The cross-section of a mesh bar was considered as circular.

Nomenclature used:
d - mesh bar diameter,
E - modulus of elasticity (Young's modulus),
J - moment of inertia of cross-section,
l – length of mesh bar,
M(x), M - sum of moments or moment,
ε - unit elongation,
σ - stress during tearing,
y – mesh bar deflection (beam deflection).

The value of the elasticity modulus is defined basing on the breaking strength of the twine sample. The elasticity modulus can be calculated using formula:

$$E = \frac{\sigma}{\varepsilon} \qquad (1)$$

The moment of inertia of cross-section J of the investigated material in relation to the neutral axis is the sum of products of particular elements of the cross-section and a second power of the “gravity” centre distance of those elements from this axis. For circular cross-section it can be calculated according to the formula:

$$J = \frac{\Pi d^4}{64} \qquad (2)$$

Formulas for calculation of the curvature radius (e.g. Kurowski and Niezgodzinski 1955) were used to describe the shape of bends mesh bar, as follows:

$$\rho = \frac{\left(1 + y'^2\right)^{\frac{3}{2}}}{y''} \qquad (3)$$

$$\rho = \frac{E \cdot J}{M(x)} \qquad (4)$$

- equation (3) illustrates the mathematical approach, while
- equation (4) describes the physical approach

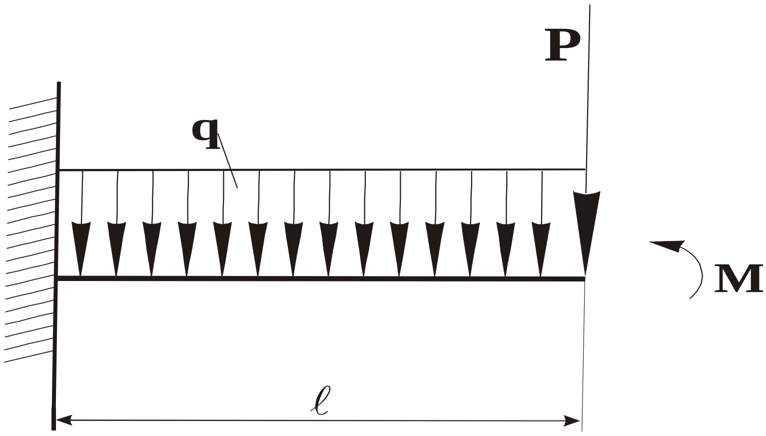

Figure 1. Load on the mesh bar during towing – general scheme.

In general, it can be assume that during towing the mesh bar is exposed to cumulated forces (P) acting upon the knots and continues distributed load (q) caused by hydromechanical forces. The scheme of forces and moment is presented in Figure 1.

After comparing equations (3) and (4), a second order differential equation is obtained which must be solved to gain the value of the bar (beam) deflection (y) as a function of a position (x). For the mesh bar which is firmly situated in the knot of the mesh, the boundary conditions are as follow:

$$y\big|_{x=0} = 0 \,, \quad y'\big|_{x=0} = 0 \,, \quad y'\big|_{x=l} = 0 \qquad (5)$$

Obtained equation describing the deflection of the mesh bar, according to elaborated method is as follows:

$$y=\int_0^x \frac{k\cdot x\cdot\left[q\cdot\left(\frac{x^2}{3}-l\cdot x+\frac{2}{3}\cdot l^2\right)+P\cdot(l-x)\right]}{\sqrt{1-k^2\cdot x^2\cdot\left[q\cdot\left(\frac{x^2}{3}-l\cdot x+\frac{2}{3}\cdot l^2\right)+P\cdot(l-x)\right]^2}}dx \quad (6)$$

where ***k*** is constant value for particular twine and equal:

$$k=\frac{1}{2\cdot E\cdot J} \quad (7)$$

Formula for calculation mesh bar deflection is quite complicated so, it was necessary finding the solution to use one of the numerical methods to solve it. Of the different methods of numerical integration, Czebyszew's method was used.

Base on that theory a deflection of mesh bar with different diameter was calculated. The results are presented on Figure 2.

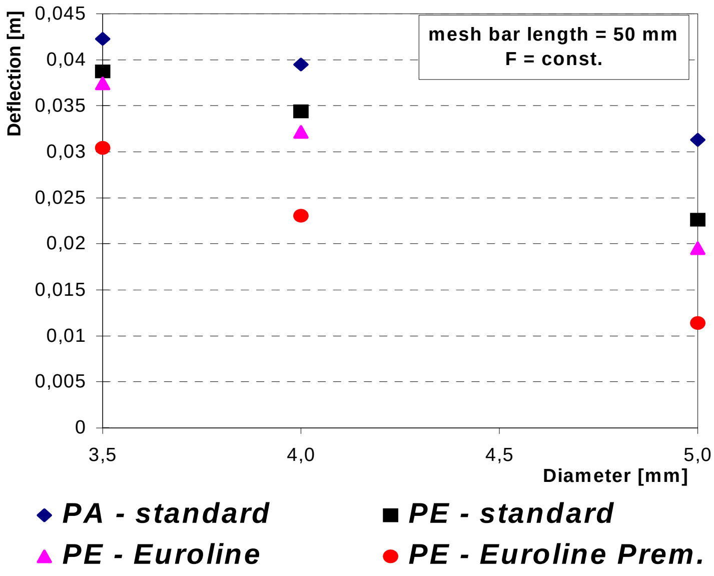

Figure 2. Possibilities of deflection of mesh bars made of different twine diameter and material.

Turned 90° codend construction

The big mesh-opening causes some problems in constructing codends using both standard and turned meshes. The problem *arises* when we want these two types of netting to join into one construction. When we don't take this problem into account – i.e. we use the same circumferences (in the stretched state) of both elements such a construction would be improper because these two elements react in different ways. Both netting have tendency to keep its previous shape. This creates a state of balance, which causes some difficulty for the turned netting in proper deployment. In practice such a connection cannot work properly. In codends improvement of that situation consists in a proper circumference fit i.e. in reducing the number of meshes around in turned codend and on that way adjusts number of meshes of turned part to the circumference of the belly end. Such a reduction should take 20% to 40% of the standard netting circumference, depending on the twine stiffness used in the turned codend. It will causes proper work of such set.

The turned codend properties

Properly designed turned netting set (i.e. codend and extension) has circular cross-section of a diameter 2,5 to 3 times bigger than standard one made of the same number of meshes around (notice that the standard codend cross-section is hardly circular). This causes different water conditions in the codend – a greater amount of water flows through the extension and codend and velocity of water flow is also increased (Moderhak 1993a, 1993b). According to the law of continuity is:

$$V=S\cdot v \quad (8)$$

where:
V- volume of water flowing through the codend,
S - surface of the cods' cross-section,
v - water flow velocity through the codend.

Executing calculations for the standard and turned codend (assuming the same flow velocity and circular cross-section in both cases) we obtain that the volume of water flowing through the turned codend is 6 to 9 times greater than water flowing through the standard codend.

The consequences of different mechanical properties of turned codend are:

- increased in catch abilities

as a result of different water flow conditions. Bigger amount of water flow through the turned codend makes highest possibilities of higher catches. That is confirmed by observation of a catches obtaining by other type of codends (see Table 1) – better catch abilities in spite of better selectivity.

Table 1. Catches and retention of cod juvenile during commercial fishing in the period 2000 – 2002.

Type of codend	No. of fishing days	Undersized cod	*Average catch per hour* [kg/h]
		%	
Vessel A – 2000			
Standard 120 mm Turned 90 mm	35 110	7.24 3.85	54.7 61.1
Vessel A – 2001			
Standard 120 mm	27	11.57	51.0
Turned 90 mm	93	4.02	59.0
Turned 100 med mer	19	1.59	101.4
Vessel B – 2001			
Standard 120 mm	20	11.19	56.6
Turned 90 mm	87	4.10	72.15
Turned 100 mm	6	2.40	61.37
Vessel A – 2002			
Turned 90 mm	46	7.03	49.4
Turned 100 mm	49	3.99	53.9
Vessel B – 2002			
Turned 90 mm	50	6.03	52.7
Turned 100 mm	42	2.57	52.5

- reduction of netting drag

Increased water flow through the codend causes reduction of hydromechanical drag and as consequence less fuel consumption - water flows through the codend easily avoiding blocking of belly end.

- selectivity improvement

Greater codend diameter results in bigger side surface, which combined with wider mesh opening improves its selectivity. Comparing the shapes and the side surfaces of turned codend and the surface of Bacoma window (extension not included in the of turned codend) the side surface of the turned codend is over 4 times greater than Bacoma window surface.

- better stability of movement

Greater codend diameter equals greater stiffness and this result in a greater stability during fishing – less side declination of movement, thus greater mesh shape stability that result in reduction of selectivity range (SR).

- better codend strength

Turning meshes 90° cause better breaking strength. It has been proved during breaking strength studies (Moderhak 2000) that turned meshes have 10% to 25% higher breaking strength than standard meshes made of the same twine diameter similar for PA and PE twines (i.e. Figure 4). It's caused by a different twine layout in both types of meshes and codends. In turned ones twines have direction of tearing force but in standard ones perpendicular to the tearing force.

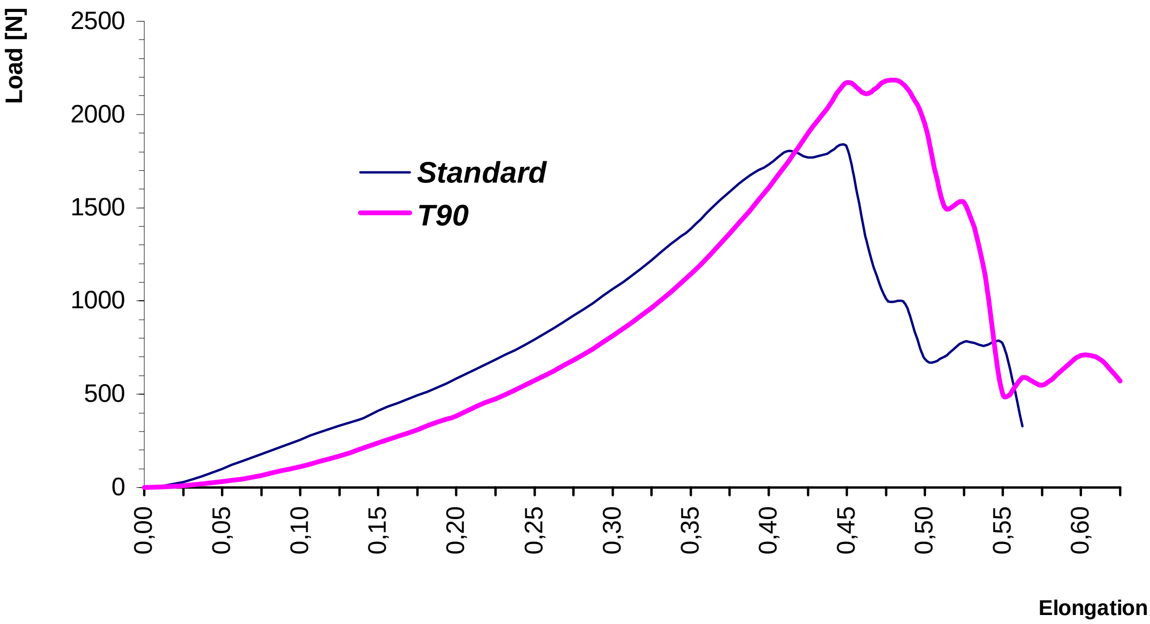

Figure 4. Strength of standard and turned meshes made of polyamide twine.

Conclusion

This paper contains a brief technical analysis of some problems that arisen in connection with introducing into fishing constructions of turned meshes netting.

Based on the theoretical approach it is possible to evaluate the technical constructions use in fishery for designing and constructing fishing gear. Trawling gear is subjected to by the laws of mechanic and hydromechanics. Understanding these laws enables us to wider and faster evaluate and improve different netting constructions and estimate their usefulness in fishery.

Using different engineering methods it is possible to introduce to the fishery new more selective gear faster.

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