Fisheries Technology Committee **ICES CM 2000/B:03**

REPORT OF THE

WORKING GROUP ON FISHING TECHNOLOGY AND FISH BEHAVIOUR

IJmuiden, The Netherlands
10–14 April 2000

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

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1 INTRODUCTION

1.1 Terms of Reference

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Venue: Haarlem, The Netherlands

Date: 10–14 April 2000

In accordance with ICES C.Res. 2000/2B03, the Fishery Technology Committee recommends that: The Working Group on Fishing Technology and Fish Behaviour [WGFTFB] (Chair: Dr A. Engås, Norway) will meet in IJmuiden, Netherlands from 10–14 April 2000 to:

a) review and consider recent research into unaccounted mortality in commercial fisheries;
b) review ongoing work for reducing unintended effects on the seabed and associated communities of fishing operations and gears, including ghost fishing.

WGFTFB will report to the Fisheries Technology Committee at the 2000 Annual Science Conference.

Justifications:

a) Several countries are conducting or have recently completed significant studies in this area and the subject would benefit from a review of progress and an evaluation of the results obtained. The last review of significant studies occurred in 1996 by the ICES Study Group on Unaccounted Mortalities. A review of more recent work will determine the need for revision and update on planning and methodology for studying this subject.
b) All fishing activities have influences that extend beyond removing target species. The approach recommended by FAO is that responsible fisheries technology should achieve management objectives with the minimum side effects and that they should be subject to ongoing review. WGFTFB members and others are currently undertaking a range of research programmes to provide the means to minimise side effects.

Suggested work item for the FTFB working Group:

In addition, the FTFB Working Group also made the following suggestions for work to be initiated prior to the next meeting in April 2000:

- techniques to quantify fish behaviour from underwater videos and still photographs (Action: B. McCallum, Dick Ferro, and Chris Glass)
- implementation and acceptance of gear-related technical measures (Action: Norman Graham)
- prepare a Web-based manual concerning fishing gear measurement and observation devices for use in fishing gear research and development (Action: Bavouzet, Carr, Hall, and McCallum)

Cover sampling induced mortality in experiments assessing the survival of fish escaping from trawls. Mike Breen, G. I. Sangster, and A. V. Soldal. Oral presentation

Abstract: Most techniques that estimate post-selection mortality in fish escaping from trawls use codend covers to sample the population of escaping fish. These covers are designed to minimise any possible abrasive injury among the captive population. Early direct observations made by divers suggested the fish held within these covers were not subjected to any undue stresses or injury. However, more recent observations by various researchers, have indicted that there is a significant water flow in the cover. Moreover, some fish, particularly smaller individuals, struggle to maintain position in the cover and often fall back and lie on the netting at the rear of the cover. Recent survival experiments were described that showed dramatic improvements in the observed survival of haddock and whiting following changes in sampling protocol. There were two possible explanations for the improved survival. Firstly, developments in the cover sampling technique now permitted researchers to take samples at the end of tows of commercial lengths (3–4 hours). Secondly, the effective time period over which fish were collected in the cover (sampling time) had been reduced. A comparative experiment was described which demonstrated that the duration of the tow had no significant effect on the observed mortality of haddock and whiting in the experiment. However, it did show that a reduction in sampling time may significantly improve haddock and whiting survival. This observation was confirmed within analysis of a comprehensive data set of survival estimates collected for haddock and whiting using comparable techniques. The resultant models were constructed using Generalised Linear Modelling with data fitted to a binomial distribution, using 12 possible explanatory variables. This analysis showed that haddock mortality was a function of sampling time, mesh size and mean fish length, while whiting survival was a function of sampling time, towing speed, mesh size, depth and codend catch.

Discussion: Measure lactic acid content in fish tissue as a clue to injury mode. It seems that small fish are not substantially more vulnerable to physical injury during the actual escape attempts. Underwater video showed small fish dropping back to be pressed against the back of the cover. Not all of these were dead, but did seem to be exhausted. There were no 0-group fish in the handline-caught control group, but there were in the codend control group and these did not suffer elevated mortalities. Catch size seemed to have no major effect on mortality except when the catch composition included abrasive fish such as skates.

By-catch and discards of red king crab in the cod gillnet fishery, possible solutions. Hallvard Godøy. Oral presentation plus paper

Abstract: Bycatch of red king crab (*Paralithodes camtschatica*) in stationary fishing gears, especially gillnets, is an increasing problem to the inshore fishermen in the northern part of Norway (Finnmark county). The results are high unaccounted mortality of king crabs together with the crabs' damages on the gear and catch. In the cod gillnet fisheries, the problem might be solved by using specially made gillnets ("norsel-mounted nets") where the net itself is floated 0.5 meters above the seabed. The norsel-mounted nets were compared with standard nets in the Varangerfjord (eastern Finnmark) in the period 17 March – 28 May, 1999. The trials showed that norsel nets needed more floats than the standard nets to get the net to stand properly in the sea (to get the norsels stretched out suitably). By using extra floats (rings) on the norsel-mounted nets the bycatches of king crab were reduced to an acceptable level with an average of 0.6 crabs/net, compared with 3.3 crabs/net on standard and 6.7 crabs/net on norsel nets without extra float. Norsel nets caught only about 1/3 as many fish as standard nets. The catch results indicated that the gear configuration functioned in order to reduce the bycatch of red king crab. Loss of fish up to 65% is however not satisfying. Further work is needed to find a solution that gives a minimal loss of fish. Knowledge about the different species' behaviour is of importance in the further development of a more selective gear.

Discussion: Gillnets have been a traditional means for catching crabs in Japanese fisheries so shaker technology may exist there, or other means to get crabs out of gillnets efficiently and without damaging them. No tests were done to specifically evaluate whether norsels change the proportion of crabs to fish, but crab/fish ratios were reduced. In a different fishery, spider crab bycatch was reduced by using braided twine in the meshes near the leadline. Dropper-equipped (similar to norsels) gillnets tested in the UK showed severely reduced catch of cod, but hake catches were satisfactory. In experiments in the UK large-mesh lower panels helped reduce crab bycatch but at the price of high reductions in fish catch rates. Norwegian fishermen are willing to see some reductions in fish catch rates if less time can be spent in clearing crabs out of nets. King crabs caught in this Norwegian gillnet fishery and season (winter) are small and in poor condition so are not useful for retention. Gillnet crab mortality estimates must be provided to crab assessment biologists but this is not presently done.

A simulation of an increase of mesh size, increased effort and the potential of increased post-selection mortality. Alain Fréchet. Oral presentation plus paper

Abstract: This paper investigated one of the many management implications of an increase in mesh size but taking into account the potential for an overall increase in mortality given the underlying expectation of a short term immediate increase in effort. No field experiment results have been used to asses this potential effect, however, the simulation provides the basic elements to test operationally the impact of the decision to increase mesh size on any potential increase of total mortality. It does not provide proof that such an increase would necessarily result in an increase of the overall fishing mortality. Whatever may be the case, it underlines the uncertainty of the overall effect of such a management measure.

Discussion: Small fish are most vulnerable to escape mortalities, but they also suffer the highest natural mortality so the apparent effect may be higher than the real one. Still, unknown escape mortalities need to be assigned to the right cause in order to have accurate assessments. When observers can be employed good statistics on catch and discard rates can be obtained, but observers or other means are not applicable for all situations so most stock assessments are based solely on landing statistics, neglecting discards & escape mortalities.

Injuries to haddock observed in a fish survival experiment. Mike Breen, M. Farrington and A. V. Soldal. Oral presentation

Abstract: It is recognised that in any survival experiment it is as important to identify the causes of mortality in the observed mortality, as it is to estimate the magnitude of mortality. The detailed examination of injuries on the dying subjects can provide important indictors to the cause of death. Most previous injury studies in experiments assessing the survival of fish escaping from fish gears have concentrated on skin injuries, and in particular scale loss. While other injuries have been examined these assessments have only examined dead fish. This presentation described an assessment that aimed to study the differences in injuries between dead and surviving fish in an attempt to identify possible causes of mortality. The assessment consisted of a detailed post mortem of all dead fish that were removed from seabed cages in a fish survival experiment. The post mortems examinations recorded individual biological parameters (length, weight, age, etc) and any visible injuries or abnormal conditions (both externally and internally). In total, 178 different parameters were recorded for each fish. A sub-sample of 20 fish was taken from the surviving fish in each cage of the experiment; a total of 200 fish. It was observed that the most common injuries in both dead and surviving haddock were of an abrasive nature: skin damage, fin loss and eye lesions. The occurrence of these injuries was significantly greater among dead haddock, but also these injuries were more severe. Some conditions were seen exclusively in dead haddock, including eye lesions and the presence of blood and gas in the abdominal cavity. A number of potentially lethal injuries were identified and these were seen predominantly in dead fish. These included gill haemorrhages and inflammation and brain haemorrhage and contusions.

Discussion: Not all injuries are fatal. Most mortality studies have focused on visible skin & fin injuries, but there's no proof that these are fatal. Would the observed fin injuries progress to the same extent if the fish were not confined? Best guess is that these are suffered during the escape process or within the cover, not the cage. Captivity stress has been implicated in compromised immune responses. Most mortalities occurred early on, suggesting that confinement mortalities not so important.

A VPA formulation to include sub-components of fishing mortality. Alain Fréchet. Oral presentation plus paper

Abstract: Three different ways of formally including sub-components of unaccounted mortality were described and reviewed. They allow the inclusion of various levels of knowledge of the sub-components of fishing mortality in virtual population analysis.

The inclusion of unaccounted mortality in the VPA will likely result in an estimation of a larger stock size given that these additional sources of mortality were previously unknown. The change in perception of stock size will thus require a precise and stable estimate of each sub-component of F. The main effects of including sub-components of unaccounted mortality into VPA will be seen in terms of increased recruitment and higher productivity. This is not likely to be reflected immediately to a higher advice for fishing quotas given that the recent estimates of sub-components are likely to be maintained for the short-term projection period. However, results of this exercise will likely be closer to reality and will identify the scale of each type of loss. It will be up to management to decide on which sub-component of F mitigation should occur.

Is sub-lethal captivity stress a problem in fish survival experiments? Mike Breen and M. Farrington. Oral presentation

Abstract: Captivity induced stress has been identified as a potential source of mortality in fish held captive in survival experiments. This potential source of mortality is usually monitored using a control population of fish, which are held in the same conditions as the test fish. However, this approach is unable to monitor any sub-lethal effects that captivity induced stress may be having on the subject populations. This could present a problem in that, when compounded with the acute stress responses and/or injuries from the initial test stressor, these additional captivity stresses may induce a mortality that may not normally be observed. This presentation described an experiment to assess whether indicators of chronic captivity stress could be identified in a population of captive fish, held in seabed cages during a survival experiment. A two level approach was taken to the monitoring. Firstly, blood samples were obtained from captive haddock and haddock caught by handline for controls. All blood samples were taken within 5 minutes of capture to ensure the acute stress responses of capture did not interfere with the results. All captive fish had been held in the seabed cages for at least 72 hours prior to sampling. A total of 15 blood parameters were measured, but no conclusive indications of chronic captivity stress were observed. The second approach recorded the behaviour of captive haddock and whiting with respect to feeding and their reaction to approaching divers. Five levels of behavioural response were noted: from non-feeding and complete avoidance of divers to aggressive feeding and attraction to divers. This progression of behaviour types was given as evidence of adaptation by the captive fish to captivity. All cages of captive fish were seen to have been fully acclimatised to captivity within six days of capture. However, this period of acclimation was noted to coincide with the peak period of mortality in the cages, although no cause and effect could be established.

Discussion: At this point there has not yet been an examination of whether the tow length has any effect on the rate of acclimation for the experimental fish. The researchers in these studies acknowledge that there is room for improvement in the blood analysis techniques employed.

Unaccounted *Nephrops* mortality and its implication to stock assessment. Mats Ulmestrand. Oral presentation

Abstract: In order to estimate possible *Nephrops* management implications of changes in estimates of discard mortality and escape mortality, Length-Cohort Analyses (LCA) were carried out on the Skagerrak/Kattegat *Nephrops* stock using the average *Nephrops* male length composition data for the years 1992–98. Investigation of management implications was tested by letting discard mortality be 0.70, 0.75, 0.80 and 0.85. Selectivity parameters from 70 mm diamond mesh was used, escape mortality was fixed at 0.10 and natural mortality was set to 0.3. The results on discard mortality from this project are considered to be in accordance with values that have been previously assumed in *Nephrops* stock assessment. These discard results will therefore not have any implications for management decisions. In conventional *Nephrops* stock assessments the escape mortality is assumed to be zero but this project found an escape mortality of ~19%. Inclusion of escape mortality of this magnitude in a length cohort analysis showed no major change to the perception of the state of the stock in terms of biological reference points.

Discussion: New North Sea *Nephrops* regulations require use of a square mesh upper panel to encourage fish escapes.

Discarding in a European fishery: Its effect upon the spawning stock biomasses, lost landings and the implications for corrective selective measures. Andrew Revill. Oral presentation plus paper

Abstract: The North Sea *Crangon crangon* fisheries are important and successful fisheries, which generate landings with a gross value of between 50 – 70 million Euro per year. Due to lost landings the level of fish discarding in these fisheries is, however, estimated to have a significantly negative impact in both biological and economic terms upon other North Sea fisheries on the order of 17–55 million Euro per year. The North Sea plaice fishery is particularly impacted by this discarding, the bulk of which originates from the German and Northern Dutch Crangon fisheries. The discarding of sole, cod and whiting in the Crangon fisheries impacts other fisheries (in both biological and economic terms) to a much lesser extent. The unilateral introduction of corrective technical measures specified by EC Fisheries Council Technical Regulation No 850/98 will reduce these negative impacts to a degree and is supported. However, the efficacy of this technical measure is likely to vary considerably between regions. Recommendations are as follows: Selective gears need to be developed for these fisheries by the year 2002 according to EC Fisheries Council Regulations, the primary purpose of which is to reduce the discarding of juvenile plaice. These selective gears should be tailored on a regional basis to primarily eliminate the locally predominant size groups of those plaice discards. It is strongly recommended that a monitoring programme be undertaken in relation to the implementation of the EC Fisheries Technical Conservation Regulation (Council Regulation 850/98). The aim of the monitoring programme should be to assess the following: compliance by the fishermen with the regulation, enforcement, economic effects of this technical measure in relation to catches, individual vessels and fleets in the Crangon fisheries, actual benefits to stocks and landings of whitefish resulting from this technical measure, validity of all predictive modelling undertaken,

and the transferability of the results to other fisheries. This monitoring programme should start during the implementation of this technical measure and should run for some time afterwards.

Discussion: Whiting stocks in the North Sea are stressed, but the whiting discarded in the Crangon fishery are 0-group so there is little impact from discard mortality relative to natural mortality. There is no idea yet of the implications for multi-species interactions. The selectivity devices studied here have a potential to cause around 10% loss in Crangon catch rates, but market forces could largely compensate for this. The analysis accounts for current voluntary use of selective devices plus part-time usage and national usage patterns, but not for periods of exemption from use permitted under the proposed regulations. The model presented here does not account for long-term effects in fish stock size, which are likely to be even greater in magnitude than the predicted short-term effects. Evaluating the effectiveness of selective measures is likely to become increasingly important but there are no obvious recognised ways to do this.

Report from the Topic Group on Unaccounted Mortality in Fisheries. Mike Breen. Written report in Annex 1.

Two sub-groups were formed to discuss this Topic. One group was convened by Mike Breen to consider methodologies for studying and quantifying unaccounted mortality factors. The other was convened by Alain Fréchet to consider the role and employment of estimates of unaccounted mortality factors in stock assessment. Following the break-out meetings of these two groups the full Working Group reconvened and their convenors presented the following summaries of their discussions:

Summary of discussions by the methodology sub-group. Mike Breen.

It was recognised by the group that the majority of methods used to estimate mortality, with respect to the different sub-components of F, currently use captivity-based assessments. This was considered the single largest disadvantage in these techniques. Future development of methodologies should strive towards non-invasive observation of fish populations and gear interactions, and the resultant mortality effects.

A number of novel approaches and technologies were identified by the group which, while not currently used in fishing mortality estimates, may prove useful in future non-invasive approaches. These included improved technologies for remote underwater observation (e.g., high resolution sonar, scanning laser and infra-red camera systems). Also considered were tagging methods and more specifically tags which could relay data on the location and biological status of the fish. The detrimental effects of fitting such tags was discussed and it was noted that technology is now available to remotely fit tags at depth using robotic arms (Starr Oddi, Iceland). Methods for assessing the effects of physical injury and trauma were considered. A 'Virtual' scallop developed by Seafish in the UK was shown to the group. It incorporates accelerometers to record the relative motion experienced by the scallop during the capture process. Also recent developments in tomography were described. This is a non-destructive technique which utilises NMR and x-ray technology to obtain high resolution images of internal tissues of living and dead organisms.

The issue was raised whether the perfect estimate of mortality was achievable, or indeed necessary. It was identified that there are currently two fundamental approaches to the problem. Firstly, the researcher may minimise sources of experimentally induced mortality (e.g., using laboratory based experiments) often to the detriment of the replication of commercial conditions within the experiment or, alternatively, using field based experiments the researchers may appropriately mimic commercial fishing operations and conditions but unintentionally induce an experimental mortality. The group agreed that both approaches will be necessary in future investigations of unaccounted mortality. The latter allows the researcher to derive reasonable estimates of mortality in field conditions and the inclusion of these within stock assessments; accepting that these values are likely to be overestimates and are applied assuming the "Precautionary Principle." Meanwhile using the former approach, it is possible to focus on the mechanisms causing injury and mortality in individual fish. It was recognised that it is necessary to direct a high level of effort, at a small number of subject specimens, in this type of work.

Finally, the group discussed whether there was presently a need to formally review the currently used methods for investigating unaccounted mortality and provide advice on standardised methodologies, discussion of potential pitfalls in present methodologies, etc. It was agreed that the guidelines provided by this report were sufficient for this purpose, at this early stage of development of techniques in this field.

Summary of discussions by the assessment sub-group. Alain Fréchet.

Most of the discussion concerned the lack of integration and knowledge of research on unaccounted mortality from gear technologists into stock assessments and fishing forums. There is a general recognition that, for most fisheries, the most important sources of unaccounted mortality, aside from the official landing statistics, are expected to be found in discard mortality, followed by illegal, mis-reported and un-reported landings. These last three sources, although potentially important, may be very difficult to obtain given the legal implications if they were officially declared. A suggestion was done to arbitrarily adjust the catch at age by a given percentage to allow for such mortality factors. Investigations into these sources of mortality are likely to attract more attention from managers than others, which are potentially less important sources of mortality, such as drop out mortality, ghost fishing mortality, avoidance mortality and habitat mortality.

Research into escape mortality however, has shown variable, but sometimes important levels of mortality. This source of mortality, by opposition to others mentioned above can be assessed by experimental trials at sea. Results can be used to give priority on management actions.

The usefulness of pursuing investigations into escapement mortality could be evaluated by performing simulation studies using assessment modelling techniques. This has not been widely done yet. This would make it possible to illustrate the potential cost and benefits of further research into escape mortality. Participants agreed that new research into escapement mortality should be expanded to assess seasonal and species specific variations. Other research priorities in escape mortality should consider the effect of condition. Roundfish species such as haddock, whiting, cod and hake appear more vulnerable to escape mortality than flatfish and research should be focused on these species.

There was a general agreement that all technical exclusion devices and selectivity studies should ideally be accompanied by escapement experiments as the benefits of a proper exclusion or selection by a device or gear may be misleading if high levels of escapement mortality exist. Such work is both complex and expensive. Collecting discard data is likely to be seen by managers as better value for the funding.

The Study Group on the use of Selectivity and Effort Measurement in Stock Assessments (SGSEL) has attempted to incorporate post-selection estimates in the haddock and whiting assessments. Few stock assessments have enough reliable estimates of sub-components of fishing mortality to be formally included. Very large amounts of data are needed to estimate such parameters, they are likely to vary according to species, season, gear, area, etc.

Discussion of combined reports: Some discomfort exists with the subcomponents equation, that it implies more knowledge than we really have. Perhaps it is more useful as a philosophical and discussion tool and should not be treated as a definitive statement for use in stock assessment or other quantitative purposes. Many of its components, for example, cannot be easily defined or evaluated, and the relationships may be multiplicative or interactive or take many forms other than additive. Escape mortality studies were originally developed to evaluate the long-term impacts of various selectivity devices and so were aimed at relative effects, but interest has lately developed in developing absolute mortality evaluations to be used in stock assessments. These imply different goals, methodologies, levels of accuracy, and time horizons. Assessment biologists are only now becoming aware of these possibilities but so far little motivation has developed from that quarter. There is a need to heighten this awareness among assessment biologists, those who consider ecosystem effects, etc. There may be value in doing modelling studies or other analyses to determine the potential value of unaccounted mortality research so as to direct efforts or recruit support. Our efforts should be driven from the top down in response to managers' needs and requests.

There was a proposal that the Topic Group's suggested recommendations be put forward as an EU Concerted Action in order to secure funding for travel and other expenses in conjunction with or as an alternative to proposing a Study Group, Suggested Work Item, Special Topic, or other activity within the ICES arena. Simulations could be done in the meantime to evaluate the potential contributions of the various unaccounted mortality components and thus help justify a Special Topic, EU Concerted Action, or other formal activity. There was a suggestion that the topic be proposed as a Theme Session for a future Annual Science Conference as a strategy for getting the participation and interest of the stock assessment community. Proposing a Concerted Action is another mechanism for sounding out and recruiting interest from assessment biologists. A consensus emerged that members of the Working Group need to take individual initiatives in view of the difficulties involved in mobilising a rapid ICES action. A small group will form to prepare a recommendation from the Working Group.

3 POSTER SESSION

A new selectivity curve in comparison to the logistic and Richards' curve. Eckhard Bethke.

Abstract: Traditional selectivity functions describe the selectivity of a codend gear by one function over the whole length range. These equations show a little probability to escape also for large fish. However, escape is not possible for all fish. There are fish with a chance but also fish without absolutely no chance to escape. So, here a function is introduced which consists of two parts. The first part describes the effect of retention for fish having a chance to escape the codend. The second part describes the effect for fish without any chance to escape. There the retention rate is simply equal to one. The transition from part one to part two of the equation is associated with the point where the fish can just escape. Then the circumference of the mesh corresponds approximately to the circumference of fish. For the first part of the equation a modified Gaussian distribution was chosen. This means that fish with a length lower than a maximum length have a chance to escape. Furthermore, escape is easier for small fish having a small circumference. Two types of curves are proposed, a two-parameter curve and a three-parameter curve corresponding to the logistic curve and the Richards' curve, respectively. For the estimation usually iteration procedures are used. The initial parameters necessary for this procedure can directly be read from a diagram of the raw data. The shapes of the new two-parameter curve and that of the logistic curve are similar. The equation presented here is much handier and fits better in some cases. The main advantage given by the new equation is the easy mathematical background for a seasonal selectivity function.

Discussion: What physical justification is there for an L_{100}, when selectivity is actually dependent on girth? It is a convenience. L_{100} represents a point of discontinuity in the selection function.

New UW-observation systems in Hamburg for towed and static gear. Otto Gabriel. Video presentation

Measurements of distance fished during the trawl retrieval period. Charles W. West and John R. Wallace.

Abstract: Observations of sampling trawl performance made during a multi-vessel groundfish trawl survey conducted during 1998 and again in 1999 raised concerns that the trawls might be continuing to fish during the retrieval period, after the end of the sampling period but before coming off bottom. Following the 1998 survey, a simple geometric analysis of times and positions recorded at critical moments during and following each sampling tow was developed to estimate the following parameters: 1) the distance along the bottom that the gear swept during the retrieval period, and 2) the speed at which the trawl moved over the seabed. This analysis suggested that the distances swept were substantial, and systematically increased with the depth of the tow. The effective trawl speed approached or even exceeded the towing speed specified by the sampling protocols, and this varied systematically among the participating vessels. The same analysis was performed for sampling tows conducted during the 1999 survey and compared against trawl positions recorded during the same period by an ultra-short baseline acoustic positioning system. Both techniques yielded similar results, and were in accord with the findings from the 1998 data: distances swept by the trawls during the retrieval period were substantial and the trawls were moving at speeds comparable to fishing speed, and these effects varied systematically from depth to depth and vessel to vessel. Neglect of these effects could increase the impact of depth-related bias and inter-vessel variability on survey results while knowledge of them could help explain the "vessel effect" commonly observed when comparing the fishing performance of two or more vessels.

Discussion: Errors in tow duration and distance fished during survey tows of the magnitude described here make a case for longer sampling tow durations, although these impacts can be mitigated by use of instrumentation as described here. It is not known how fish behaviour and catching performance during this period compare to the nominal tow period.

Species selectivity of fabricated baits used in Alaska demersal longline fisheries. Dan Erickson.

Abstract: A species-selective fabricated bait was developed and tested for the Alaska demersal longline fishery targeting sablefish (*Anoplopoma fimbria*) and Pacific halibut (*Hippoglossus stenolepis*). Trials took place on commercial longline vessels near Seward, Alaska during July and September, 1999. The fabricated bait fished as well or better than herring (control bait) for sablefish and Pacific halibut, while reducing bycatch of spiny dogfish shark (*Squalus acanthias*), skate (*Raja spp*.), arrowtooth flounder (*Atheresthes stomias*), and Pacific cod (*Gadus macrocephalus*) by more than 6x. Hook timers demonstrated that this novel bait released attractants over a longer period of time than herring. This project was a collaborative effort among numerous individuals from Alaska Fisheries Development Foundation, Alaska SeaLife Center, Center for Applied Regional Studies, MARCO Marine, Seattle, and Wildlife Conservation Society. The research was funded by Alaska Science and Technology Foundation and managed by Alaska Fisheries Development Foundation.

Discussion: Observations were made of fish behaviour around the gear, and these suggested that cod were more visually-oriented than sablefish and halibut.

Effect of water speed on the footrope contact of a bottom trawl. David Somerton.

Abstract: Most techniques that estimate post selection mortality in fish escaping from trawls use codend covers to sample the population of escaping fish. Recent observations by various researchers, have indicted that there is a significant water flow in the cover. Moreover, some fish, particularly smaller individuals, struggle to maintain position in the cover and often fall back and lie on the netting at the rear of the cover. In addition, comparative experiments and analysis of survival data has shown that a reduction in the effective time period over which fish were collected in the cover (sampling time) can significantly improve haddock and whiting survival. This cover induced mortality was concluded to be the result of the substantial water flow in the survival covers, which forced fish to swim at exhausting

speeds and may have inflicted abrasive injury on contact with the cover netting. This poster presented the design for a new survival cover, which reduces the internal water flow to negligible levels in an attempt to eliminate cover induced mortality. The effectiveness of the design with respect to hydrodynamics and stability has been successfully assessed in a flume tank. However, further field trials are required to determine its effects on a captive population of fish.

Discussion: Water speed seems to be a better standard for regulating survey trawl performance than speed over the ground. There were no side currents in the experimental area. Swept area is always measured in this methodology, but standardising on speed through water will stabilise gear performance. Speed over the ground has a strong influence on sediment penetration by the groundgear.

A new cover design for fish survival experiments - a solution to cover induced mortality? M. Breen, R. Kynoch, F. G. O'Neill and G. I. Sangster.

Abstract: Most techniques that estimate post selection mortality in fish escaping from trawls use codend covers to sample the population of escaping fish. Recent observations by various researchers, have indicted that there is a significant water flow in the cover. Moreover, some fish, particularly smaller individuals, struggle to maintain position in the cover and often fall back and lie on the netting at the rear of the cover. In addition, comparative experiments and analysis of survival data has shown that a reduction in the effective time period over which fish were collected in the cover (sampling time) can significantly improve haddock and whiting survival. This cover induced mortality was concluded to be the result of the substantial water flow in the survival covers, which forced fish to swim at exhausting speeds and may have inflicted abrasive injury on contact with the cover netting. This poster presented the design for a new survival cover, which reduces the internal water flow to negligible levels in an attempt to eliminate cover induced mortality. The effectiveness of the design with respect to hydrodynamics and stability has been successfully assessed in a flume tank. However, further field trials are required to determine its effects on a captive population of fish.

Numerical and experimental study of the 36x47 survey bottom trawl. Vincent Benoît.

Abstract: Ifremer, the French national research institute for the exploitation of the sea, has developed DynamiT, a new software for trawl simulations. DynamiT is the result of a four-year cooperation between Ifremer and the Ecole Centrale de Nantes to develop a new "dynamic" method of calculation of the mechanical and hydrodynamic behaviour of all trawl types. The new software takes account of strengthening ropes, hanging ratios and the elasticity of twines/ropes. This means, for example, that users can visualise the effect that a stiff net panel would have on the trawl. DynamiT calculates the trawl's dynamic behaviour, making it possible to estimate, for a given towing speed, the time required to reach a stable shape once the towing conditions have changed (e.g., direction, speed, or warp length). Several studies were conducted to validate the new method. Sensors measuring distances, pressure, water-flow velocity, tensions, directions, etc., were placed on strategic points of the trawl, such as the wings, head rope, footrope and otter boards. This software opens up new possibilities in research and fishing applications. For example, DynamiT has already been implemented to investigate selectivity (determination of the shape of the meshes in the codend) and can calculate the mechanical stresses on the seafloor of any part of the trawl. Consequently, it could be used to develop a new model for forecasting the impact of fishing activities on the seafloor.

Development of a recruitment index for shrimp (*Pandalus borealis*) in the Gulf of St. Lawrence. H. Bouchard, J. Lambert, and L. Savard.

Abstract: The forecast of the strength of a year class for shrimp must be done in the year prior to its capture. In order to assess the year-class strengths, a research project was put in place in 1998 aimed at improving forecast capability by developing a recruitment index for shrimp. A rigid frame was designed to; 1) catch a constant proportion of all size shrimp present in the sampling area; 2) be easily operated on a stearn trawler of 19.2 m; 3) avoid mud, rock and sessile organisms in the catch. The rigid frame is 4.6 m wide by 2.4 m high, mounted on skates which are the only parts in contact with the ocean floor. The trawl is 20.4 m in length with a mesh size of 44 mm. A 19 mm liner was added to the last 15.5 m to retain small shrimp. The lower part of the net is fixed at 20 cm over the bottom. The rigid frame trawl proved to be very efficient in catching one and two year old shrimp that would otherwise not be caught or retained by commercial or existing research fishing gear. The trawls used in the commercial fishery have a 40 mm mesh like the conventional bottom trawl used for the research surveys; however, the latter also has a liner of 19 mm in the cod end. Despite the presence of the liner, the research trawl does not catch shrimp less than 15 or 17 mm (OCL) in great numbers because it can only be used over a smooth bottom where small shrimp are rare. Similarly, the commercial fishery targets larger shrimp and avoids bottoms sustaining concentrations of small shrimp. The robustness of the rigid frame trawl allows its use over rough bottom and the mesh size is small enough to retain shrimp as small as 4 mm (OCL) without loosing larger shrimp.

Mapping the seabed off the Magdalen Islands with a Simrad EM-1000 multibeam echosounder: a tool for studies on lobster. L. Gendron and R. Sanfaçon.

Abstract: Mapping the sea bed off the Magdalen Islands (Québec) was initiated in 1995 to support studies on American lobster (*Homarus americanus*) requiring some knowledge of the sea bottom. The objective is to produce detailed and high resolution maps of the bathymetry and reflectivity of the grounds located on the northeast side of the Magdalen Islands, that support lobster populations and fishing activities. This is done through the use of a Simrad multibeam echosounder (EM-1000). In 1996 and 1999, sediment sampling and underwater photography were done to validate the reflectivity images and clearly characterize soft (mud, sand) and rocky (gravel, pebbles, boulders and bedrock) grounds. The maps are useful in a number of research projects: 1) lobster abundance survey using a *Nephrops* trawl on soft bottoms; 2) lobster abundance surveys using scuba diving on prime rocky habitats; 3) spatio-temporal distribution of fishing effort and lobster abundance.

Development of an abundance index in the Magdalen Islands from a trawl survey. L. Gendron, H. Bourdages, and G. Savard.

Abstract: A trawl survey was initiated in the Magdalen Islands (Québec) to obtain indices of lobster (*Homarus americanus*) abundance – recruits and pre-recruits – and help forecast recruitment to the fishery one to three years in advance. Preliminary trials made in 1994 with a *Nephrops* trawl showed that this type of gear was less selective than traps with respect to size. Lobsters down to 55 mm carapace size (two to three molts away from commercial size) were readily caught by the trawl. The use of *Nephrops* trawl is however restricted to soft bottoms and therefore not appropriate to catch cryptic or emergent juveniles that are dependant or remain in the vicinity of shelter-providing habitats. Vagile juveniles, adolescents and adults that forage and disperse more widely are more vulnerable to the trawl.

Matthias Paaschen described the findings of the Fourth International Workshop on Methods for the Development and Evaluation of Maritime Technologies in Rostock, 3–6 November 1999. These have been published as *Contributions on the Theory of Fishing Gears and Related Marine Systems*, Neuer Hochschulschriftenverlag, Rostock.

4 REPORT OF THE STUDY GROUP ON METHODS FOR MEASURING THE SELECTIVITY OF STATIC GEAR (SGMMG)

Arne Carr, Chair.

The SGMMG met on 8–9 April in IJmuiden, Netherlands. The study group participants were:

Arill Engås	Alain Fréchet
Pingguo He	Chris Smith
Esteban Puente	Matts Ulmestrand
Marianne Farrington	Ole R. Eighard
Charles W. West	Hallvard Godøy
Terje Jörgensen	Arnold Carr

Two papers were presented, each providing valuable discussion of elements of the study group's Terms of Reference, as follows:

"Effects of soak time on catch per unit effort of longline and gillnets of the Northern Gulf of St. Lawrence cod stock" by Marthe Berube, Hugo Bourdages and Alain Fréchet

"Index of saturation of longline and gill nets in Sentinel fisheries for cod in the Northern Gulf of St Lawrence" by Sylvie Brulotte, Alain Fréchet

Pingguo He presented a paper on the "Selectivity of Traps and other Gear." The discussion in this paper included separating pots from traps as they have different characteristics.

Work performed during 1999 and early 2000 on the gillnet and longline chapters was presented. These two sections were further expanded into a final draft outline that would be used in the current process of writing these sections. Draft outlines for traps and for pots were also produced. All these were discussed during concurrent breakout groups and then presented to the full study group at the end of the two day session.

SGMMG recognised that major work must progress in the writing of the manual sections with two dates most important: substantial progress prior to the fall ASM meeting and a draft for the Study Group to review by January 2001. Those that were present at the two-day meeting will be joined by those unable to be present that have previously committed themselves to the drafting of the manual.

5 REPORT OF THE STUDY GROUP ON MESH MEASUREMENT METHODOLOGY

Ronald Fonteyne, Chair. The Report of this Study Group's meeting is presented in ICES CM 2000/B:2.

Discussion: The Study Group will not consider gillnet materials at this time, even though a standard measurement technique is needed. This issue should be taken up by another group.

6 SUGGESTED WORK ITEMS

Prepare a Web-based manual concerning fishing gear measurement and observation devices for use in fishing gear research and development. G. Bavouzet, A. Carr, C. Hall, and B. McCallum.

Discussion: Such a manual cannot be practically implemented without participation by manufacturers and other commercial interests, but such commercial involvement lies outside the terms of reference of the WG/FTFB. Accordingly the participants will seek a different medium, specifically an EC-sponsored Thematic Network, which does support commercial participation and can provide some funding. While it was noted that EU funding is available to initiate and establish such efforts, other forms of long term support will be needed to maintain it.

Implementation and acceptance of gear-related technical measures. Norman Graham. Oral plus written report

Abstract: Recent studies have shown that the estimated discard levels in commercial marine fisheries have declined in recent years. Several explanation for this phenomenon are given, not least is the increased use of more species and size selective capture methods and technologies. In order to determine which factors influence and facilitate the use of such devices in management strategies, a review was undertaken. Scientists, researchers, fishermen and administrators were questioned as to the level of usage of selective measures, what background management schemes were in use and whether the use of such devices were voluntary or mandatory. Analysis of the data gathered and comparing this with historic data shows that the level of usage has greatly increased in certain fisheries. This has been particularly prevalent in shrimp fisheries, which have been well documented a having the highest ratios of discards in relation to target species catches. Introduction of management plans that include some form of discard ban or caps have facilitated the use of such devices. Pressure form the public and environmental groups have also influenced the introduction of better harvesting strategies. Other factors include trade embargoes, direct legislation, introduction of endangered species acts and other ecological legislation.

Discussion: Bycatch caps in the US North Pacific fisheries have not been as effective as they could have been in promoting use of bycatch reduction devices (BRD's) due to the practice of extending the management benefits of bycatch reduction to the entire fleet rather than to the individual users. This situation is being reconsidered. Fisheries with high levels of observer coverage often feature higher use of BRD's but examples do exist of strong voluntary usage. Ideal methods of incentives and incentives have not yet been developed.

Techniques to quantify fish behaviour from underwater videos and still photographs. B. McCallum, Dick Ferro and Chris Glass.

Presented at the Joint Session.

7 SPECIAL TOPIC B: UNINTENDED EFFECTS ON THE SEABED AND ASSOCIATED COMMUNITIES OF FISHING OPERATIONS AND GEARS, INCLUDING GHOST FISHING

Review of the IMPACT II Report. Niels Daan. (Full document available on ICES web site). Oral

The EU DG Fisheries asked ICES for a review of the "IMPACT II Report: The Effects of Different Types of Fisheries on the North Sea and Irish Sea Benthic Ecosystems" by Lindeboom and De Groot, and to formulate management advice as to how the effects of the gears discussed in the report on benthic ecosystems could be measurably reduced without unduly reducing the possibilities of catching commercially important species. ICES was invited to consider all possibilities such as establishing closed areas for bottom gears, reducing the weight of bottom gears, etc.

Summary: The ICES group began by establishing some definitions. “Bottom trawls” included beam trawls and otter trawls currently in use. They reviewed the research design for the projects covered in the IMPACT II Report, the analytical methods, the strength of support for the findings in the relevant literature, and other evidence. They established a list of potential impacts on benthic species, communities, and habitats. They examined the scientific evidence for each effect in the North Sea and Irish Sea and in other areas, then ranked them according to probable degree of seriousness and evaluated the need for corrective measures. They developed lists of categories of corrective measures considering the intrinsic spatial scale of the measure with respect to the scale of the fishery, then cross-tabulated the list of potential impacts and the list of possible mitigation measures to come up with recommendations for action.

Potential effects: To some extent the developed classifications were somewhat arbitrary since the effects overlap, operate together, and interact. Further, trawling operates simultaneously with other processes, both anthropogenic and natural, and discrimination can be extremely difficult. The criteria for ranking the severity of effects were as follows: on the temporal scale, permanent effects are of greatest concern; on the spatial scale widespread effects are of greatest concern; and when considering the direction of change, negative effects or declines were given more weight than positive effects. General issues included the likelihood that low-energy environments are more affected than high-energy environments, and the potential for recovery may be affected.

The developed list of potential effects included: habitat degradation (ranked by likely severity, removal of physical features, reduction in biogenic features, reduction in habitat complexity, and reduction in physical structure (e.g., sediment composition); and effects on biota (ranked by likely severity, loss of species from part of their normal range, declines in populations with low turnover rates, population fragmentation, alteration in relative species abundance, fragile species more affected than robust, surface-dwelling species more affected than deep-burrowing species, sub-lethal effects on individuals, increases in populations with high turnover rates, establishment of favourable conditions for scavenger species). Effects on food web and ecosystem properties were considered but rejected for inclusion in the analysis on the grounds that these are indirect effects with little scientific consensus on their nature. These included viewing the fisheries as an additional predator, altered energy pathways leading to species replacement or different functional roles, over-fishing versus intrinsic effects of fishing, and top-down and bottom-up effects.

Factors considered when evaluating the potential of mitigation measures included: 1) the recovery of populations and habitats may take place over time scales from weeks to centuries, in the worst case the reduction or cessation of the activity may be required and the measure made permanent to perpetuate the recovery; 2) while a monotonic relationship exists between the intensity of trawling and the degree of change, it still may be that a large reduction will be required to yield a measurable improvement; 3) technical measures are species and habitat specific – there are no generic solutions; 4) a combination of measures may enhance the effect if they act synergistically; and 5) adding economic incentives my enhance the effectiveness of mitigation measures.

After considering these two lists and their interaction, the group identified the following recommended management measures, in descending order of effectiveness and priority: 1) reduction of fishing effort by at least 30%; 2) closed areas or zones combined with effort reduction; 3) substitution of alternative lower impact gears, but with the awareness that this might lead to other unanticipated adverse effects; 4) gear modifications, if effective ones can be found that will also be acceptable to industry; 5) habitat rehabilitation in conjunction with area closures; and 6) changes in governance, particularly required to ensure the effectiveness of effort reduction and habitat rehabilitation.

Recommended specific actions for immediate implementation were: 1) prevent further expansion of areas exposed to bottom trawling; 2) prevent further increases in the number of bottom trawlers; 3) strengthen interactions with other agencies; and 4) improve the capabilities to measure impacts.

Discussion: There are no clear universal criteria how much disturbance is acceptable; it is necessary to independently evaluate each situation, and in any case there is little prospect for a consensus to develop any time soon on acceptable levels of impact. So far there has been no observable impact of these recommendations on EU or national legislation or practice. What about positive effects such as increases in scavenger populations? There are some situations where this seems to occur, but always in combination with negative impacts and this is a strong negative if the bias is towards being conservative. “Novel gears” were not generally ranked as having great potential because there is a tendency for industry to take innovations and adapt them for higher economic efficiency with little regard for such concerns as impact mitigation.

Latest findings in project “REDUCE.” Bob van Marlen. Oral with paper

Abstract: Recent research in beam trawling is directed at reducing impacts on benthic infauna and epifauna and by-catches of non-target and juvenile target species whilst maintaining the catch levels of target species. A first step is to reduce the mortality due to catching by altering the design of the nets through drop out zones made of large meshes in the belly of the net, and/or modifying the rigging of the tickler chains. This is done in the international EU-funded project REDUCE (FAIR-CT97–3809, Reduction of environmental impact of demersal trawls). Drop-out zones formed by cutting large meshes in the lower panel can be effective in reducing by-catches of benthic fauna, but the penalty is also a loss in marketable flatfish (sole, plaice, dab). Heavy benthic organisms (shellfish) seem to drop out of the gear. An alternative parabolic tickler chain arrangement increased catches of flatfish and benthos, which was not the aim. Parallel chains seem to offer more potential in reducing benthos by-catches, particularly shellfish, but losses in commercial flatfish might occur.

Discussion: In the absence of any prior indications the “drop-out zones” were installed in the bosom area solely on the basis of theoretical considerations. The project’s objective was to reduce aggregate catches of benthos in the codend, with little targeting on more vulnerable or critical species. The approach was exploratory in nature, evaluating in a relatively crude way the potential for further development of promising vs. non-promising alternatives.

Investigation of naturally and deliberately lost gillnets in Norwegian waters. Dag Furevik. Oral with paper

Abstract: At the coast of Norway an experiment with deliberately lost gillnets and pots have been performed, and during retrieval of naturally lost gillnets they have been studied in close detail with regard to catch rate, fish species and biofouling. In the experimental study the catch rate of old gillnets decreased significantly compared to a newly set gillnet. Multimonofil nets caught more edible catch then monofilament nets. Fish pots did not seems to catch fish after the bait had been exhausted but the catch of crab increased. Naturally lost gear which where a couple of years old caught sometimes a good deal of fresh fish. This is particularly so for Greenland halibut. The biofouling of the gillnets seems to be less in offshore areas then at the coast.

Discussion: The lost gillnet fleets recovered in Norway were several hundred meters long. With modern navigation gear it is relatively easy to recover lost gillnets unless waters are too deep or there is a long delay. Bad weather, entanglement on the bottom or conflicts with other trawlers or seismic vessels are the most common causes of loss. Ghost net catch rates are high, but are much less than active net catch rates. The bottom swept by the recovery gear is substantial and may have an impact, but if loss locations are known there is less need to drag it. Report rates of loss are not as high as they could be, perhaps from P.R. concerns. The fishermen do try to retrieve their own lost nets but there is no incentive to prolong efforts. Gillnet retrieval efforts are conducted each year by the Government. Canadian Greenland halibut gillnet fishermen are voluntarily putting identifying tags on their nets, and data from this could be used to study loss rates, etc.

Reducing the benthos by-catch in flatfish beam trawling by means of technical modifications. R. Fonteyne and H. Polet. Oral with paper

Abstract: In the flatfish beam trawl fisheries the by-catch 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 devices were tested. A drop-out opening and large diamond and square mesh escape zones just behind the groundrope were not effective in release the benthos by-catch and induced an unacceptable decrease in commercial catch. Square mesh windows inserted in the belly just in front of the cod-end were more promising. With these devices a significant reduction in weight and number of most benthic species could be realised. 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 by-catch reduction and an acceptable loss of marketable fish.

Discussion: There are numerous examples of selective gears in use, but their effectiveness depends on implementation, management measures, and acceptance and use by fishermen. The escape windows were about 2 m long and 1.5 m wide. Quality of the fish catch was improved when benthos bycatches were lower. Future mortality studies will examine both bycatch mortality and mortality of infauna. Industry representatives participate in these studies in an advisory and liaison capacity, so communication and co-operation can go a long way to contribute to success.

Preliminary results from the EU project “REDUCE.” Mark Fonds. Oral

Abstract: Bycaught benthos were examined onboard the ship from catches made with the longitudinal chains vs. the normal chain mats. There were significant reductions for some bivalves and snails but increases in epifauna. Flatfish catches were reduced, but for some species this included undersized fish that would have been discarded. Some experiments were also conducted with electrical stimulation on beam trawls. There were reductions in nearly all benthos species, including many that were significant, for both infauna and epifauna. However, the catches of flatfish were also reduced so trials were made with one tickler chain added back to the electrodes. In this case the benthos bycatch reductions were not so impressive, with slight reductions for infauna but increases for epifauna.

Discussion: These trials were made at realistic speeds for the smaller beam trawlers since technological considerations limit use of present electrical stimulation technology to shorter beams. The longitudinal chains also show promise if fish catches can be increased. After decades of trawling the benthos species in the North Sea are dominated by small-sized species compared to areas with shorter histories of beam trawling. The increased catches of epifauna must be explained on a species-by-species basis. At the present time there is an EU ban on electrical fishing that must be lifted to implement this technique commercially, but there may also be ethical concerns. The modest reductions in bycatch rates in conjunction with the reductions in catch of target species are discouraging, especially in view of possible damage to uncaught animals. There were differences between the trawls that went undiscovered until well into the experiments and this could have confounded the results.

Development of scallop dredge instrumentation. Philip MacMullen and Roger Horton. Oral

Abstract: Instrumentation is being developed to understand dredge dynamics and to investigate the physical impacts of dredge operations on scallops and the seabed. A "model scallop" was developed with an embedded 3-way accelerometer and datalogger, and this device also recorded rotation. This could be used to study impacts on the scallops themselves as well as survive and function when attached to the dredge. Tests of dredge dynamics were done by attaching the model scallop to the dredge frame or loosely tethered within the dredge bag. The instrumentation can be used to compare and develop characteristic signatures for specific ground types. The system can be used to develop selective dredges. Other instrumentation was developed to measure dredge towing tension, tooth bar angle from the horizontal, tooth angle of attack to the seabed, tooth penetration, and other physical dredge performance parameters.

Discussion: It is possible to make model scallops of varying sizes in order to study observed size differences in type and severity of injuries. There is interest in seeding model scallops in the dredge's path to study capture situations.

Reducing sea bed contact of shrimp trawls. Pingguo He and Dave Foster. Oral with paper

Abstract: Bottom trawls may alter the physical and/or biological characteristics of the seabed as a result of the trawl doors, bobbins, discs, tickler chains, chafing mats, and other gear components coming into contact with the seabed. In order to reduce the seabed contact of the ground gear, flume tank tests and preliminary sea trials were conducted of shrimp trawl with a modified ground gear. Flume tank tests indicate that the number of bobbins on the Skjervoy footgear may be reduced to as few as nine without significantly altering the geometry and stability of the trawl. The nine-bobbin rig would only contact between 4 to 12% of the seabed between the wingends, a five-fold reduction when compared with the area of seabed likely contact by the conventional 31-bobbin rig. Reducing the number of bobbins on the footgear from 31 to 9 reduced drag by 12%, reducing fuel consumption. However, further tests are required to identify mechanisms to stabilize the trawl rigged with drop-chains, such as the weight of the drop-chain, fishing line floatation or fishing line material. Preliminary sea trials indicate that footgears with reduced numbers of bobbins may result in footgear intermittently off bottom, but this may not necessarily result in reduction in catch of shrimps. Trawls with less bobbins on its footgear was more likely to incur damage, especially on grounds with rough sea and bottom conditions.

Discussion: Most of the gear damage was seen on the lower wing panels, probably due to the chain cutting into the mud and deflecting it up into the wing. It might be possible to deter this by threading rubber discs onto the chain. The objective was to reduce the area contacted by bobbins, not necessarily to reduce the sum of pressure forces on the seabed, but since the use of fewer bobbins reduces the overall effective weight of the gear there is probably no problem.

Sampling of benthos from commercial vessels in western waters. Alison Hewer and Bill Lart, presented by Phillip MacMullen. Oral

Abstract: Seafish was contracted by the UK Fisheries Departments to study the feasibility of sampling benthos ('trash') on commercial fishing vessels. For a variety of reasons the sampling took place in parallel with another exercise sampling discards of finfish species. The exercise involved beam and otter trawlers and was carried out in ICES areas VIIe and VIIf. The objectives of the work were to:

- develop protocols for collecting, storing and analysing samples of benthos,

- investigate the relationships that might exist between fishing methods and the species of retained benthos, target and discarded fin fish, and
- compare results with those from other workers.

The work was undertaken in parallel with a finfish discard sampling exercise taking place entirely aboard commercial fishing vessels. Samples were then taken to a laboratory ashore and the species present were identified. A cluster analysis was performed on a simple presence/absence basis. Analysis of 6 trips taken from 18 hauls showed clear differences in the proportion of retained benthos between gear types with significantly more being present in the beam trawl trips. Comparison with results obtained from a series of research vessel cruises showed a different association between benthic species, substrate and target species for chain matrix beam trawls. This indicates that commercial vessels may target a wider range of ground types that FRVs. It is concluded that it is possible to obtain information on the environmental effects of fishing from commercial benthic bycatch studies and that it is possible to relate habitat, benthos, fish species and gear type. Further work is being undertaken which will result in 12 months' data becoming available.

Discussion: The willingness of fishermen to participate in collection of data on discards depends on how much threat they feel concerning the use of the data.

Damage of deep water coral reefs (*Lophelia pertusa*) and fish distribution on and off the coral reefs outside the Norwegian coast. D. M. Furevik, J. H Fosså, and P. B. Mortensen. Oral with paper

Abstract: The deep water coral reefs (*Lophelia pertusa*) have been known to fishermen for a long time. For the last three years the Institute of Marine Research has studied the coral reefs closer. The coral reefs are distributed along the Norwegian coast especially from mid Norway and further north. Several of the reefs have been damaged by trawler activity, and two coral-reef areas have already been protected from active fishing gear. Fishing trials with longline and gillnets showed that especially redfish but also tusk and ling were more abundant in the coral-reef areas then outside. The three fish species had different feeding regimes. Ling fed mainly on other fish species, while tusk fed mainly on bottom dwelling invertebratae as for example crustaceans and anneuda. Redfish fed exclusively on pelagic crustaceans.

Report from Topic Group B. Using gear technology to understand and reduce unintended effects of fishing on the seabed and associated communities: background and potential directions. Topic Group Chair: Craig Rose. See Annex 3 for text.

Discussion: This information and/or methodology might also be relevant to concerns about the impacts of fishing gear on seabed oil-industry structures and vice versa.

The Working Group broke out into **two discussion groups** to consider proposed, current, or recent research on fishing operations and their impacts (Philip MacMullen, convenor), and considerations for applying the results of such research (Arne Carr, convenor). Following these discussions the Working Group as a whole reconvened and was briefed on the discussions.

1) Proposed, current or recent research on fishing operations and their benthic impacts. Philip MacMullen.

Country	**Topic**
Belgium	reducing benthos retained by beam trawls and electrotrawling studies to reduce ground contact
Canada	scallop dredging – seabed mapping and effort targeting (commercial) plus other habitat mapping
Canada	Flume tank tests of shrimp trawl ground contact
Euroteam 1	Bivalve dredge instrumentation, benthic impacts and mitigation strategies from Northern Europe to Mediterranean
Euroteam 2	Completed work on beam trawl instrumentation, mainly measuring compression forces
Euroteam 3	ghost fishing impact and mitigation studies from Arctic to Mediterranean waters

Country	Topic
France	New whole trawl and door impact studies including mathematical modelling and benthic impacts/sea trials
Germany (Rostock)	Sediment tank testing of forces generated by gear components and their impacts on benthic organisms
Germany + partners	Proposed study on benthic impact of beam trawling for *Crangon*
Ireland	Impact of *Nephrops* trawls on Irish Sea grounds
Netherlands	Minimising benthos retained by beam trawls and electrotrawling studies
Norway	Impacts of all gears on *Lophelia* reefs, conservation strategies
Norway	New long term trawl impact study in Barents Sea comparing the impacts of varying levels of trawling activity.
Norway, Canada and US	Regular ground dragging exercises to retrieve lost gear
Sweden	Impact of *Pandalus* trawling on previously closed grounds using multiple (~30)indicators for benthic impacts
UK	Flume tank and full scale trials of doors with wheels (commercial)
USA (New England)	Essential Fish Habitat (EFH) identification/mapping
USA (Alaska)	footrope instrumentation
USA (Alaska)	Evaluating var. ground survey techniques, impact of trawling on hard and soft substrates using submersibles and ROVs
Flume tanks	General and continuing use for feasibility trials of new devices

Issues considered for each research item:

- How was the work initiated and who set the priorities?
- Were clear, quantifiable objectives set?
- Any other indicators used for achieving objectives?
- Indicators used for other impact studies?
- Experiences of X-disciplinary work between gear technologists and benthic people?
- Need and potential for standardising methodology within and between disciplines?
- Relating experimental and commercial conditions
- Establishing cause and effect in complex relationships

2) Considerations for applying the results of fishing impact research. Arne Carr.

This group first focused on what has stimulated the research?

The main initiative in the United States and Canada has been related to concerns about actual fishing gear impacts and the national initiatives to identify and designate areas as Essential Fish Habitat (EFH). Some general scientific interest has also driven some of the research.

In Europe interest in fishing impacts has had similar motivations, but there has been specific interest in reducing the negative effects of beam trawling and some other trawling in the Irish Sea and North Sea.

Recent, current, and new research was reviewed and is listed in the group report. This discussion also noted some industry-driven research in Eastern Canada and in Alaska.

Issues of critical concern for the group included the following:

- Lack of communication and discussion between those undertaking the research and fishery managers;
- Need to include the insight of commercial fishermen;
- Difficulty of determining cause and effect;
- Need for standard research protocols;
- Communication amongst researchers to be aware of methods and results.

One issue of particular interest was the matter of determining what specific damage should be studied in any particular situation, and means for quantifying results relating to these damages. A suggestion was made to review the literature on the impacts of navigational dredging as some criteria may have already been established in this field.

The discussion then focused on fishing gear and the possible and potential impacts of the components of each type of fishing gear, both active and passive. A table was constructed that outlines the components, the relative bottom area contact of each component, and the type of effect the component induces. The reader is cautioned that the area contact and the impact effect are not comparable between the active and passive fishing gears. Further, impacts vary by specific component, by gear design, by mode of operation, and the *in situ* conditions and habitat.

8 NEW BUSINESS

8.1 Meeting Place and Time for the 2001 FTFB Working Group meeting

WGFTFB and WGFAST were invited by Dr David Somerton and Dr Bill Karp to meet in Seattle, Washington USA. It was suggested that Study Groups be scheduled for 21 & 22 April, while the WGFTFB and WGFAST would meet between 23 and 27 April, with the FAST/FTFB Joint Session being held during the middle of the week.

8.2 New Chair for WGFTFB

Ole Arve Misund, Chair of the Fisheries Technology Committee, described the ICES procedures for appointing a Working Group or Study Group Chair.

David Somerton and Phillip MacMullen have both volunteered to serve as the new Chair of the WGFTFB. The Group recommends that the choice be made by the Fisheries Technology Committee at the Statutory Meeting for its recommendation to the Council. The two volunteers will each prepare a brief statement of their interest to be posted on the FTFB web site. Working Group members who wish to express a preference or other comment will direct these to their national representative prior to the Annual Science Conference.

9 RECOMMENDATIONS FOR A SPECIAL TOPIC TO BE CONSIDERED AT THE 2001 FTFB WORKING GROUP MEETING

Review of methods to reduce the variance of abundance indices obtained from assessment surveys using fixed and mobile fishing gears. Proposed by David Somerton.

Priority	Trawl surveys provide necessary information for tuning fisheries management models. Producing more precise indices of abundance without an increase of survey costs is considered, by all fisheries agencies, to have a high priority.
Scientific Justification	Research on operating procedures and sampling designs of trawl surveys and on the analysis of trawl survey data has progressed considerably during the last decade. Because of declining budgets, fisheries agencies must be increasingly concerned with survey efficiency and obtaining the most precise abundance indices possible with available resources. This topic is intended to attract fishery technologists as well as statisticians and stock assessment scientists.

Relation to Strategic plan	The proposed topic is consistent with the ICES scientific objective: Developing the scientific basis for sustainable use and protection of the marine environment, including living marine resources.
Resource requirements	No new resources will required for consideration of this topic at the annual meeting of the FTFB Working Group
Participants	Approximately 50 members and guests are expected to attend the meeting.
Secretariat facilities	None
Financial	No financial implications
Linkages to Advisory Committees	There are no direct linkages to the advisory committees
Linkages to other organisations	The work in this group is closely aligned with similar work in the FAST Working Group

10 SUGGESTED WORK ITEMS, 2001

In addition, the FTFB Working Group also made the following suggestions for work to be initiated prior to the next meeting in April 2001:

To develop and review techniques which can be used to evaluate the effectiveness of introduced technical measures." A. Revill (England), P. Suuronen (Finland), and N. Graham (Scotland).

<u>Justification</u>: Technical measures (specifically gear modifications in our case) have been and continue to be used as a tool by fishery managers. Predictive evaluations as to the effectiveness are generally made prior to introduction of such measures. However, very few studies have been made post-introduction as to the actual effectiveness. Such evaluations are necessary in order to justify the use of technical measures in management strategies. A post introduction evaluation of the true effectiveness of a measure would also provide valuable information as to the reliability of all predictive assessments. This principle is a common feature in many fields of science.

<u>Relation to strategic plan</u>: With reference to the ICES scientific objectives, this topic addresses the issues of quantifying human impact, the issues of uncertainty and risk and provides a forum for a multi-disciplinary approach.

<u>Discussion</u>: It is essential to consider means for evaluating the effectiveness of technical measures right from the outset. Restricting the discussion to gear modifications might possibly limit the interest. Objectives of the technical measures might be spelled out in the topic and include such issues as bycatch and habitat impact as well as selective fishing. Evaluation of effectiveness implies a need for expertise that lies outside WGFTFB.

<u>Disposition</u>: It was proposed that this be formulated as a Suggested Work Item calling for a small topic group chaired by Revill to review the subject by correspondence and present a report at the next meeting of the WGFTFB.

To determine the use of chafing gear and net strengtheners on codends in regard to need, impact on selectivity, and whether fisheries in certain locations can have this gear reduced and the codend area of the trawl net modified to improve selectivity." Arne Carr and Chris Glass.

<u>Discussion</u>: The "chafing strip" as used experimentally in New England is a narrow strip along the bottom of the codend rather than all the way or halfway around as in common commercial practice. Lastridge ropes also affect selectivity.

<u>Disposition</u>: Arne and Chris will develop this idea as a Suggested Work Item to produce a questionnaire/survey to be circulated and analysed before the next WGFTFB meeting.

11 SUGGESTED TOPIC FOR A THEME SESSION FOR THE 2001 ANNUAL SCIENCE CONFERENCE

What information does ecosystem management need from ecologists and gear technologists to assess ecosystem effects of fishing and implement policies. WGECO (co-chair: ?), BEWG (co-chair: Karel Essink) & WGFTFB (co-chair: Dick Ferro). Proposed by Dick Ferro.

Justification: The study of ecosystem effects of fishing requires the expertise of both ecologists and gear technologists. There is a need to establish a framework to ensure that common priorities are set, common objectives are agreed upon, and consistent methodologies applied.

The session might address such topics as:

1) Adequacy of information currently available
2) Methods of data acquisition
3) Design of experiments to produce relevant and useful conclusions for management
4) Definition of medium-term strategies to provide management information
5) Priorities for further work

12 SUGGESTED TOPIC FOR A THEME SESSION FOR THE 2002 ANNUAL SCIENCE CONFERENCE

Unaccounted mortality in fisheries. Proposed by Mike Breen and Alain Fréchet.

Justification: Over the last decade, there has been considerable new and innovative research into identifying and estimating unaccounted sources of mortality in fisheries. These are discard mortality, illegal, misreported, and unreported mortality, escape mortality, drop-out mortality, ghost fishing mortality, avoidance mortality, and habitat mortality. As it has been pointed out in many instances, this area of research needs to be better understood by researchers, managers, and industry. Many activities and a co-ordinated collaborative workshop on this topic are planned in 2001, where gear technologists and assessment biologists will perform case studies and simulation of the various effects of unaccounted mortality in stock assessments. A review of the current knowledge in unaccounted mortalities, means of incorporating such estimates into assessments and review of research priorities will profit attendants and is likely to stimulate further work that could be presented at the ICES Theme Session of 2002. Given these issues the Annual Science Conference is the most likely forum where all disciplines such as gear technologists, stock assessment biologists, and fisheries managers will be present and could be sensitised to unaccounted mortality issues.

13 SUGGESTED MEETING PLACE AND TIME FOR THE 2002 FTFB WORKING GROUP MEETING

Prof. Józef Swiniarski, Dr Otto Gabriel, and Dr Matthias Paaschen propose that the meeting be held at Insko, Poland in June at the model research station of Sczeczin University, alternatively in Rostock, Germany in April at the University of Rostock and the Federal Research Centre of Fishery.

14 SUGGESTED SPECIAL TOPIC FOR THE 2002 WG/FTFB MEETING

Engineering methods in fishing technology. Proposed by Otto Gabriel, Matthias Paaschen and Prof. Józef Swiniarski

Model tests and mathematical simulation of fishing gears. This topic should have relation to the prediction of selectivity in the early stages of gear design. Variation of parameters and materials and their influence on the fishing gear (shape, strength, and loads).

15 OTHER ISSUES

FTFB Web site. David Somerton.

Discussion: The WG recommend that the web page be further developed over the next six months then formally request that ICES acknowledge and support it.

Theme session for 2000 Annual Science Conference on "Efficiency, Selectivity, and Impacts of Passive Fishing Gears." Arne Carr, Chair.

The Working Group were informed of this Theme Session and encouraged to submit presentations.

Question to the membership: Should the Working Group retain the current format? The group is generally satisfied with this format. Barring unforeseen developments the WGFTFB would prefer a 3-day session with one day for the Joint Session.

16 LIST OF PARTICIPANTS

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17 NATIONAL REPORTS

ICES FISH CAPTURE COMMITTEE

WORKING GROUP ON FISHING TECHNOLOGY AND FISH BEHAVIOUR – HAARLEM, APRIL 2000

REPORT OF ACTIVITIES - BELGIUM

Agricultural Research Centre – Ghent

Sea Fisheries Department

R. Fonteyne and H. Polet

SELECTIVITY AND DISCARDS REDUCTION

The study on the development of environment friendly fishing methods for brown shrimp (*Crangon crangon*) in the Belgian coastal waters was continued. The main aim of this study is to develop a shrimp trawl that (a) fishes in a species and length selective way, (b) reduces the unwanted by-catches, (c) thus reducing the impact of this coastal fishery on the environment and (d) improves the quality of the catches. The experiments with a sorting grid were concluded. The systems worked on flat hard sandy bottoms and clean catches. As soon as trials were carried out on commercial vessels, however, with large catches and a range of fishing grounds, too much commercial shrimps were lost and clogging was a serious problem. The project to use electrical pulses as an alternative stimulation in the shrimp beam trawl was continued and offers good perspectives. This project aims at the development of a shrimp trawl that increases the species and length selectivity of the groundrope. The first sea trials were quite successful and proved at least that the pulses stimulated shrimps and no other animals.

The EU-project Fair PL-98–4164 "*Nephrops* trawl discard reduction using activating selection grids" was continued and aims at the study of the possibilities of using sorting grids in the *Nephrops* fishery to reduce discarding.

Related to selectivity was the MESH project in which mesh measurement methodologies for fisheries inspection and research were evaluated. The Sea Fisheries Department acted as co-ordinator of this EU Concerted Action in which all EU fishing nations were represented. The project was completed and a proposal for the development of an objective mesh gauge was submitted in the frame of the EU 5th Framework Programme.

Cooperation was given to the EU-project aiming at the design and implementation of a selectivity database.

Ecological effects of fishing activities

The EU-project FAIR PL97–3809 "Reduction of adverse environmental impact of demersal trawls" was continued and runs in co-operation with the Martin Ryan Marine Science Institute (National University of Ireland, Galway), the Rijksinstituut voor Visserij Onderzoek (IJmuiden, the Netherlands), the Nederlands Instituut voor Onderzoek van de Zee (Den Burg, Texel, the Netherlands), Rijkswaterstaat Directie Noordzee (Den Haag, Netherlands) and the Bundesforschungsanstalt für Fisherei (Hamburg, Germany). The main objective is to assess methods to reduce the adverse impact of demersal trawls on benthic marine organisms through changes in net design and alternative methods of stimulation. Various benthos escape devices were tested. A square mesh window in the belly of the net, just in front of the cod-end looks very promising.

The EU sponsored project TRAPESE (Trawl Penetration in the Seabed) to study the physical impact of trawls on the seabed was completed. The other partners are the University of Rostock (co-ordinator, Germany), RIVO-DLO (IJmuiden, the Netherlands) and the Netherlands Institute of Applied Geoscience TNO (Utrecht). In-situ measurements were made involving side-scan sonar and RoxAnn observations of fishing tracks. The penetration depth was determined by comparing lithological characteristics and X-ray photographs of boxcorer sediment samples taken on the track before and after fishing.

NATIONAL REPORT CANADA,

S. J. WALSH

Dept. Fisheries and Oceans, Science Branch, Northwest Atlantic Fisheries Centre St. John’s, Newfoundland Canada

PROJECT LIST

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1)*Size Sorting Grid for Inshore Shrimp Fishery*: Size sorting systems have proven very successful in the offshore shrimp fishery. This Canadian Centre for Fisheries Innovation project aimed to provide a preliminary assessment of the effectiveness of a size sorting

grid similar to that designed for inshore use. An 11mm size sorting grid was designed by the Marine Institute of Memorial University of Newfoundland and fabricated by industry. This was tested initially in the flume tank and later during sea trials for 5 days. The size sorting grid was installed behind the existing Nordmore grid.

2*) Seabed Friendly Shrimp Trawl:* For some time, Fishery Products International Limited has been working on the development of a seabed friendly trawl that will reduce the environmental impact on bottom environment and habitat during commercial use. This project, carried out with the Canadian Centre for Fisheries Innovation and the Marine Institute of Memorial University of Newfoundland, examined modifications to the footgear of a trawl.

3) *Testing of a New Design Deepwater Turbot Trawl*: During the past year, the Canadian Centre for Fisheries Innovation and the Marine Institute of Memorial University of Newfoundland have worked in cooperation with Fishery Products International to design, construct and test a new "Millennium" deep water turbot trawl for FPI vessels in the 1500 horsepower class.

4) *Underwater Observations - Shrimp Pot Fishery:* With increases in shrimp stocks and quota allocations over the past few years, larger vessels have been able to take advantage of the opportunity by harvesting the resource using the traditional otter trawl. In order for smaller vessels to participate in this lucrative fishery in the near shore areas, new harvesting techniques will have to be adopted. Shrimp pots and beam trawls, if effective, would allow smaller vessels to participate and the cost of gear-up could be reduced substantially as compared to otter trawling. This Canadian Centre for Fisheries Innovation-Marine Institute of Memorial University of Newfoundland project carried out underwater observations of shrimp pots using a video camera and evaluated and suggested modifications with respect to pot design and operational practices. Two types of pots were evaluated: (1) Maine-style rectangular shrimp pot and (2) Modified crab pot.

5) *Evaluation of the Performance of Braided Polyethylene Netting and Ultra*

Cross Dynema Netting: The majority of shrimp trawls being used by harvesting enterprises in the Newfoundland industry are made of braided polyethylene (PE) netting

due to lower costs, availability and tradition of using PE netting. Recent R & D has lead to the emergence of super-strong fibres such as Spectra and Dyneema. Even though they are more expensive, their use in trawls cuts fuel consumption. This Marine Institute of Memorial University of Newfoundland- Canadian Centre for Fisheries Innovation project will test trawls made with these fibres in the flume tank and at sea for efficiency and effectiveness.

FISHERIES AND OCEANS CANADA

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1)Impact of Trawling on Seabed: Flume tank testing was conducted to observe the effect on trawl performance of reducing the number of steel bobbins from 31 to 9. Sea trials were conducted to determine if this reduction in the number of rollers would result in loss of shrimp catch.

2)Size Sorting in Cod Growout Cages: A rigid grate system was used to separate small from large cod during a cod grow out aquaculture project. This separation is usually done by hand and is time consuming and stressful to the fish. Using the grate system, which can be done when towing the cages, is faster and less damaging to the fish.

3)Recapture of escaped salmonoids from aquaculture cages: Tests were conducted to investigate the effectiveness of small mesh traps to recapture salmonoids which had escaped but were still in the vicinity of the aquaculture cages.

Fisheries and Oceans, Canada

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1) ***Rigid frame survey trawl for shrimp:*** The first challenge of the research project was to improve the catchability of small shrimp. This led to the development of a new type of fishing gear. A rigid frame trawl was designed to: 1) catch a constant proportion of all size shrimp present in the sampling area; 2) be easily operated on a rear trawler of 19.2 m; 3) avoid mud, rock and sessile organisms in the catch. The rigid frame is 4.6 m wide by 2.4 m high, mounted on skates which are the only parts of the gear in contact with the ocean floor. The trawl is 20.4 m in length with a mesh size of 44 mm. A liner of 9 mm was added to the last 15.5 m to retain small shrimp. The lower part of the net is fixed at 20 cm over the bottom. The rigid frame trawl proved to be very efficient at catching one and two year old shrimp that would otherwise not be caught or retained by commercial or existing research fishing gear.

ICES FISH CAPTURE COMMITTEE

WORKING GROUP ON FISHING TECHNOLOGY

AND FISH BEHAVIOUR

Haarlem 10. - 14. APRIL 2000

National Report of Activities

GERMANY

Federal Research Centre for Fisheries

Institute for Fishery Technology

Codend selection in the Baltic cod trawl fishery

The investigations with codends of Baltic cod trawls were continued in cooperation with colleagues from Poland.

Differences in the 50 % length of 120 mm diamond mesh codends were found for single twine meshes (L50 = 38 cm) and double twine meshes (L50 = 33 cm).

With a codend of 103 mm diamond meshes turned by 90° L50 could be increased up to 40 cm.

The investigations of multi panel codends (6 panels, 3 with diamond meshes, 3 with square meshes) were continued.

Investigations to improve the selectivity and to reduce the discards of beamtrawls in the brown shrimp fishery

In cooperation with Rijksinstituut voor Visserijonderzoek IJmuiden (coordinator), Centrum voor Landbouwkondig Department Zeevisserij Oostende, and University of Newcastle upon Tyne – Dove Marine Laboratory the EU research project DISCRAN (Reduction of discards in *Crangon* trawls) was started to reduce the bycatch of young fish and undersized brown shrimps. With sorting grids of 20 and 30 mm bar distance the total catch was reduced by 30 % – 41 % (30 mm) and 20 % – 47 % (20 mm). The catch reduction of marketable shrimps was only 5 % – 9 % (30 mm) and 7 % – 14 % (20 mm).

An image processing system was developed and used for length measurements of big quantities of shrimps in a considerably shorter time than with a traditional measuring board.

Development of a longline system for the eelfishery in the Baltic Sea

The enormous amount of bycatch (up to 90 %) of undersized fish of all other species e.g., cod, plaice etc. in the Baltic trawl fishery on eel can be reduced by means of alternative fishing techniques, e.g., longlining. The longline system developed for this purpose at the Institute for fishery technology was modified and improved. Especially the replacement of the random baiter by an exact baiter increased baiting rate and catch rate.

Investigations in the bycatch of ducks in the Baltic inshore fishery with set nets

The bycatch of ducks in the Baltic set net fishery could not be reduced by modified technical parameters of the set nets e.g., net height, mesh size, hanging coefficient. Ducks are mainly concentrating and diving on mussel grounds where they will find sufficient food. If these areas are closed for the set net fishery it should be possible to reduce this bycatch considerably.

Modified design of a jet beamtrawl

With the modified jet beamtrawl twenty nozzles of ½“ diameter are mounted on a flexible hose running.5 m in front of the groundrope.148 cubm/h water of 3 bar are supplied by a pump of 33.0 kW mounted on the beam. Compared to a traditional beam trawl with tickler chains the catch – mainly plaice and dab - as well as the bycatch was still lower with the jet beam trawl.

Investigations in hydroacoustic methods in stock assessment

The application of hydroacoustic methods in stock assessments of pelagic species was extended and improved in close cooperation with other member countries of ICES, especially in the North Sea (herring) and the Baltic (herring, sprat). The hydroacoustic data are stored in a database at the Danish Institute for Fisheries Research, Hirtshals.

University of Rostock

Institute of Maritime Systems and Flow Technology

Impact of towed fishing gears on the seabed (TRAPESE)

The EU research project "TRAWL PENETRATION IN THE SEA BED (TRAPESE)”, joint project of Rostock University (coordinator), Centrum voor Landbouwkondig Onderzoek, Department Zeevisserij Oostende, Rijksinstituut voor Visserijonderzoek IJmuiden and the Netherlands of Institute of Applied Geoscience Utrecht, was finished in December 1999.

The main target of the project was the quantitative analysis of the mechanical influence of a towed fishing gear on the sediment of the sea bottom. The measured data and information obtained by means of digital image processing procedures can be used for a qualified forecast of possible mechanical modifications of the sea bottom due to fishery activities.

Systematic laboratory tests with models of fishing gear elements as well as in-situ experiments at sea with beam trawls of different dimensions were performed to measure the penetration into the sediment, the local pressure load on the sea bottom as well as the load distribution in the sediment.

The main results of the research work are:

1. The development of a qualified methodology for the evaluation of effects on the sea-bottom due fishing activities with towed gear.

2. The supply of reliable measuring data, picture information and computer software.

The direct influence of the fishing gear on benthic flora and fauna was not determined.

Investigations of codend selectivity in the Baltic flatfish fishery

Investigations with full scale trawls and models of trawls prove that a direct connection exists between the construction of the trawl´s afterpart and the local flow and pressure distribution in this part of the trawl.

1999 first investigations of possible effects of a changed flow passing through the net on the selectivity characteristics of fishing gears were started at the Rostock University in coopration with the Institute of Fishing Technology of the Federal Research Centre for Fisheries Hamburg. Laboratory tests and full scale measurements were concentrated on trawl codends for the flatfish fishery in the Baltic Sea.

Calculation of netlike structures

The algorithms for the calculation of hydrodynamically loaded, heavy and ideally flexible systems consisting of individual ropes or netlike twine segments were already presented in Lorient / France in 1997 under the name RopeNetCalculator. Apart from modelling large mesh structures (for example foreparts of midwater trawls), test calculations with a procedure for modelling trawl´s afterparts were performed. Here the formation of substitutional meshes is concerned, which is required for the calculation of the small mesh section of complete trawls. In a special strategy trawl´s afterparts and foreparts are linked numerically in a way that their separate calculation can be justified. Thus the determination of shape and load of the single elements is already possible on a normal PC with tolerable computing time.

Long term underwater video observation

In the Baltic Sea approx. 10 km West of Warnemünde at a depth of 11–12 m an artificial reef has been constructed and operated for almost 5 years for research purposes.1997 the Rostock University started a long term observation project using an UW video camera with wireless transfer of the video signals from a mast near the reef to a laboratory ashore at a distance of about 10 km. Big schools of cod could be observed, which roamed around and through the reef structures. At present the extension of the reef structures is taken into consideration, in order to get a higher concentration of fish at the reef which might be of interest for the commercial fishery.

Progress Report The Netherlands, 1999–2000

Fishing gear technology related projects carried out at RIVO-DLO, by B. van Marlen.

1. Concerted Action SELDAT-2 (FAIR-CT98–4044, Selectivity Database)

The project started in October 1999 with the objective to create a database with fishing gear selectivity information. Two small teams were established that worked primarily by correspondence and then met to produce a Requirement Specification document, that forms part of the Invitation to Tender Document. This will be discussed by a Steering Committee in April 2000, and then published to find a consultant for the physical design of the database.

2. Project: Separation of mackerel and horse mackerel in pelagic pair trawling.

Further trials at sea were conducted in the fall of 1999 on the commercial pair trawlers SCH-22 and SCH-23. The emphasis was on the possibility of identifying single targets of fish using advanced echo-sounder equipment (SIMRAD EK-500).

3. Project: TRAPESE (Study 96/006, Trawl penetration in the sea-bed).

The project was finalised in December 1999. Major conclusions are: The physical impacts of fishing gears on the sea bed are in general limited due to variability of sediments in time and space. The average pressure of beam trawl shoes exerted on the bottom varies from 1.0 to 11.0 kPa. The depth of disturbance ranges from 1 to 8 cm depending on sediment and gear type, with the higher values in softer grounds. In-situ or laboratory based direct observations on the actual collision of gear components with biota on the sea bed are recommended.

4. Project: REDUCE (FAIR-CT97–3809, Reduction of adverse environmental impact of demersal trawls)

Technical trials were carried out on RV ISIS in January 1999 and RV TRIDENS in March 1999 on drop-out zones in the lower panel of beam trawls. Sole catches seem most sensible to changes in the net design. Creating large meshes in the lower panel resulted in a loss in marketable fish ranging from 25% to 35%. A 15 % to 30% loss was found for plaice and dab. These losses in flatfish can be diminished by reducing the drop-out zone. Heavier shellfish seem to drop out of the net through the large meshes. A 20% to 25% reduction in benthos catches in weight can be, but the penalty is a loss in commercial catches, particularly sole, and to a lesser extent plaice and dab.

Alternative chain arrangements were studied in two trips on RV TRIDENS in March 1999 and in October 1999. Prior to the sea trials designs of alternative chain rigs were tested at model scale (1 to 5) in March 1999 in the SEAFISH tank in Hull. A parabolic arrangement of chains running from the beam resulted in higher catches of flatfish and benthos, contradictory to the objective. Parallel chains caught substantially less sole, and marginally less plaice, but also significantly less benthos, and if sole catches could be enhanced this configuration might be promising.

Trips on electrical stimulation were carried out in April 1999 and November-December 1999 on RV TRIDENS in collaboration with VERBURG-HOLLAND B.V. of Colijnsplaat. The stimulation field was brought 3m further back in the trawl and the net adjusted by commercial skippers. The results were again analysed using the SAS-software package. Quite similar results were found as in 1998. Sole catches were of the same order of magnitude for the electrified net, but plaice catches were about half in spite of the gear modifications. Benthos weight was 40–50% less for the electrotrawl. Length selectivity was not observed. Survival tests revealed that the survival of sole and plaice with electrical stimulation was not worse.

5. Project: DISCRAN (Study 98/012, Reduction of discards in *crangon* trawls)

The project started in March 1999 to run for two years. It is a follow-up from Study 94/044 RESCUE. The objective is to develop selectivity devices appropriate to the European shrimp fishery in order to reduce discarding of undersized shrimps and (predominantly) juvenile flatfish. Flume tank trials on sorting grid and veil designs were carried out in the SEAFISH tank in June 1999. An extended series of sea trials was carried out in November-December 1999 on RV ISIS on experimental beam trawls fitted with a 60mm veil, and sorting grids with bar spacing of 15mm and 20mm, compared against a standard beam trawl. The data is still to be analysed.

UK (Scotland) - Report of Activities in 1999

FISH BEHAVIOUR EFFECTS ON SELECTIVITY

Trials with Baltic panels to reduce discarding of immature cod were carried out on FRV *Clupea*. Bad weather severely hampered RCTV observations of escape behaviour. Large quantities of fish were washed out through the side panels on the surface using a hooped cover, suggesting that this technique of assessing selectivity may not be appropriate for such panels.

GEAR SELECTIVITY

The Marine Laboratory has been closely involved with developing a range of technical measures to improve whitefish conservation which the UK may soon introduce unilaterally to reduce the discarding of the good 1999 haddock year class. With this in mind, a simulation program has been developed to predict the catch, discards and fate of survivors resulting from fishing a gear with specific selective properties on a known population of haddock. The aim is to allow a fisherman to see the possible benefits and losses which changes in codend design will have. This program was demonstrated at the Fishing 2000 exhibition in Glasgow.

At the request of the Scottish White Fish Producers Association two comparative fishing trials using 90mm square mesh panels on seine netters (flydraggers) were carried out. Analysis of the catch data indicated a 40% reduction in undersized haddock retained and a minimal loss of marketable fish when such panels were used.

An EU project to measure the effect of a 90mm square mesh panel on the discards and landings of a demersal trawler was initiated by the North Atlantic Fisheries College, Shetland and the Marine Laboratory, Aberdeen. Trials commenced in July 1999 and will continue for one week per month throughout 2000.

GRID SELECTIVITY

In collaboration with several other institutes FRS Marine Laboratory has completed the first phase of two FAIR projects. **Eurogrid** aims to develop a selective whitefish grid system for towed gear fisheries in the North Sea and adjacent waters while **Netrasel** has a similar objective for species separation and *Nephrops* size selectivity in the North Sea and species separation in the Aegean Sea. A joint cruise with the Institute of Marine Research, Bergen was carried out on FRV *Scotia* to test the efficacy of an articulated steel grid in mackerel size selection.

FISHING EFFORT

The capture efficiency of commercial scallop dredges was investigated using new underwater diving techniques. Dredge efficiency values obtained from the six underwater surveys completed were 45.1%, 29.2%, 32.9%, 49.3%, 14.7% and 26.3%. This gives a mean of 32.9 %. Data from the post dredging divers survey showed that 40.9 % of non-recessed scallops and 44.7 % of recessed scallops that were missed (i.e., escapes) by the gear were <100mm (MLS). Damage by the gear was recorded on all scallop escapes from the six divers surveys using a new classification.

SURVEY GEAR

A new 896m pelagic sampling trawl with 100 tonne mackerel bag and 8 square metre otterboards fitted with one spoiler was tested in near-surface and mid-water modes on FRV *Scotia*. Seventy seven instrumented data blocks at various warp lengths and towing speeds were carried out but no fishing trials have yet been undertaken.

OIL INSTALLATION / FISHING GEAR INTERACTION

A new project to investigate the dispersal of cuttings pile components by demersal towed gears was initiated.

ROUNDFISH AND *NEPHROPS* SURVIVAL AFTER COD-END ESCAPE

This EU funded project was completed, in collaboration with Denmark, Sweden and Norway, and the final report submitted (Nov 1999). The key findings of the work were the high survival potential of escaping haddock (86 - 97%), whiting (90 – 100%) and *Nephrops* (73 – 95%). This compared favourably to the relatively low survival of discarded *Nephrops* (19 – 39%). Haul towing duration had no significant effect upon subsequent escape mortality of haddock and whiting. However, it was demonstrated that the collection of fish in a codend cover after escape was inducing a significant and unintentional mortality in the observed specimens. Work is now continuing to develop a method of sampling escaping fish without introducing this experimental error.

PHYSICAL AND MATHEMATICAL MODELLING

The SFIA flume tank was used to study the pulsing of a half scale cod-end both with and without a small mesh cover attached. Although cod-end movement was similar in both cases the torque required to move the covered cod-end was much greater. Theoretical analysis of equations governing cod-end geometry and twine bending identified a non-dimensional parameter which characterises the geometry of cod-ends made of stiff twine.

An EU funded project on developing a predictive selectivity model was successfully completed.

ICES Working Group on Fishing Technology and Fish Behaviour
(Haarlem, The Netherlands, 10–14 April, 2000)

Progress Report Spain, 1999–2000

Fishing Technology related projects carried out at AZTI (Technological Institute for Fisheries and Food) by Esteban PUENTE & Jose FRANCO.

A study to identify, quantify and ameliorate the impacts of static gear lost at sea (FANTARED 2 – EC-FAIR-CT98–4338)

The study aims at evaluating the extent and impact of the loss of fishing gears. During its first year, a survey among the Spanish Cantabrian gillnet fishing fleet skippers was done in spring 1999 to determine the importance of the phenomenon as well as the main causes leading to the loss of fishing gears. A simulation pilot study has been carried out during autumn in 70 fathoms depth trying to reproduce the loss of nets in open sea. Several replicates of tangle net fleets were set in October 1999 and retrieved one and four months later. Species caught and their stage were recorded in order to estimate the catch rate of the nets. A new simulation exercise starting in summer will be carried out in the year 2000 covering a longer period of time for retrieval of experimental nets. Preliminary tests were also carried out with the side scan sonar to determine the validity of this technology in detection of real net losses.

The project is under way (1999–2001).

Hake semi-pelagic longline selectivity and evaluation of selectivity models for hook and line gear (EU Study 96/062)

The general objective of this study is to analyse the effect of hook size on catching efficiency and selectivity of the semi-pelagic longline targeting hake. All data collected during the fishing trials onboard a commercial longliner with four different sizes of hook have been processed. A final report has been produced which is still in the evaluation process. The main results of the study are: a) in the range of hooks used, small hooks have a significant higher hake catch rate than big hooks; b) there was no significant differences between hook sizes concerning the hake size distribution on the longline catches. c) The hook size has a significant effect on the species catch composition. Different methods and models were used to describe the selectivity of the longline for hake. Nevertheless, it was not possible to model the selectivity for this species as a result of the overlapping of size distributions.

The project is finished (1999)

Trammel net selectivity studies in the Algarve (Southern Portugal), Gulf of Cadiz (Spain), Basque Country (Spain) and Cyclades Islands (Greece) (EU Study 98/014)

Trammel net is one of the main small scale fishing gears in south European artisanal fisheries. This project aims at characterising its fishing pattern in the main *metiers*. A survey among fishermen of the Cantabrian Region (north of Spain) has defined the main trammel net fishing *metiers* characteristics (type of fishing gear, target species, fishing season, etc...) and the relative importance of each *metier* in terms of amount of fishing fleet involved in the activity. A complementary survey concerning the technical characteristics of the fishing gears has provided detailed data on the main types of fishing gears used. According to that data an experimental trammel net fishing gear has been mounted with combination of two and three mesh sizes in the outer and inner panels respectively. A first set of twelve one day fishing trials has been carried out in order to assess the selectivity of trammel nets in relation with the mesh size. Similar fishing trials but in different seasons are planed during the year 2000.

The project is under way (1999–2001)

Study of the fishing pattern of the High Opening Trawl and Pelagic Trawl in the hake fishery of the Biscay Bay (EU Study 97/016)

Both high opening and pelagic trawls have played an important role in the Biscay Bay fisheries of hake during the last years. This project seeks to give an overview of their fishing patterns in terms of composition of the catches, level of discards, catch efficiency and codend selectivity. A program of seasonal observations onboard fishing vessels has been implemented to obtain data on catches and discards in an haul by haul basis. Moreover, several seasonal fishing trials have been performed using the method of the alternate hauls to study the codend selectivity. The information gathered is currently being processed.

The project is under way (1998–2000).

AZTI Remote Sensing Service (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 will send these maps during the tuna fishing season to the Basque coastal tuna fishing fleet. The aim is to provide information in order to detect areas of maximum probability of catching tuna.

The project is under way.

Creation of a communications network for the artisanal fishing fleet (Financial Support: ARTEPYME, Department of Agriculture and Fishing/Basque Government)

AZTI is installing 100 PCs on board coastal fishing vessels and fishing organisations offices. Different software will be also provided (to register catch, to receive and send messages, etc). The aim is to create a network including the fishermen organisations, the fishing companies (fishing vessels and offices on land) and AZTI to exchange information. None of the coastal fishing vessels have satellite communications.

The project is under way.

Improvement of the tuna attractiveness in the pole and line fishery (Financial Support: Department of Agriculture and Fishing/Basque Government)

Tuna sound recordings have been obtained in the pole and line fishery. Feeding and swimming noises from albacore (*Thunnus alalunga*) when attacking the live bait have been recorded, analysed and filtered. Playback of these recordings will be made to study fish behaviour and the possibility of using as an acoustic stimulus. On the other hand, a simple high speed zooplancton recolecting device has been constructed to allow the fishing vessel to catch zooplancton for feeding the live bait on the fishing ponds on board and improve the condition of the fish.

The project is under way.

Remote sensing application in the tuna purse seine fisheries. (Financial Support: ATYCA, Department of Agriculture and Fishing (Basque Government).

Tuna purse seiners use remote sensing information from different commercial companies to be able to detect areas for fishing by means of fish finding maps. The aim of this project is to install on board the tuna purse seiner a HRPT Portable Station. The skipper will use a friendly software to be able to process satellite information and obtain by himself location of oceanographic events (thermal boundaries, eddies, etc.) and plankton concentration to decide areas of fishing.

The project is under way (1999–2001)

Selectivity studies of pair trawling in NAFO Regulatory Area using sorting grids. (Financial Support: Ministry of Agriculture, Fisheries and Food (Spain); Department of Agriculture and Fishing (Basque Government).

A cruise on board the pair trawlers "Nuevo Virgen de la Barca" and "Nuevo Virgen de Lodairo" was carried out in Divisions 3LMNO to estimate the selectivity properties of bottom trawls fitted with sorting grids. 62 hauls were performed with 35mm and 55mm separation bars SORT-X grid. Only partial results for Reinhardtius hippoglossoides were obtained for the 35mm separation bars.

Project finished in 1999.

GEAR RELATED RESEARCH IN 1999. NATIONAL REPORT. SWEDEN

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_Improving Technical Management in Baltic Cod Fishery (BACOMA). EU-project. Contact person: P-O Larsson or Vesa Tschernij.

_Size Selectivity and Relative Fishing Power of Baltic Cod Gill Nets. EU-project. Contact person: P-O Larsson or Vesa Tschernij.

_Selective whitefish grid system for demersal towed gear fisheries in the North Sea and adjacent waters. EU-project. Contact person: P-O Larsson or Vesa Tschernij.

_Selectivity Database (SELDAT). EU-project. Contact person: P-O Larsson or Vesa Tschernij.

_Evaluation of mesh measurement methodologies for fisheries inspection and research (MESH). EU-project. Contact person: P-O Larsson or Vesa Tschernij.

_Development and testing of grids for the Skagerrak and North Sea shrimp fishery. EU-project. Contact person: P-O Larsson or Mats Ulmestrand.

_Experimental study of the selectivity of eel-pots in a population with a known size distribution and under seminatural conditions. Contact person: Håkan Westerberg.

_Behaviour studies of fish in relation to fixed gears in the Baltic Sea. Studies on non-visual net detection in salmonids and the dependence of environmental variables on detection distance. Contact person: Håkan Westerberg.

_Studies of acoustic attraction and herding of whitefish (Coregonids) and perch in the Baltic Sea. Contact person: Håkan Westerberg.

_A Fishing Technology Center, directed at coastal fishery at the Skagerrak coast, has started some R&D projects on gear development, e.g., to improve selectivity in crab and *Nephrops* pots, to improve selectivity and seal protection in eel pots and to develop a totally new type of ”otter board”, aimed at reducing fuel demand and harmful effects on the sea bed. Contact person: Christian Almström (ftc@tmbl.gu.se), FTC, Strömstad, Sweden.

ANNEX 1 – REPORT OF THE FTFB TOPIC GROUP ON UNACCOUNTED MORTALITY IN FISHERIES

FTFB Working Group, Haarlem, The Netherlands, 10 – 11 April, 2000

1. Terms of Reference

In accordance with ICES resolution C.Res.1999/2B03 the Working Group on Fishing Technology and Fish Behaviour (WGFTFB) (Chair; Dr A. Engås, Norway) will meet in Haarlem, Netherlands from 10–14 April 2000 to:

a) review and consider recent research into unaccounted mortality in commercial fisheries.

To facilitate this, a Topic group was formed in January, 2000 and worked by correspondence, co-ordinated by M.Breen (UK). The purpose of this group was to produce a report, based on the following actions:

> 1. Define how the sub-components (Fy) of unaccounted fishing mortality may be calculated and incorporated into stock assessment models.
>
> 2.Produce a summary of current knowledge on the magnitude of the various sub-components (Fy) of unaccounted fishing mortality, the causes of mortality and the methodologies used for mortality studies.
>
> 3.Identify and discuss any potential sources of error within mortality estimates with respect to unintentionally induced mortality by the experimental protocol and deviations in protocol from commercial fishing practices.
>
> 4.Compile a comprehensive bibliography on unaccounted mortality (including grey literature).
>
> 5.Review the conclusions and recommendations from the Study Group on Unaccounted Mortality in Fishes (ICES CM 1997/B:1) and discuss whether these have been fulfilled.

The report will be presented, reviewed and discussed at the FTFB WG meeting at Haarlem, Netherlands on 10th April 2000. Two discussion groups will be formed (Convened by M. Breen and A. Fréchet)

<u>Contributors to the Report:</u>

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2. Introduction

The problem of unaccounted mortality in fisheries has been recognised since Holt's early work in the 19^{th} century (Harley *et al.,* 2000). Ricker (1976) first categorised the various potential sources of unaccounted mortality with his review of mortality in the Pacific salmon fishery. These subcategories of fishing mortality were then formalised into a simple unifying model by the ICES Sub-group on Methodology of Fish Survival Experiments (ICES, 1994) which has been further developed by subsequent ICES Study Groups on Unaccounted Mortality (ICES, 1995 and 1997) and other authors (Chopin *et al.,* 1996). There have been a number of recent reviews which have discussed the concept of unaccounted mortality, but these have generally concentrated on one particular aspect, usually bycatch and discards (Alverson & Hughes, 1996; Alverson, 1998; Chopin & Arimoto, 1995; and Hall, 1996).

This report will summarise and enhance these various definitions of unaccounted mortality and then demonstrate how these mortality estimates may be included in stock assessment models and the fishery management decision making process. It will further review the current state knowledge on unaccounted mortality in commercial fisheries and provide a critique of the various methods used to define these mortality estimates, highlighting any potential sources of error. The report will conclude with a discussion of the Unaccounted Mortality Problem and why estimates of mortality are rarely included in stock assessment models and the fishery management decision making process.

2.1 Unaccounted Mortality in Fisheries - A Definition.

For the effective management of any fishery, the overall mortality associated with the exploited population of fish should be fully understood. The mortality rate within a population can be described, over a known time interval (*dt*), in terms of the rate of change in numbers of fish (*dN/dt*) in that population and the total number (N_0) of fish at the beginning of *dt*:

$$dN/dt = Z.\ N_0$$

where Z is the instantaneous mortality coefficient. If that population is exploited as a fishery, the instantaneous mortality coefficient (Z) will be a function of the instantaneous coefficient of fishing mortality (F), as a direct result of the fishing operations, and the instantaneous coefficient of natural mortality (M):

$$Z = F + M$$

The Study Group on Unaccounted Mortality in Fisheries (ICES, 1995) defined Fishing Mortality (F) as “The sum of all fishing induced mortalities occurring directly as a result of catch or indirectly as a result of contact with or avoidance of the fishing gear.” They further recognised the following definable sub-components of F:

$$F = Fc + Fb + Fd + Fe + Fo + Fg + Fa + Fh$$

<u>Landed Catch (Fc):</u> Catch mortality should include all reported or estimated commercial fishing landings, plus landings from recreational fisheries and subsistence fisheries. This subcomponent was not considered in any detail by the previous study groups on unaccounted mortality and it will not be discussed in this report.

<u>Illegal, misreported & unreported landings (Fb):</u> is the mortality of fish that should be accounted for in Fc but is not because the records of landings are: not reported: underestimated; or misreported with respect to area and/or species.

<u>Discard mortality (Fd):</u> is the mortality of fish actively released by fishermen after capture.

<u>Escape mortality (Fe):</u> is defined as the mortality of fish that actively escape from a fishing gear, prior to the catch being landed on deck.

<u>Drop out mortality (Fo):</u> is the mortality due to captured fish dying and dropping out of the gear, prior to the catch being landed on deck. Examples include fish washed out of a codend during trawling or haulback, or fish lost from hooks and gillnets.

<u>Ghost fishing mortality (Fg):</u> is the death of fish being caught in ghost fishing gear. Where ghost fishing gear is lost or discarded gear that continues to fish for an indefinite period after its initial loss or discarding.

Avoidance Mortality (Fa): is the mortality directly or indirectly associated with the stress, fatigue and injuries of fish actively avoiding fishing gear.

Habitat degradation mortality (Fh): is any mortality associated with the degradation of an aquatic environment as a direct result of fishing activity.

In practice, it may prove difficult to differentiate between the mortalities associated with different sub-components. One example being Fe and Fo, where both sets of individuals effectively pass through but fail to be retained by a fishing gear, however one is alive as it escapes and the other is dead. While it is important to recognise the philosophical difference between these two groups in reality this may prove difficult to quantify in the field. Conversely, any researcher collecting fish "escaping" from fishing gear (particularly mobile gears) should be aware that a proportion of the observed mortality may also be defined as "drop out mortality" (Fo).

Each sub-component of F can be further described as the sum of the products of the likelihood of an individual fish encountering sub-component "y" (P_y^E) and the probability of mortality of that fish as a result of encountering sub-component "y" (P_y^M):

$$F_y = P_y^M . P_y^E$$

Where:

F_y: Fishing Mortality Rate for sub-component "y"

P_y^M: Probability of mortality of an individual fish encountering sub-component "y" (where $0 \leq P \leq 1$)

P_y^E: Probability of an individual fish encountering sub-component "y" (where $0 \leq P \leq 1$)

P_y^M & P_y^E are functions of the explanatory variables i..k.

That is, for an individual within an exploited population of fish there is a definable probability that it may encounter a fishing gear and on encountering that gear it may: escape; be caught but discarded; be caught and landed; be caught and landed illegally; and so. The probability of any one of these events is "the probability of encounter" (P_y^E) for that particular sub-component of F. Further to this, any fish encountering one of these events then has a definable probability of dying because of that encounter. This is the "probability of mortality" (P_y^M) as a result of an individual fish encountering sub-component "y".

Thus the overall fishing mortality associated with a fishery, as described by the instantaneous fishing mortality coefficient (F), may now by defined as:

$$F = \sum [P_y^M . P_y^E]$$

A study (or combination of studies) must quantify each of these factors (P^M & P^E) if it is to be of use in estimating the magnitude of Fy for a species in any particular fishery. Moreover, the explanatory variables (i..k) must relate to the explanatory variables used to describe the exploited stock (N_0) in any stock assessment calculations. That is, N_0 (from equation 1) must also be a function of the explanatory variables (i..k), otherwise the mortality estimates cannot be related to the population they are supposed to represent.

For a number of the sub-components, namely Fc, Fb and Fo, the value P^M is by definition likely to be 1 and therefore irrelevant. Also for some species and fisheries the effective P^M value for discards will also be 1. The magnitude of Fc is estimated on a regular basis for many fisheries and therefore the calculation and magnitude of this sub-component was never considered by the previous Study Groups.

In addition to the eight sub-components of fishing mortality (Fy), a number of other factors may by considered as subsets of at least some of these sub-components, for example mortality as the result of enhanced risk of Predation (Fp) and Infection (Fi). In practical terms it is likely to prove difficult to define the magnitude of these subsets with respect to each sub-component. Furthermore, for some sub-components, namely Fc, Fb and Fo, the defining of these subsets is irrelevant as all fish will have died anyway.

To include Predation (Fp) and Infection (Fi) mortality in the calculation of Fy the probability of mortality (P_y^M) must be broken down into its component parts:

$$F_y = P_y^E [1 - (1-P_y^m)(1-P_y^p)(1-P_y^i)]$$

Where:

F_y: Fishing Mortality Rate for sub-component "y"

P_y^m: Probability of mortality of an individual fish as a direct result of encountering sub-component "y" (where $0 \leq P \leq 1$)

P_y^p: Probability of mortality of an individual fish as a result of enhanced risk of predation after encountering sub-component "y" (where $0 \leq P \leq 1$)

P_y^i: Probability of mortality of an individual fish as a result of enhanced risk of infection after encountering sub-component "y" (where $0 \leq P \leq 1$)

P_y^E: Probability of an individual fish encountering sub-component "y" (where $0 \leq P \leq 1$)

P_y^E, P_y^m, P_y^p & P_y^i are all functions of the explanatory variables i..k.

This simplistic probabilistic approach has been used by a number of authors to compare the levels of mortality in different sub-components (namely Fd and Fe) in the same fishery (Sangster *et al.*, 1996, Lowry *et al.*, 1996 and Wileman *et al.*, 1999). It also highlights the potential and large scale problem of estimating the magnitude of unaccounted mortality in world fisheries. Using this approach, it is clear that considerable effort is required to adequately estimate the mortality from estimate a single sub-component of F for one species in just one fishery. This must then be repeated for the other nine possible sub-components of F in that fishery. Finally we must then multiply this effort by the many thousands of commercially important species and fisheries in the world today.

The following section will discuss alternative ways of calculating unaccounted mortality and including mortality estimates in stock assessment models and the fishery management decision making process.

3. Incorporating Mortality Estimates into Stock Assessments

3.1 A VPA formulation to include sub-components of fishing mortality

3.1.1 Introduction

Over the last decade there has been increased acknowledgement and research into the overall effect of fishing practices and their effects on mortality of targeted species. A suite of sub-components of the fishing mortality (F) have been identified (ICES, 1995). This paper attempts to illustrate various ways to incorporate measured values of mortality into virtual population analysis (VPA).

The sub-components of fishing mortality such as illegal, misreported, unreported landings, discard mortality, escape mortality, drop-out mortality, ghost fishing mortality, avoidance mortality and habitat degradation mortality, are for the vast majority of fish stocks, unknown. These are thus referred as unaccounted mortalities. Indeed, a very significant amount of research would be necessary to estimate all sub-components of F mentioned above for any given stock. However, such information is available for a few stocks and their effect on stock status must be taken into account in order to determine their effect on the resource.

3.1.2 Methods

There are a variety of ways to infer sub-components of F.

3.1.2.1 Modifying the catch at age

One would be to "tax" or adjust the official landing statistics for each age group and year by a factor that could be derived through a questionnaire or field experiment for as many sub-components as possible. This would be the equivalent of:

$$TC_{i,j} = RC_{i,j} \bullet \sum Elossy_{i,j} \qquad (1)$$

Where:
- $TC_{i,j}$ = total catch at age for age $_i$ in year $_j$
- $RC_{i,j}$ = reported catch at age for age $_i$ in year $_j$
- $Elossy_{i,j}$ = ratio of the expected loss due to sub-component y at age $_i$ in year $_j$.

This is a simple straightforward approach that may be used for less known sub-components of F. This modified catch at age matrix could be used as input to VPA and calibrated with abundance indices to estimate population numbers, biomass and fishing mortality. The calibration process can be done in a variety of numerical approaches (ADAPT, Laurec-Shepperd, maximum likelihood, SVPA...), but most of them essentially estimate population numbers or F in a iterative manner to maximise fit to the abundance index. Once the calibration done, the impact of each sub-components of Fy can be calculated as:

$$Fy_{i,j} = (RC_{i,j} \bullet Elossy_{i,j}) / TC_{i,j} \qquad (2)$$

These are also known as partial F's.

An example

The 1999 assessment of the cod stock from the northern Gulf of St. Lawrence (3Pn, 4RS) was done with the formal inclusion of the consumption of grey and harp seals. Although the seals are in fact a natural mortality (M) it has been included in the VPA as if it was a new fleet, by adding the consumption estimates to the fishery catch at age. It is thus hidden as a catch (F). The total mortality (Z = F+M) is re-allocated between the commercial fleet and the seals at the end of the calibration process.

The total numbers consumed by both seal species at age is in Table 1. Once the calibration against the abundance indices completed, an overall estimate of fishing and seal mortality is produced (Table 2). The proportion of the fish consumed by seals compared to the total catch (commercial and seals) is shown in Table 3. Once the calibration is done, the partial F's can be calculated as shown in equation 2 (Tables 4 and 5).

3.1.1.2 Estimating an instantaneous F in a probabilistic fashion.

Another approach would be to evaluate directly a value for the instantaneous rate of fishing mortality as described in the working paper "*Unaccounted Mortality in Fisheries – The Theoretical Background*". In this case, each sub-component of F is estimated by:

$$Fy = P_y^M \bullet P_y^E \qquad (3)$$

Where: Fy = Instantaneous fishing mortality rate for sub-component y

P_y^M = Probability of mortality of individual fish encountering sub-component y ($0 \le P \le 1$)

P_y^E = Probability of an individual fish encountering sub-component y ($0 \le P \le 1$)

Once the best estimate of each individual F's are known, they can be added to be used as terminal year F. A good estimate of P_y^E is crucial as it will reflect stock size and the level of effort.

3.1.1.3 The survival approach

The formulation has been developed by Mesnil (1996) to take into account discards and their survival rate into VPA. In this case, the net removals (R) can be estimated by adjusting the catch at age by ratio of the landings to the catch which incorporate the survival rate. More formally:

$$R_{i,j} = L_{i,j} + D_{i,j} – S_{i,j} \bullet D_{i,j} \qquad (4)$$

Where:

	$R_{i,j}$	=	Net removal of age $_i$ in year $_j$
	$L_{i,j}$	=	Landings in number
	$D_{i,j}$	=	Discard in number = $C_{i,j} \bullet (1-P_{i,j})$
	$S_{i,j}$	=	Survival rate of discards ($0 \leq S_{i,j} \leq 1$)
	$D_{i,j}$	=	Discards in numbers ($0 \leq D_{i,j} \leq 1$)

This can be generalised as:

$$R_{i,j} = C_{i,j} \bullet [1- S_{i,j} \bullet(1- P_{i,j})] \qquad (5)$$

Where: $C_{i,j}$ = Catch at age $_i$ in year $_j$
$P_{i,j}$ = Proportion landed ($0 \leq P_{i,j} \leq 1$)

This last equation could be generalised to account for all sub-components of fishing mortality.

The first and the last method are linked, in the first case, the catch at age is adjusted by the expected ratio of loss due to any sub-component whereas, the last method involves the use of survival rates. Both methods will imply a calibration to an index in the VPA. The second approach does not directly assess stock size but leads to an estimate of instantaneous fishing mortality where the notion of stock size is incorporated in the parameter $P_y^{E.}$ Each method has it’s advantage.

3.1.2 Discussion and conclusion

All three approaches are further complicated given that many fisheries involve **multiple gears**. Many of the sub-components of F are likely to be gear specific, for example ghost fishing mortality is more likely to be high for gill nets and low for longline (ICES, 1997), discard mortality can be high for small mesh mobile gear like shrimp trawls (Alverson, 1998). A better understanding of the scale of the sub-components of F linked with the proper use of each fishing gear is essential. Based on the precautionary approach, the gear with the highest value of unaccounted mortality should be avoided.

In theory, fishing **management measures** should be uniform for a given stock but in practice these can change in a smaller scale. This may lead to changes in fishermen behaviour that may affect significantly the illegal, misreported and unreported landings in localised areas. This will complicate the assessment of such practices.

Many sub-components of F are short term mortalities and are amenable to be included in VPA’s. However, effects such as ghost fishing mortality and habitat degradation mortality are more important on the **long term**. Their effects may be additive through time and difficult to incorporate as yearly estimates in VPA.

The approach used here is based on a single species fishery but in reality, few fisheries have no **by-catch**. In certain cases, the fishing efficiency can be very low and can lead to high levels of unaccounted mortalities for commercial and non-commercial species. Lindeboom and DeGroot (1998) estimate a catch efficiency of 5 to 29% for marketable fish (mostly, sole, dab and plaice) in the North Sea beam trawl fishery which include a large amount of discards. In the *Nephrops* fishery, *Nephrops* account only an average of 28% of the catch, roundfish dominating the reminder of the catch.

The inclusion of unaccounted mortality to the VPA will likely result in an estimation of a larger stock size given that these additional sources of mortality were previously unknown. In this example, the VPA had to “feed the seals”. The change in perception of stock size will thus require a precise and stable estimate of each sub-component of F. The main effects of including sub-components of unaccounted mortality into VPA will be seen in terms of increased recruitment and higher productivity. This is not likely to be reflected immediately to a higher advice for fishing quotas given that the recent estimates of sub-components are likely to be maintained for the short term projection period. However, results of this exercise will likely be closer to reality and will identify the scale of each type of loss. It will be up to management to decide on which sub-component of F mitigation should occur.

Table 1: Northern Gulf Cod. Consumption of cod ('000) by Grey seals (A) and Harp seals (B).

= *Used in the VPA.*

A

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
1	38283	39504	41234	43145	44351	44193	47214	48160	50610	52504	53817	54735	55835	55661	59949
2	13429	13857	14464	15134	15557	15502	16562	16893	17753	18417	18878	19200	19586	19524	21028
3	6421	6626	6916	7237	7439	7413	7920	8078	8489	8807	9027	9181	9366	9336	10056
4	3673	3790	3956	4139	4255	4239	4529	4620	4855	5037	5163	5251	5356	5340	5751
5	1205	1244	1298	1359	1397	1392	1487	1517	1594	1653	1695	1724	1758	1753	1888
6	394	407	424	444	456	455	486	496	521	540	554	563	575	573	617
7	67	69	72	76	78	78	83	85	89	92	94	96	98	98	105
8	87	90	94	98	101	101	107	110	115	120	122	125	127	127	136
9	7	8	8	8	9	9	9	9	10	10	10	11	11	11	12
10	9	10	10	11	11	11	12	12	12	13	13	13	14	14	15
11	9	9	9	10	10	10	11	11	12	12	12	12	13	13	14
No. 1+	63585	65613	68487	71661	73663	73400	78419	79990	84060	87206	89386	90910	92738	92448	99570
No. 3+	11873	12252	12789	13381	13755	13706	14643	14937	15697	16284	16691	16976	17317	17263	18593
Tons 1+	3795	3916	4088	4277	4397	4381	4681	4774	5017	5205	5335	5426	5535	5518	5943

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
1	62765	65730	68117	71918	73433	79797	85153	87686	93745	96453	103467	111108	126475	135491
2	22016	23056	23894	25227	25758	27991	29869	30758	32883	33833	36294	38974	44364	47527
3	10528	11025	11426	12063	12317	13385	14283	14708	15724	16179	17355	18637	21214	22727
4	6021	6306	6535	6899	7045	7655	8169	8412	8993	9253	9926	10659	12133	12998
5	1976	2070	2145	2265	2312	2513	2681	2761	2952	3037	3258	3499	3983	4266
6	646	676	701	740	756	821	876	902	965	993	1065	1143	1301	1394
7	110	115	120	126	129	140	149	154	165	169	182	195	222	238
8	143	150	155	164	167	182	194	200	213	220	235	253	288	308
9	12	13	13	14	14	15	17	17	18	19	20	22	25	26
10	15	16	17	18	18	20	21	21	23	24	25	27	31	33
11	14	15	16	16	17	18	19	20	21	22	24	25	29	31
No. 1+	104247	109172	113137	119449	121966	132537	141432	145639	155703	160200	171850	184542	210065	225039
No. 3+	19466	20386	21126	22305	22775	24749	26410	27195	29075	29914	32090	34460	39226	42022
Tons 1+	6222	6516	6753	7130	7280	7911	8442	8693	9294	9562	10257	11015	12538	13432

B

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
1	161779	170113	176532	180689	184080	190370	200666	209064	218951	226866	230368	236751	252330	270233
2	43820	46078	47817	48942	49861	51565	54354	56628	59307	61450	62399	64128	68348	73197
3	10020	10536	10933	11191	11401	11791	12428	12948	13561	14051	14268	14663	15628	16737
4	3115	3276	3399	3480	3545	3666	3864	4026	4216	4369	4436	4559	4859	5204
5	338	355	369	378	385	398	419	437	458	474	481	495	527	565
6	96	101	105	107	109	113	119	124	130	134	136	140	149	160
7	21	22	23	24	24	25	26	27	29	30	30	31	33	35
No. 1+	219189	230482	239178	244810	249405	257927	271877	283254	296650	307373	312119	320767	341874	366130
No. 3+	13590	14290	14829	15179	15463	15992	16857	17562	18393	19058	19352	19888	21197	22701
Tons 1+	13820	14532	15081	15436	15725	16263	17142	17860	18704	19380	19680	20225	21556	23085

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
1	290577	310089	327687	343595	360353	376547	395559	410295	430583	444749	458726	458398	459776
2	78708	83993	88760	93068	97608	101994	107144	111135	116631	120468	124254	124165	124538
3	17997	19205	20295	21280	22318	23321	24499	25411	26668	27545	28411	28391	28476
4	5596	5971	6310	6617	6939	7251	7617	7901	8292	8565	8834	8827	8854
5	607	648	685	718	753	787	827	857	900	929	959	958	961
6	172	184	194	203	213	223	234	243	255	263	272	271	272
7	38	40	43	45	47	49	52	54	56	58	60	60	60
No. 1+	393694	420130	443974	465527	488231	510172	535931	555897	583385	602577	621514	621069	622937
No. 3+	24410	26049	27527	28863	30271	31631	33228	34466	36171	37361	38535	38507	38623
Tons 1+	24823	26490	27993	29352	30784	32167	33791	35050	36784	37994	39188	39160	39277

Table 2: Fishing mortality (commercial and seals)

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
3	0.16	0.13	0.15	0.12	0.11	0.15	0.11	0.16	0.16	0.14	0.17	0.15	0.20	0.27	0.28	0.32	0.35	0.50	0.63	0.69	0.61	0.69	0.51	0.68	0.56
4	0.20	0.14	0.13	0.12	0.09	0.09	0.12	0.10	0.12	0.14	0.10	0.13	0.12	0.17	0.25	0.27	0.34	0.39	0.73	0.85	0.73	0.59	0.74	0.46	0.75
5	0.37	0.25	0.25	0.16	0.20	0.18	0.20	0.15	0.19	0.24	0.13	0.20	0.17	0.15	0.19	0.27	0.38	0.44	0.65	0.80	0.43	0.38	0.28	0.46	0.21
6	0.37	0.31	0.28	0.39	0.38	0.32	0.36	0.33	0.26	0.26	0.31	0.28	0.29	0.38	0.31	0.38	0.49	0.68	0.80	1.16	0.24	0.20	0.18	0.19	0.30
7	0.39	0.34	0.43	0.62	0.53	0.50	0.52	0.45	0.40	0.33	0.48	0.41	0.45	0.47	0.39	0.50	0.56	0.67	1.08	1.35	0.13	0.09	0.09	0.15	0.10
8	0.49	0.39	0.50	0.54	0.35	0.60	0.59	0.43	0.57	0.30	0.43	0.46	0.49	0.73	0.50	0.67	0.61	0.80	1.34	1.67	0.36	0.16	0.14	0.29	0.16
9	0.39	0.38	0.49	0.59	0.42	0.40	0.38	0.35	0.60	0.40	0.51	0.33	0.67	0.80	0.41	0.67	0.81	0.91	1.35	1.41	0.14	0.08	0.05	0.13	0.09
10	0.45	0.45	0.72	0.56	0.48	0.57	0.23	0.43	0.71	0.43	0.52	0.41	0.47	0.56	0.41	0.79	0.67	0.83	1.39	1.71	0.39	0.24	0.12	0.29	0.11
11	0.36	0.41	0.52	0.61	0.61	0.40	0.49	0.22	0.56	0.68	0.62	0.41	0.69	0.84	0.69	0.81	0.64	1.16	1.91	2.26	0.83	0.65	0.34	0.23	0.11
12	0.28	0.51	0.40	0.40	0.69	0.81	0.44	0.57	0.15	0.37	0.85	0.29	0.46	0.67	0.46	1.10	0.55	0.74	1.36	1.47	0.16	0.07	0.05	0.18	0.11
13	0.42	0.37	0.48	0.58	0.44	0.50	0.50	0.41	0.52	0.34	0.48	0.40	0.54	0.67	0.44	0.61	0.66	0.79	1.26	1.48	0.21	0.11	0.09	0.19	0.11

Table 3: Proportion of the cath at age due to seals

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
3	0.94	1.00	0.98	1.00	1.00	0.99	0.96	0.98	0.98	0.95	1.00	0.99	0.99	1.00	0.99	0.98	0.98	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00
4	0.61	0.60	0.57	0.72	0.73	0.69	0.70	0.55	0.72	0.63	0.75	0.79	0.80	0.90	0.90	0.86	0.80	0.81	0.76	0.88	1.00	1.00	1.00	0.98	1.00
5	0.15	0.18	0.12	0.15	0.15	0.12	0.10	0.19	0.10	0.12	0.23	0.13	0.23	0.24	0.32	0.36	0.29	0.32	0.27	0.49	0.99	0.99	0.99	0.93	0.93
6	0.03	0.08	0.07	0.04	0.03	0.04	0.03	0.03	0.04	0.03	0.04	0.04	0.04	0.05	0.06	0.08	0.12	0.11	0.13	0.14	0.94	0.95	0.91	0.65	0.72
7	0.02	0.02	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.03	0.02	0.04	0.06	0.06	0.08	0.74	0.87	0.76	0.42	0.43
8	0.01	0.03	0.02	0.04	0.05	0.02	0.02	0.03	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.04	0.04	0.07	0.11	0.19	0.82	0.88	0.82	0.38	0.60
9	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.05	0.72	0.55	0.34	0.11	0.16
10	0.01	0.01	0.00	0.01	0.01	0.02	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.02	0.02	0.04	0.03	0.10	0.78	0.83	0.67	0.12	0.25
11	0.02	0.01	0.01	0.01	0.02	0.02	0.04	0.04	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.03	0.06	0.04	0.09	0.14	0.92	0.93	0.94	0.51	0.47
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4: Partial F seals.

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
3	0.15	0.13	0.15	0.12	0.11	0.15	0.10	0.15	0.16	0.13	0.17	0.14	0.19	0.27	0.28	0.31	0.35	0.50	0.62	0.69	0.61	0.69	0.51	0.68	0.56
4	0.12	0.09	0.07	0.09	0.07	0.06	0.08	0.06	0.09	0.09	0.08	0.10	0.09	0.15	0.23	0.23	0.27	0.31	0.55	0.75	0.73	0.59	0.74	0.46	0.75
5	0.06	0.04	0.03	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.04	0.04	0.06	0.10	0.11	0.14	0.18	0.39	0.42	0.38	0.27	0.42	0.20
6	0.01	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.06	0.08	0.10	0.16	0.22	0.19	0.17	0.12	0.21
7	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.07	0.11	0.10	0.08	0.07	0.06	0.04
8	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.06	0.14	0.32	0.30	0.14	0.11	0.11	0.09
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.07	0.10	0.04	0.02	0.01	0.01
10	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.04	0.16	0.30	0.20	0.08	0.04	0.03
11	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.04	0.05	0.17	0.32	0.77	0.61	0.32	0.12	0.05
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Table 5: Partial F fishery.

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
3	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
4	0.08	0.06	0.05	0.03	0.02	0.03	0.04	0.05	0.03	0.05	0.03	0.03	0.02	0.02	0.03	0.04	0.07	0.07	0.18	0.10	0.00	0.00	0.00	0.01	0.00
5	0.32	0.20	0.22	0.13	0.17	0.15	0.18	0.12	0.17	0.21	0.10	0.17	0.13	0.12	0.13	0.17	0.27	0.30	0.48	0.41	0.00	0.00	0.00	0.03	0.01
6	0.36	0.29	0.26	0.38	0.37	0.31	0.35	0.32	0.25	0.25	0.29	0.27	0.28	0.35	0.29	0.35	0.43	0.60	0.70	1.00	0.01	0.01	0.02	0.07	0.08
7	0.38	0.33	0.42	0.61	0.53	0.49	0.52	0.45	0.39	0.33	0.48	0.40	0.45	0.46	0.38	0.48	0.54	0.63	1.01	1.24	0.03	0.01	0.02	0.09	0.06
8	0.48	0.38	0.49	0.52	0.34	0.59	0.58	0.41	0.56	0.30	0.42	0.46	0.47	0.72	0.48	0.64	0.58	0.74	1.20	1.35	0.06	0.02	0.02	0.18	0.06
9	0.39	0.37	0.49	0.59	0.42	0.39	0.38	0.35	0.60	0.39	0.51	0.33	0.67	0.79	0.41	0.67	0.81	0.90	1.33	1.34	0.04	0.04	0.03	0.12	0.08
10	0.44	0.45	0.72	0.56	0.48	0.56	0.22	0.42	0.70	0.42	0.52	0.40	0.46	0.55	0.40	0.77	0.66	0.80	1.35	1.54	0.09	0.04	0.04	0.25	0.09
11	0.36	0.41	0.51	0.60	0.59	0.39	0.47	0.21	0.55	0.66	0.61	0.40	0.69	0.83	0.68	0.78	0.60	1.11	1.74	1.94	0.06	0.04	0.02	0.11	0.06
12	0.28	0.51	0.40	0.40	0.69	0.81	0.44	0.57	0.15	0.37	0.85	0.29	0.46	0.67	0.46	1.10	0.55	0.74	1.36	1.47	0.16	0.07	0.05	0.18	0.11
13	0.42	0.37	0.48	0.58	0.44	0.50	0.50	0.41	0.52	0.34	0.48	0.40	0.54	0.67	0.44	0.61	0.66	0.79	1.26	1.48	0.21	0.11	0.09	0.19	0.11

3.2 A simulation of an increase of mesh size, increased effort and the potential of increased post-selection mortality

3.2.1 Introduction

Recent research on the general topic of unaccounted mortality has provided important insights into a variety of sources of mortalities that are not taken into account in the management of the fisheries (ICES 1995, 1997), assessments and indirectly in the establishment of TAC's. The major categories of sub-components were identified by an ICES study group that met in 1995 (ICES, 1995). These are generally referred to as unaccounted sources of mortalities, of course, as the knowledge and research increases, these must be renamed as sub-components of fishing mortality (F).

One particular source of mortality may have unwanted effects, this is referred to as post-selection mortality (Lowry and Sangster 1996, Sangster *et al.,* 1996, Wileman *et al.,* 1999). This is the mortality endured by any given specie as it escapes the catching process for any given gear. In the past, selectivity studies were focused in determining the exact size and specie targeted for in a given fishery. Since then, many sources of mortality linked with the use of particular gear has shown that the overall mortality may be much greater than what is observed during gear retrieval. Strictly speaking all selectivity studies should be accompanied by a post-selection survival experiment.

This paper aims to investigate one of the many management implications of an increase in mesh size but taking into account the potential for an overall increase in mortality given the underlying expectation of a short term immediate increase in effort.

More recently a series of experiments were undertaken to estimate the potential post-selection mortality for different species and gear. The mortality is heavily influenced by the fishing practice, the fishing gear and the targeted specie. Sangster *et al.,* (1996) have conducted such experiments on saithe and haddock of the North Sea for a different mesh sizes and with the use of diamond and square mesh.

3.2.2 Methods

The fate of the various sizes of a given specie in the fishing process will be highly variable, especially at length. Generally, the fate can be expressed by four categories (Figure 3.1):

- Legal size fish caught in the cod-end (F_c)
- Discarded fish that may survive or not (F_d), the surviving fish would be $S_d = 1\text{-}F_d$
- Escaped fish that survive (S_e)
- Escaped fish that die (F_e)

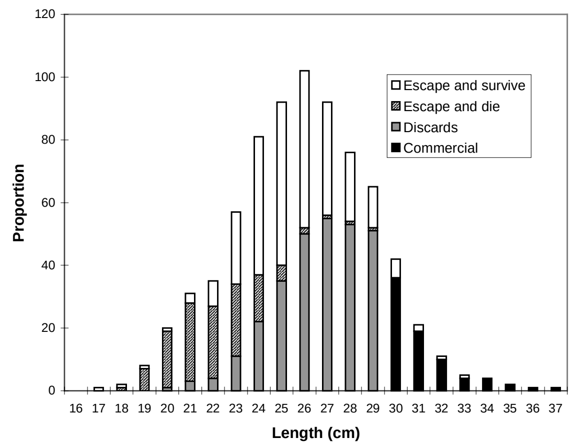

Figure 3.1: Typical fate diagram.

In this case the overall mortality which takes into account post-selection mortality could be expressed as:

$$F = F_c + F_d + F_e \qquad (1)$$

and the survivors would be:

$$S = S_d + S_e \qquad (2)$$

The overall efficiency of the gear would be:

$$E = F / S \qquad (3)$$

Each parameter can be estimated for each length increment. The mortality estimates are calculated in terms of number of fish. Fish in the F_e and F_d categories are generally of a smaller size than F_c. The economic benefit to the fisherman will come with the commercial size fish and the approach to optimise the catch is generally through a yield per recruit calculation. For a given TAC and mesh size, the total removals, R (in weight) can be calculated for each size increment:

$$R = \Sigma_{l=0}^{\infty} AW_l \bullet (F_c + F_d + F_e) \qquad (4)$$

Where AW = average weight at length class $_l$

In many cases F_d and F_e are unknown and generally the TAC is accounted for only by $R = \Sigma_{l=0}^{\infty} AW \bullet F_c$. The impact of this exercise will depend of the scope of F_d and F_e relative to F_c and will be influenced by size.

Depending on the state of the resource an increase in mesh size may require more effort to catch the same tonnage. From Sangster *et al.,* (1996) and Halliday and White (1989) the increase in mesh size will require a short term increase in effort. After a number of years of the application of a larger mesh, the population is likely to respond by increasing it's average size (if there is no over exploitation and recruitment is unaffected) and thus will require less increase of effort (Table 3.2.2.1).

Table 3.2.2.1: Examples of short term (A) and long term (B) increase in effort required to keep a constant catch (α). Taken from Halliday and White (1989).

A) Short term

Mesh size (mm)	4VsW Cod	4X Cod	5Z Cod	Haddock 4VW	Haddock 5Z	Pollock 4VWX + 5
130	1.00	1.00	1.00	1.00	1.00	1.00
140	1.13	1.08	1.07	1.18	1.20	1.04
152	1.36	1.23	1.25	1.58	1.63	1.14
165	1.75	1.45	2.07	3.33	2.66	1.31

B) 4 years latter

Mesh size (mm)	4VsW Cod	4X Cod	5Z Cod	Haddock 4VW		Pollock 4VWX + 5
130	0.75	0.65	0.69	0.89		1.66
140	0.83	0.66	0.70	1.02		1.74
152	0.96	0.71	0.76	1.29		1.95
165	1.20	0.77	1.14	2.35		2.35

The short term increase in effort (α) linked to an increase of mesh size should reduce F_c because the fish will have a larger size and average weight and should reduce discards F_d given the larger average size. However, larger amounts of fish are likely to pass through the meshes and if post-selection mortality is high, could result in an increase of F_e. The short term increase in effort (α) will affect the various segments of F in a different manner.

If R < [$\alpha \bullet AW_l \bullet (F_c + F_d)$] + ($\alpha \bullet AW_l \bullet F_e$) then the increase in mesh size has a negative short term impact on the resource by actually killing more escapees than the expected benefit of less fish of a larger size.

3.2.3 Discussion and conclusion

Sangster *et al.*, (1996) have shown a stable proportion of post-selection mortality, irrespective of mesh size. Their study was done with otter trawl mesh sized ranging from 70 to 110 mm. This means that there is a linear relationship between short term increase in effort to reach a given catch and the resulting post-selection mortality (Figure 3.2).

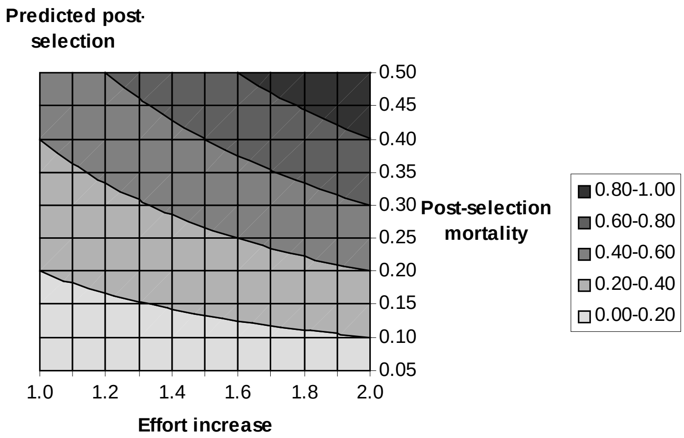

Figure 3.2: Possible outcome of a short term increase of effort due to an increase in mesh size and a constant post-selection mortality.

This simulation provides the basic elements to test operationally the impact of the decision to increase mesh size on any potential increase of total mortality. It does not provide proof that such an increase would necessarily result in a increase of the overall fishing mortality. Whatever may be the case, it underlines the uncertainty of the overall effect of such a management measure.

4. Review of Current Knowledge on Unaccounted Mortality

4.1 The Review Process

The single largest problem, in the short period of time available the Topic Group, was to identify and review any material relevant to the subject of "Unaccounted Mortality". To do this a multi-level approach was taken. Firstly, a list of Reviewers were identified, who were known to be researching the magnitude of some sub-component of unaccounted mortality. They were asked to produce a summary of current knowledge on the magnitude of their 'chosen' sub-component (Fy) of unaccounted fishing mortality, the causes of mortality and the methodologies used for mortality studies. In particular, identifying the fisheries/fishing operations for which no appropriate methodologies exist.

The Reviewers were:

Discard mortality (Fd): Lee Alverson, Norman Graham, Marianne Farrington (Static Gears), Henry Milliken (Static Gears) & Graham Sangster (Towed Gears),.
Escape mortality (Fe): Mike Breen (Towed Gears), Marianne Farrington (Static Gears) & Henry Milliken (Static Gears)
Ghost fishing mortality (Fg): Arne Carr
Predation Mortality (Fp) & Habitat degradation mortality (Fh): Aud Soldal.
Illegal and Misreported Landings (Fb): Robert Kynoch.

Very little work has been identified in the past concerning the remaining sub-components: Avoidance Mortality (Fa) and Drop out mortality (Fo).

The second level of the review were the Reporters, who reviewed individual pieces work (in a set format) and returned it to the review group. The set format was defined by a questionnaire (Appendix I) which summarised all the information required by the Reviewers.

The reporters were recruited into the review process by direct contact from the Chair and other members of the review group, or by information that was posted on the ICES website and FTFB mailing list, which advertised the group and invited assistance and comment from interested parties.

In the long term the results of this review will be inputted to a database that is currently being prepared. This could then stand as the basis for a long term review process on Unaccounted Mortality.

4.2 Current Knowledge

This section of the report reviews the current state knowledge on unaccounted mortality in commercial fisheries; adding to and consolidating reviews by previous ICES reports (ICES 1994, 1995 and 1997). Comprehensive reviews are provided for the key areas of discard mortality (Fd) (towed and static gears), escape mortality (Fe) (towed and static gears) and ghost fishing (Fg). The mortality estimates from the work reviewed in these sections are summarised and tabulated in appendix I and a detailed discussion is given in the main text. Only limited data was available for predation mortality (Fp) and habitat degradation mortality (Fh), although the reviews are believed to include all currently available work. The paucity of available data also limited the review of illegal and misreported landings (Fb) to a case study within a single EU country, Scotland. No comparison of the relative magnitude of unaccounted mortality between different sub-components of F is available, due to the limited time available to the Topic group in preparing this report. Complete references for all work cited in this report are provided in the Bibliography (Appendix II).

4.2.1 Discard Mortality

4.2.1.1 Definition

Prior to discussing the issues, causes and effects of by-catch and discards Alverson *et al* (1994) identifies that the expression ‘by-catch’ has adopted several possible meanings and connotations. Within the context of this section, the definitions used by Alverson *et al* and McCaughran (1992) are used. By-catch refers to the species other than the target species or assemblage retained by the fishing gear. Discards are the portion of the catch which is returned to the sea for economic, legal or personal considerations. To outline the causes of discarding, Figure 1 considers the fate of a theoretical catch entering a fishing gear. The mix of species entering the gear will depend on the gear type, area of operation, season etc., but for the purposes of explanation it may be considered a generalisation.

The catch retained by the gear may initially be split into two components, target and incidental catch. The target species may be defined as the dominant species or group of species aimed for by the fisherman, and may therefore refer to one species of fish, or an assemblage of species. Where several species are targeted, they are typically referred to as a multi-species or multi-target fisheries. One such example is the North Sea trawl fishery where cod, haddock and whiting are captured simultaneously, each species providing a significant economic return to the operator.

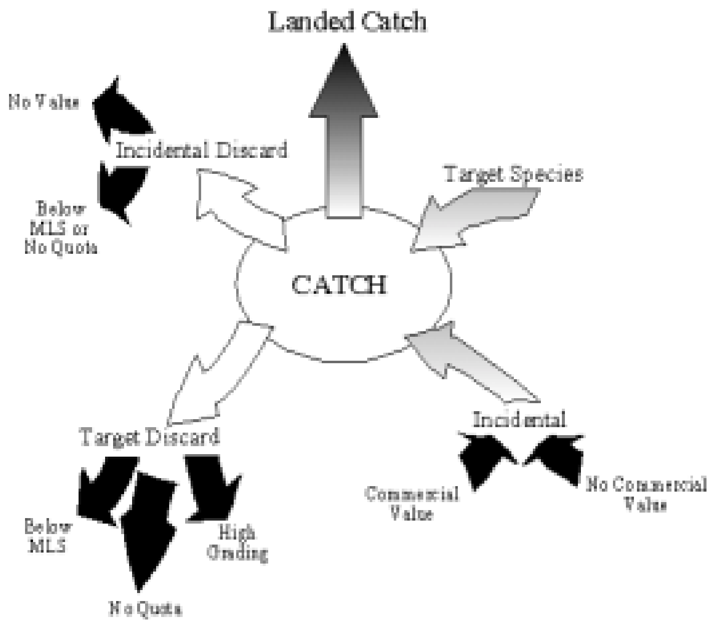

Figure 4.1. Fate of a multi-species catch.

4.2.1.2 Incidental Catch Discards

Incidental catch refers to all other species which inhabit the same ecological niche as the target species and are susceptible to capture by the fishing equipment used. As the other organisms retained may or may not have an inherent market value, incidental catch can be sub-divided into commercial and non-commercial components. Both of these groups of species may be more correctly described as by-catch, i.e., organisms retained other than the target species. From this definition, (also see Alverson *et al.,* 1994), it is clear that from an economic perspective, the term by-catch not only describes the portion of the catch with no economic value, but also some portion of marketable catch. This marketable by-catch, also referred to as by-product in some areas, can and does form an important source of income for the fisherman. The non-marketable element of the catch is generally discarded unless some form of legislative system prevents this.

Incidental marketable catch may also be discarded due to legal considerations. In certain fisheries where by-catch consistently forms an element of the marketable catch, by-catch limits based either on landed or retained catch may be set. This may take the form of a separate quota allocation or a set percentage based on the target species catch. If the quota allocation is low, and does not reflect the abundance available, then discarding of marketable species will occur. Similarly, if the retained marketable by-catch exceeds the legal percentage limit, the excess will also be discarded.

4.2.1.3 Target Species Discards

As with the incidental catch, the target species also has several possible fates. Due to legal or economic considerations, some of the catch may be landed and sold, where the remainder is discarded. Depending on the legislative framework governing the fishery, discarding of the target catch occurs for several reasons.

In management regimes where minimum landing sizes (MLS) and minimum mesh sizes (MMS) are used in order to protect or reduce the capture of juveniles, a large proportion of target discards will comprise of fish which are below the MLS and are therefore illegal to sell. The retention of fish below MLS is generally a consequence of poor size selectivity or the non-discriminative nature of the particular gear in question.

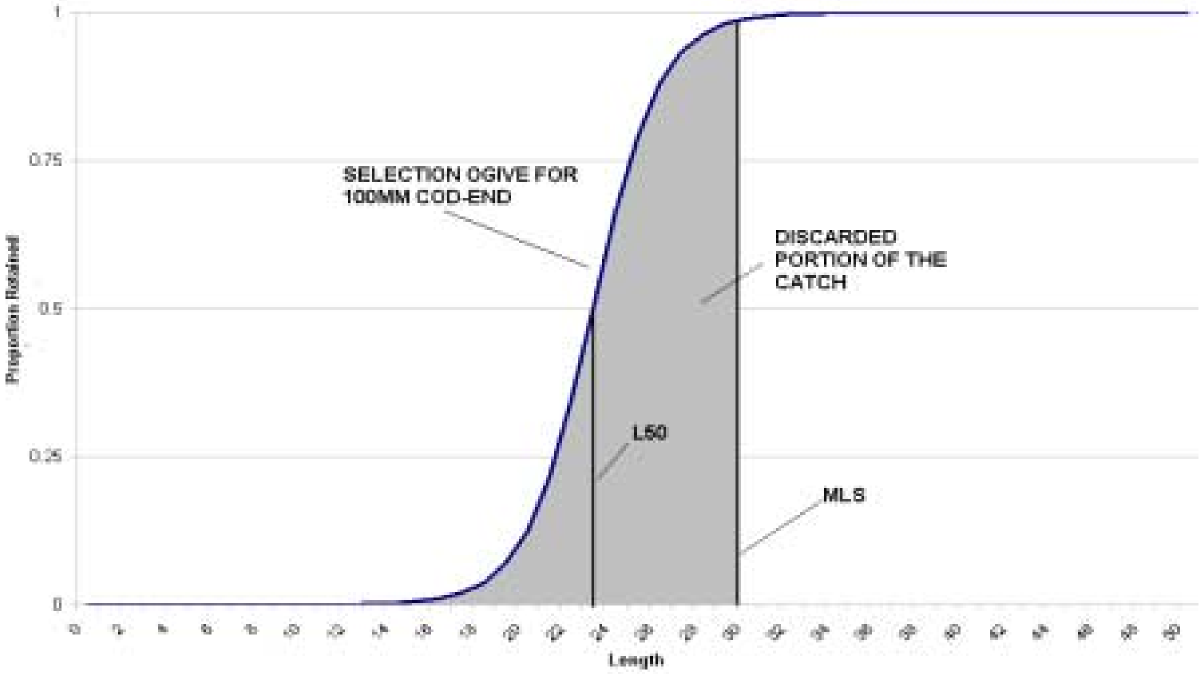

Figure 4.2. Typical haddock selection ogive from 100mm mesh, double 6mm twine cod-end

Figure 4.2 shows a typical haddock selection ogive for a cod-end constructed with a mesh size of 100mm, the MMS for the North Sea (from Graham & Kynoch, 1999). The curve describes the probability of a fish being retained as a function of fish length, where to the left of the curve, all fish have escaped, to the right of the curve all fish would have been retained. It can be seen that for smaller fish, the probability of retention is low, the converse being true for larger fish. In this example, all fish approximately 23cm in length entering the cod-end have a 50:50 chance of escaping, this point being known as the 50% retention length or L50 and is a common parameter used to describe the selectivity of a particular cod-end. The current minimum landing size for haddock in EU waters is 30cm therefore, the shaded area to the left of the point of MLS highlights the proportion of fish retained in the cod-end and are subsequently discarded.

From inspection of the selection curve, it can be seen that almost all fish of 30cm entering the cod-end will be retained. From an operators perspective this is desirable, as almost all the marketable fish entering the gear have been retained. However, a significant portion of the fish below this size are retained as described above.

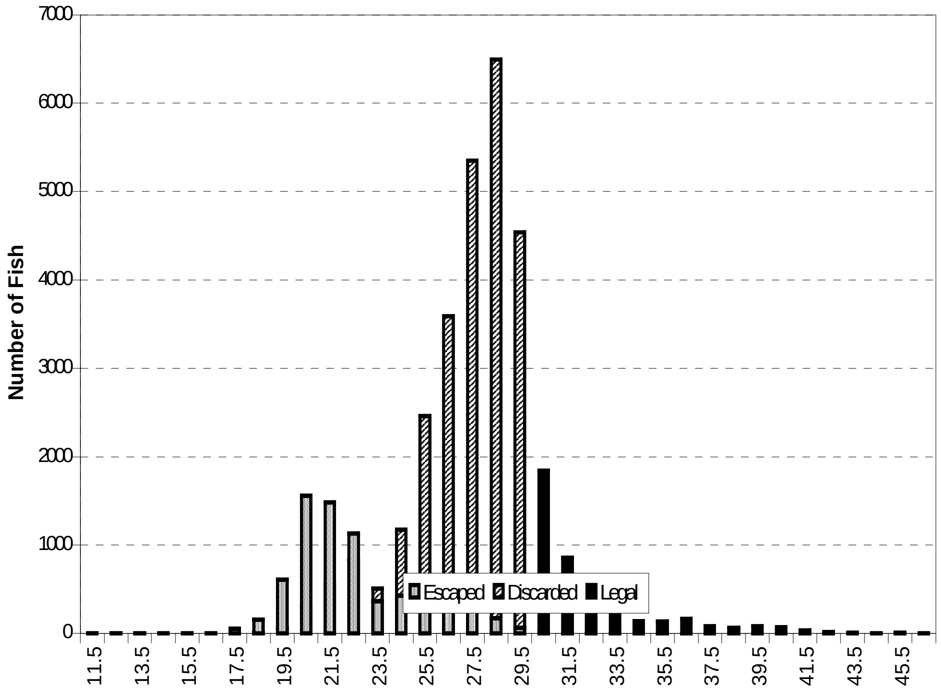

Figure 4.3. Fate of a typical haddock population entering 100mm mesh, 6mm double twine cod-end.

To illustrate this effect on an actual population of haddock entering the trawl, in Figure 3, the selection curve is applied to the length frequency of the population summed from several fishing hauls conducted during June 1998. From this example it can be observed that large numbers of juvenile fish are retained, and in this case would have been discarded. The levels of discards will depend on various factors, but would be particularly high when fishing in areas with high concentrations of juvenile fish, for example, if a strong pre-recruit year-class is present. Discards of this nature could be greatly reduced if the legal minimum lading size was below the zero retention point of the gears used in the fishery. However, by the very nature of having a minimum landing size, and hence a potential catch out with the availability of the gear, would provide an economic incentive for operators to reduce the selective properties of their fishing gear.

However, particularly with multi-species fisheries, using a MMS in this context has limitations if physiological differences exist between the principal species. If maximising yield per recruit for each species is a management objective, MMS alone will not provide a suitable tool for achieving this. Each species has explicit yield per recruit curves, these depending on the maximum size attained by each species, the natural mortality and growth rates. As a consequence of this, the optimum size of capture for each species will be different. Macer (1982) estimates that for the North Sea mixed trawl fishery the mesh sizes required to give optimum yield for cod is 250mm, haddock 140mm and whiting 90mm, whereas the current MMS is 100mm, clearly a compromise. As a result of these physiological differences the current MLS for cod, haddock and whiting is 350mm, 300mm and 230mm respectively, requiring one mesh to select the three different sizes inevitably results in further discarding.

4.2.1.4 High Grading and Quota Induced Discards

High grading can also result in considerable numbers of target species discards. This occurs when an operator decides for economic reasons that the smaller grades of legal fish (above MLS) do not offer a sufficient financial return and are subsequently discarded. There are several possible explanations for this phenomenon. Firstly, due to poor market prices for the smaller grades, if storage space is limited, it may be better, financially, to select the larger individuals from the catch, which realise a higher price per unit, than to use the limited space for smaller fish. Secondly, in areas where fisheries are managed by the issuing of catch or quota allocations, tight quota restrictions on a particular species may result in the operator maximising their return by exhausting the quota with larger fish, again giving a higher price per unit. Thirdly, marketable species may be discarded in favour of a higher value species.

The problem of over-abundance in comparison to resource allocation is also of concern with multi-species or multi-target fisheries. The yearly allocation of TACs for each species can and do vary independently each year. Some TACs will decrease and some increase depending on stock predictions, these being then reflected in the quota allocation. If the stock predictions are underestimated or based on a precautionary principle then the allocations may not truly reflect the availability of fish on the fishing grounds. In this situation, the quota allocation for the species with the small TAC may be taken quickly. However, if sufficient allocations are available for the other species, fishing operations will continue. Inevitably, this results in the capture and subsequent discarding of the species with which the quota allocation is exhausted.

In summation by-catch is more correctly used to describe any catch retained other than the target species and can include marketable and non-marketable incidental catch, and discarded target species which are dumped for legal or economic reasons. Therefore by-catch can have two possible fates, either sold for economic return or discarded.

4.2.1.5 Estimates of Discard Levels

It has long been recognised that discarding of commercial and non-commercial fish species occur in many fisheries (Salia, 1983) and in biological and economic terms the consequences can be highly negative. Alverson *et al* (1994) suggest a estimate of 28.7 Mt of by-catch with 27.0 Mt of discards per year. The incidental catch and subsequent discarding of non-target and undersize fish and shellfish can have adverse effects the population biomass and recruitment levels. Several case studies for example are given here.

Pope (1993), based on average values from 1987–1991, estimates that 54% of fishing mortality (F=0.542) of 2-gp haddock can be attributed to discards. The total catch of haddock from the North Sea between 1963 and 1996 averaged an annual catch of 274,000 tonnes. Of this total, 238,000 tonnes is taken for human consumption, of which 96,000 tonnes is discarded (40%) and 36,000 tonnes caught in the industrial fisheries for pout and sandeel. Similar quantities of discards and industrial by-catch are taken in the whiting fishery. Between 1983 and 1996 an average of 41,000 tonnes of whiting were discarded (44% fish caught by the demersal fleets by weight) and an average of 26,000 tonnes taken as by-catch in the industrial fisheries. The majority of the haddock and whiting discarded in the North Sea are sub-legal size fish and are therefore a direct consequence of an inappropriate match between mesh size and minimum landing size.

It has been demonstrated that the U.S. South-eastern shrimp fishery is a significant source of mortality for several commercial and recreationally important fin-fish species. Nicols *et al* (1990) estimates that 20 million individual red snapper (*Lutjanus campechanus*) were caught in 1999, Warren (1994) estimates that 34million red snapper are retained as by-catch from a total by-catch estimate of 1 billion pounds per year. Phares (1990) attributes 90% of the fishing mortality on 0 & 1 group fish to the activities of the Gulf shrimp fleet. Due to the excessive fishing mortality of red snapper, weakfish (*Cynoscion regalis*) and Spanish mackerel (*Scomberomorus maculatus*), the Gulf of Mexico and the South Atlantic Fishery Management Councils have introduced a programme to restore these stocks to a sustainable level. By 2019, the stock of red snapper should be restored by reducing target effort and reducing the juvenile mortality associated with the shrimp fishery by 44%.

Few studies have assessed the economic impact to other fisheries (Andrew and Pepperell, 1992, Alverson *et al.*, 1994). However, the studies that have been conducted so far have suggest that the impact may be far from inconsequential (Alverson *et al.*, 1994).

Murawaski (1994) suggests that some $50 million of potential revenue was lost due to the capture of juvenile yellowtail flounder in the Northwest Atlantic. In 1992 it is estimated that almost 77 million fish from the 1987 year class were caught, of this total 46.5 million were discarded (60%), foregone value of this catch is considerable Natural Resource Consultants Inc. estimate the loss to the trawl fleet of potential catches of crab and halibut to be worth some $50 million (NRC 1994).

Revill *et al* (1998) predicted the biological and economic impacts due to the discarding of juvenile plaice (*Pleuronectes platessa)* in the brown shrimp (*Crangon crangon)* fishery on the North East of England. It is estimated that 15.3 million plaice (0,1 & 2-gp) were discarded in 1995, primarily as a result of the small minimum mesh size needed to retain the target species (20mm). Using assumptions of natural and fishing mortality coupled with estimates of catchability at age, it was possible to predict the number of fish that would have survived over a period of several years. Furthermore, using market value prices, the potential financial loss was also derived, an estimated yield loss of some 560 tonnes worth £0.9million, assuming status quo of effort.

However, variation in recording strategies and the level of sampling has also shown to be high, with estimates in some regions very good whilst in others very tentative. However, this should not distract from the magnitude and effect of the problem.

4.2.1.6 Discards and management systems

The initial estimates provided by Alverson *et al* (1994) have been reviewed in a subsequent publication (Alverson, 1999). It is noted that the original estimates, ranging from 19 to 40 million metric tonnes, have been somewhat downgraded. Several possible explanations for the reductions have been given. Improvements in estimates of discard levels for many species and areas occurred during the 1990's. These are the result of greater number of observer and by-catch programmes and other efforts to document by-catch. Increasing utilisation of more species and size selective catching methods, greater utilisation of by-catch, particularly in shrimp fisheries. The introduction of harvesting plans which are more sensitive to the problems of discarding have greatly reduced the level of discarding in many trawl fisheries and have facilitated the use of discard and by-catch reduction technology. Two such examples are the groundfish fisheries of Norway and the North West Pacific.

In the North Pacific trawl fishery, regulations pertaining to by-catch limits of certain species are prevalent. These limits, the Prohibited Species Catch (PSC) controls have been in force since 1986. The limits, initiated by the North West Pacific Management Council, relate to by-catch in the groundfish fisheries of the Barents Sea and Aleutian Islands (BSAI) and the Gulf of Alaska (GOA). At present, there are several hundred individual by-catch limits in effect. The main species under protection are pacific halibut, rock sole, herring, red king crab and tanner crab (Smith, 1995). The by-catch of these species in the trawl fisheries for Pacific cod and pollock can cause significant restrictions in fishing potential for the operators (Gauvin, *et al.*, 1995; Pereyra, W.T. 1995).

These regulations encourage the voluntary use of some by-catch reduction devices by a series of incentives and disincentives. By-catch levels, determined by 100% observer coverage on vessels over 37m, may result in fines for exceeding specified limits and ultimately, if by-catch limits are exceeded, result in the closure of the target fishery. Smith (1995) highlights that generally, it is the PSC controls, as opposed to any setting of a total allowable catch (TAC), that controls the level of target species harvested. The economic consequences are significant. In 1994, approximately 16,000mt of flatfish species remained unharvested due to fishery closures as a result of high halibut by-catch. The lost revenue is considerable, estimated to be in the region of $6 million..

As a consequence of this management system, with the associated potential loss of income due to access restrictions to target species, a considerable amount of research into improving gear species selectivity has occurred. Hence, voluntary use of by-catch reduction devices has been greatly encouraged. Square mesh cod-ends and extensions are used in trawls for improved size selection of pollock cod and sole (large mesh) as well as separation of pollock from cod and sole catches. The use of cod-end windows in conjunction with low headline trawls are used to avoid pollock catch in sole fisheries. For similar by-catch problems top opening in the trawl extension are also used in the sole fishery. Grids are also used, but again on a voluntary basis rather than mandatory. They are principally used to prevent the capture of halibut in the sole fishery and have been used on a limited scale in the pink shrimp (*Pandalus jordani*) fishery to reduce finfish by-catch associated with this fishery.

Aspects of the fisheries management regime used in Norway have encouraged the use of by-catch reduction devices. Methods to improve species and size selection to complement conventional mesh regulations have been use in Norwegian waters (Barents Sea) since 1989. Two grid types are used on a mandatory basis in Norwegian trawl fisheries. The use of Nordmøre grid in the pandalidae (*Pandalus borealis*) shrimp trawl fishery is mandatory north of N62^0 and voluntary south of this border since 1993, it is estimated that the use has cut discarding of cod and haddock by more than 90%.

The use of such devices has been greatly enhanced by the introduction of legislation pertaining to the prohibition of discards in 1983. It is considered by the Norwegian authorities that the use of minimum landing sizes, minimum mesh sizes and by-catch regulations are not sufficient for the protection juvenile fish. The conservation policy is now directed towards the fishing operation, where the legislation pertains to minimum *catching* size as opposed to minimum *landing* size.

As a consequence, the 1983 regulations prohibit the capture of discards below a set percentage, allow for the closure of sensitive areas and include obligations to change fishing grounds if catches contain more than a specified legal amounts of by-catch (undersize fish). Prior to the 1983 Act, the Norwegian management system relating to technical measures was closely based on the on the North East Atlantic Fisheries Commission regime, where retention onboard and the landing of unauthorized by-catches and undersized fish was prohibited. However, the current legislation contains an fundamental departure from the old system relating to these laws.

The banning of discards instigated this shift in the management of Norwegian fisheries. The 1983 decreed that the undersize composition (below minimum landing size) of the catch could not exceed 15% of the total by number and that all fish retained by the gear must be landed. In this situation the vessels had to change to new fishing grounds where the level of undersized fish are of an acceptable level. Further to this, an observer programme introduced in 1983 reported that in order to achieve the desired reduction in discarding, certain areas had to be closed due to the catch composition observed, in particular in the waters surrounding Bear Island and the South Eastern Barents Sea. Catches in these areas comprised of anything up to 50% by number of juveniles. Monitoring of the size distribution and abundance of the various species is conducted by a team of observers who conduct inspections onboard various fishing vessels and also charter vessels periodically. The observers are controlled by a shore-based co-ordinator. If the estimates of undersize fish warrant a closure of the grounds, the co-ordinator informs the Directorate of Fisheries, who in turn informs the coastguard and fishing industry, the complete process takes only a matter of hours.

Under the discard legislation, with areas where the catch composition breached the limit set, access was denied unless vessels could operate within the strict bounds of the 15% limit. Inevitably these measures initially reduced the economic efficiency of the fleets by restricting the available fishing opportunities. Following this a dispensation was agreed whereby vessels who could show that they could achieve this with certain gear modifications access was granted. This restraint on commercial practice encouraged the fishermen to accept the use of more selective fishing gears. The change of focus was purely financially based. It was generally accepted by the industry that it was better to regain access to the fishery with the slight inconvenience of using more selective gear, and suffer the inevitable small loss of marketable fish associated with the new gear designs, than have no access to the fishery at all.

In relation to demersal fisheries, several BRDs are used. The Nordm⌀re grid is compulsory in the *Pandalus* fishery North of 62^0 with voluntary use south of this parallel. The basis behind the use of grids is to reduce the unwanted by-catch of commercially important juveniles such as cod and haddock. The voluntary use of grid systems south of 62^0 N has been encouraged by the reduction in sorting time when shrimp catches contained large quantities of juvenile fish. In common with the shrimp fisheries of Australia, the perceived quality of the target species improves with the inclusion of the BRD, which again encouraged the adoption of the device. One major concern with the shrimp fishermen south of 62^0 was the loss of the commercially important finfish by-catch. However, this was quickly remedied by the addition of a large mesh retaining sleeve attached to the escape hole, as the use of the grid was voluntary this did not pose a legislative problem. Although no direct commercial evaluation of by-catch reduction has been carried out, based on earlier experimental cruises, it is estimated that the inclusion of a BRD in the shrimp fishery has reduced the level of discards by the order of 90% by number.

The sort-X, a multiple grid system, became mandatory in the demersal trawl fisheries in 1997 in order to improve size selectivity. Prior to the mandatory legislation, the sort-X system was used on a voluntary basis, where the operators used large bar spacing in order to high-grade fish. Following mandatory introduction, complaints regarding the use of grids in bad weather were filed with the Fisheries Directorate. This led to a dispensation for operators during bad weather, which inevitably was abused, but new simpler designs such as the sort-V are been investigated which should negate some of these problems. If a commercially acceptable design can be developed, then the weather dispensation will be withdrawn.

A full square mesh cod-end must also be used in by seine net fleet. The introduction of a full square mesh cod-end allows assess to otherwise closed areas by the, the inclusion of this type of cod-end normally, depending on fish assemblage, reduces the overall bulk of the catch by approximately two thirds. Other devices such as shortened lastridge ropes, the H-H panel was also introduced, but due to illegal modification to the device, it was withdrawn.

It is questionable whether the introduction of closed areas and the subsequent inclusion the gear dispensation has actually achieved a desired reduction in fishing mortality. Previous to the gear dispensation, no level of fishing activity would have occurred in the closed area resulting in zero fishing mortality. With the development of more selective fishing methods access is granted, and although the discard rates are still very low, it would therefore result in increasing the discard rates from zero in these areas. Only in areas where traditional gears were allowed would show any potential benefit, as the vessel operators are unlikely to remove a BRD when moving from one area to another. In conclusion, the fishermen in the Norwegian EEZ have actually benefited from the development of selective devices due to the previously introduced closed area legislation by gaining access.

4.2.1.7 Estimates of Discard Mortality Probabilities – Towed Gears

From the work of other authors it is clear that not all discarded fish die, however the survival rates vary considerably with each species and with the fishing procedure.

Some discarded fish will die due to a number of reasons, namely,

- Shock due to the initial capture process
- During the subsequent deck handling or sorting procedures.
- The level of physical damage.
- Predation by seabirds at or near to the surface (See also 4.2.4 Predation Mortality)
- Predation on the seabed, due to their weakened state (See also 4.2.4 Predation Mortality)

Most of the work covered in this review have concentrated on discard survival from trawls, including otter trawls, beam trawls and shrimp trawls. A few other studies focused on *Nephrops* creels, long lines and purse seines.

Factors which were shown to effect mortality in this review included the following:

Trawling Process

- Number of tickler chains in beam trawls
- Duration of stay in cod end
- Catch composition and weight
- Towing speed, particularly for the smaller fish
- Fishing depth
- Tow duration
- Presence of thermocline
- Stress experienced prior to landing catch on deck
- The complex interaction of mechanical injury (internal and external) and physiological stress induced by capture
- Wounds inflicted to *Nephrops* by other animals in trawl possibly leading to blood loss and eventual death
- Weather – Mortality highly dependent on sea state
- Species
- Possible seabird predation
- With/without sand in catch (Halibut)
- Season (Differences in survival found between June and September)
- Molting condition (Lobster)
- Lifting of codend to the vessel clearly increased mortality

Deck Handling/Sampling/Transfer

- Total catch weight
- Clear relationship between discard mortality and type of damage sustained during sorting process
- Handling techniques during sampling and transfer to monitoring site
- Depends on species,
- Size of specimen,
- Time exposed in air on deck
- Temperature on deck
- Deck sorting machines influence survival by reducing mortality

- Shell condition/damage (*Nephrops*)
- Possible stress from handling procedures
- Possible swimbladder damage (in some species)
- **Monitoring and Mortality Assessment**
- Possibly some secondary infection to trawling injuries
- Effect of tagging
- Haemorrhaging in the brain, gill cover and mouth
- In lab experiments, stress, was evident, followed by reduced respiration
- Tank temperature
- Plasma levels of glucose, potassium and sodium
- Possible stress from handling procedures
- Crowding in monitoring tanks

Case Studies

The following report reviews the work which has been carried out in recent years to investigate the survival probability rates of discarded species.

Van Beek *et al.*, 1989
The authors studied the survival of undersized plaice and sole caught by otter and beam trawls in the North Sea. They also studied the survival of soles that escaped through the codend meshes in covered codend experiments. In the commercial beam trawl and otter trawl fisheries, the survival of both undersized plaice and sole was estimated to be less than 10%. The survival of soles that escaped through the meshes was estimated at 60%. Deaths were attributed to the fishing process, through the action of the tickler chains and the injuries inflicted during the stay in the net. The present day practice of processing the catch on deck would be likely to increase the mortality of the small fish which are discarded

Bergman *et al.*, 1989
The authors investigated the effects of beam trawling on densities of fish in a 2 x 2 nm area off the Dutch coast. They stated that the direct effects of beam trawling on the densities of the various fish species in the area were not found. Most small fish apparently escaped through the meshes of the commercial trawl fairly undamaged. At least 56% of dab, 85% of plaice, 100% of sole and 68% of dragonet and solonette survived the first 24 hours after capture. In this particular season (1989) and area of investigation, the amount of dead discard fish was estimated to be approximately 2–4 times the amount of marketable fish. This cannot, however, be extrapolated to other seasons or areas

Berghahn *et al.*, 1992
The authors investigated the mortality of various species of fin and flatfish bycatch from commercial shrimp trawlers that utilise automated sieving devices to grade shrimp. Mortalities increased considerably after catch passed the sorting sieve. 100% mortality was detected for Whiting and 10% for Sculpin, Hooknose and Eelpout in the discard groups. Survival of flatfish depended strongly on the species, the size of the specimens as well as the catch processing conditions and ranged from 17 – 100%. No differences were detected in the survival after sorting on different machines. They concluded that clearly the sorting methods had an important influence on the mortality of discards especially when mechanical devices were used. However, due to better sorting efficiency, the rotary sieve may reduce mortality in the bycatch

Erickson *et al.*, 1999
Trials took place on board commercial fishing vessels during 1997 and 1998 to estimate mortality of trawl-caught and discarded sablefish (*Anoplopoma fimbria*). Nearly all sablefish died during 1997, regardless of treatment level. For example, mortality exceeded 95% for short-shallow tows even when deck exposure was less than 15 minutes. The high mortality observed during 1997 was attributed to high surface water temperatures (= 18 to 20 ^{o}C). Mortality was substantially lower during 1998 trials, when surface-water temperatures were 12 to 15 ^{o}C. Mortality increased with increasing depth, towing duration, and deck exposure.

Hill and Wassenberg, 1990
The authors made a study of the fate of teleosts, non commercial crustaceans and cephalopods discarded from prawn trawlers in the Torres Strait. These three groups take up about 80% of the discards by weight, have a high mortality rate and are therefore the most likely to be eaten by scavengers. The remaining 20% of discards consists of animals such as turtles, sharks, bivalves and sponges, which are caught in low numbers and appear to have low mortality from trawling. Fish made up 78%, non commercial crustaceans 18% and cephalops 3% by weight of the material studied. Nearly all fish were dead when discarded and about half sank. About half of the non commercial crustaceans were alive when discarded and all sank when discarded. Few cephalopods (2%) were alive when discarded and around 75% sank. Sharks and dolphins were the most common scavengers of floating discards at night. Birds (common and crested terns, and lesser and greater frigates) scavenged during the day. Discards that sank, did so rapidly, taking less than 5min to reach 25m depth. Sharks and teleosts ate most of the material that reached the bottom: scavenging by invertebrates was negligible. In an adjacent area that had not been trawled for 8 years, no dolphins and fewer birds were seen scavenging floating discards but there were more sharks. In this area, significantly fewer fish were attracted to a bait on the bottom at night compared with the trawled area. The cause of the difference in scavenging observed between the two areas is not known; while it may reflect learned behaviour by some scavengers such as birds and dolphins, there may also be intrinsic differences between the two areas unrelated to trawling. Discarding from trawlers had the effect of transferring large quantities of biological material from the bottom to the surface. This made food available to scavengers, food that would otherwise be inaccessible.

Hoag (1975)
The author investigated the survival of the Pacific halibut (*Hippoglossus stenolpis*) after capture by trawls. The physical condition of over 2000 halibut caught and released by trawlers was assessed, and fish were placed in one of five categories based on their external injuries and physical activity. Fish condition was positively correlated with size and negatively with time on deck and total catch weight. Most of the fish were tagged, and the recovery rate declined with poorer condition. The criteria for judging condition were not entirely accurate as some of the fish that were considered dead subsequently recovered. The survival rate of fish was estimated from the number of tags recovered, expected rates of fishing mortality and other losses. The average survival of halibut in all conditions was estimated as 28% for those smaller than 80cm and 55% for those larger than 80cm. The survival of the smaller fish was probably underestimated and the author suggests that the survival for all sizes was about 50%.

Robinson *et al.*, 1993
The authors investigated the survivability of the juvenile bycatch (discards) and codend escapees of Atlantic cod, American plaice and Yellowtail flounder. Survival rates were determined by placing the discards in large cages and returning them to the tow depth for a period of 24h. Results varied with fishing season. Spring survival rates were 51% for cod (N=99), 66% for plaice (N=114) and 77% for yellowtail flounder (N=144). Summer survival was 9% for cod (N=244), 40% for plaice (N=182) and 66% for flounder (N=36). Winter survival figures were 36% for cod (N=47), 0% (N=37) for plaice and 50% (N=15) for flounder. The primary factors that were determined to influence survival were air temperature, decktime, fish length, tow duration and tow weight. Air temp., deck time, fish length and tow duration were most critical to plaice survival. Tow duration and deck time to flounder survival. Cod, yellowtail and plaice blood samples were taken from a sub-sample of landed fish and analysed for haematocrit, protein, lactate, chloride, glucose, sodium, potassium, total osmolarity and cortisol. With the exception of glucose, all measured parameters for cod bycatch were generally elevated above control values, even in those fish sampled within 3 mins. Of landing on deck. Yellowtail, in contrast, generally exhibited elevations in all parameters except for cortisol. No control American plaice data were available for comparison. Lactate was the only blood parameter that continued to rise in all three species as time on deck was extended. Cod also exhibited increases in protein, haematocrit, K and cortisol. Total osmolarity increased as time on deck elapsed for both yellowtail and plaice (as well as chloride in yellowtail: glucose, K and haematocrit in plaice). These data demonstrate that cod and yellowtail had been considerably stressed prior to landing. Although fish were subjected to highly stressful conditions on deck, this additional stress was less than that which the fish experienced prior to be landed. Atlantic cod bycatch, caged bycatch and codend escapees all experienced perturbations of osmotic balance and elevations in several other non osmotically linked blood parameters. In general, codend escapees were less stressed than the caged bycatch, which in turn were less stressed than the deck processed bycatch.

Millner *et al.*, 1993
Studies on the discard mortality of plaice from large beam and otter trawlers in the North Sea have estimated average mortalities of 90%. The poor survival is attributed to the tickler chains and to other injuries suffered while in the net. In order to assess whether similar mortalities occur in plaice discarded from small trawlers using light otter trawl gear without tickler chains, a study was carried out using commercial vessel fishing in the English Channel. Two separate methods were used to estimate mortality of plaice. The first involved holding the discarded and control fish in cages and recording their mortality over a period of up to 216h. In the second method, discarded plaice were tagged and returned to the sea and their recapture rate compared with a control group of plaice caught by 15–30 min tows. The results of the cage studies indicate that the short term survival of discards from otter trawl gear is high. Estimates of longer term

survival derived from the recapture rate of tagged discards confirm that survival is likely to be above 50% and could be substantially better

Neilson *et al.*, 1989
They assessed the effectiveness of a proposed 81 cm minimum landing size limit for Atlantic halibut (*Hyppoglossus hippoglossus*) in Canadian waters. They examined the survival of small fish caught by longline and bottom trawl gear and held in tanks, firstly on board a research vessel and subsequently, in a shore laboratory. Of halibut less than the proposed size limit, 35% of the otter trawl catch and 77% of the longline catch survived more than 48 hours. Factors potentially influencing halibut survival (handling time, total catch, fish length, maximum depth fished and trawl duration) were examined using proportional hazard models. On the basis of the analyses, it was concluded that in bottom trawl hauls of the duration normal in the commercial fishery (at least 2 hours) higher survival times were associated with shorter handling time, larger fish size and smaller total catch weight. Supplementary information on the condition of trawl caught halibut was also obtained from observers on board commercial trawlers.

Von Kelle (1976)
He reported on the survival rates of undersized flatfish (*Plueronectes*, *Limanda* and *Solea* species) in the German shrimp fishery. The relationships between mortality rate and haul duration, catch quantity, catch composition, fish size and treatment on board were analysed. There was a direct relationship between towing time, total catch weight and survival of small sole, dab and plaice. The survival rate of undersized flatfish was 51% for plaice, 57% for sole, and 26% for dab. Cyanea and Pleurobrachia showed a positive influence by decreasing the survival rates of fish when they appeared in the by-catch in large amounts.

Kelle 1977
Undersized plaice and dab from the bycatch of German shrimp fishery were damaged during the catch. Bleedings in the brain, gill cover and mouth were primarily encountered in fish which passed the shrimp sorting machine. Haemorrhages in the brain dominated the injuries with more than 50%. They were responsible for the death of the flatfish in most cases. The surviving fish showed a very small percentage of such injuries. Some of the bleedings, even in the brain, would be reduced within a few days if the injuries did not cover a large area. In lab experiment, the causes of injuries and death resulted from stress by chasing and by hindered respiration. Stress, followed by reduced respiration, was the main reason for high mortality. The lack of oxygen was responsible for the haemorrhages in the brain. This caused an increase in the blood pressure and thus produced ruptures in the blood vessels.

Carr *et al.*, 1992
They reported that juvenile groundfish discards and its potential waste because of a perceived low survival is a major issue in the management of the multispecies ground fishery off the coast of New England. Two cruises were completed to assess the survival of the deck discard of cod and American plaice. Survival rates were determined by placing the discarded fish in large cages and returning them to the tow depth for a period of about 24h. The first cruise, which was undertaken during early June1991, resulted in overall survival rates of 264 cod at 12% and 209 plaice at 44%. The second cruise occurred in late April 1992. The survival of the discard on this cruise was 51% for 115 cod and 66% for 178 plaice. Cod and plaice blood samples were taken from another subset of fish and analysed for haematocrit, protein, lactate, chloride, glucose, sodium, potassium, total osmolarity and cortisol. Lactate concentrations increased dramatically as time on deck increased but did not vary with length of tow. Cortisol concentrations were elevated above the control values in all fish, regardless of tow or time on deck.

Candy *et al.*, 1996
They reported that in B.C. chinook salmon are commonly taken in purse seine fisheries directed at other salmon species, but the need to conserve chinook salmon may reduce the opportunities for such fisheries to operate. To test the feasibility of a non-retention fishery (i.e., release) for chinook salmon, we used ultasonic telemetry to estimate the survival rates of chinook salmon caught and released from purse seine vessels in Johnstone Strait, B.C. From 1990 to 1992, we tracked 47 fish for durations ranging from 2h 1min to 32h 48min (mean 16h 48min). For the first 24h after release, the survival rate for all years combined was estimated to be 77% with 95% binomial confidence limits of 62% and 87%. Mortality was positively associated with longer landing time. Chinook salmon that survived spent between 57–64% of the next 24h at depths less than 50m where they were vulnerable to recapture by commercial purse seine vessels.

Chapman, 1981
The author says *Nephrops* tend to cling to one another or to the net by their claws so that some below marketable size will be caught, even in large mesh trawls. These are thrown back. Their subsequent survival appears to depend on the following factors: (a) damage in the trawl during fishing and landing, (b) effects of changes in temperature, pressure and light intensity during ascent and descent; (c) exposure in air on deck; and (d) predation by seabirds, fish and other animals during ascent and descent and on the bottom before finding a vacant burrow.

Graham, 1997
He reports that a number of discarded fish survive, but the level of survival is debatable and is dependent upon the sorting system used, the ambient temperature and level of sea bird predation.

Hokenson & Ross, 1993
They stated that short term mortality experiments were conducted on Atlantic cod, pollock, American plaice, witch flounder, winter flounder and yellowtail flounder discards in the Gulf of Maine northern shrimp fishery. Discard mortality of gadoids was generally higher than that of Flounders. Substantial additional mortality due to avian predation was incurred when discards were returned to the water. Differences among species in predation-caused mortality were apparently due to differing abilities among the fish species to sink immediately upon hitting the water. Logistic regression analysis demonstrated that air temperature, time on deck, and length of fish were the factors that most influenced mortality of winter flounder and American plaice. Differences in discards mortality rates between this study and those of large mesh trawls indicate that mortality is specific to both species and the fishery in which the species are being captured.

Kaiser and Spencer, 1995
The authors investigated the survival of animals caught by a 4m beam trawl in order to identify those species most sensitive to capture. Starfishes, hermit crabs and molluscs were highly resistant to the effects of capture (>60% survived in all cases). Fishes (except lesser spotted dogfishes), sea urchins and swimming crabs suffered higher mortality after capture. Experimental investigation of the cause of damage to certain species concluded that the chain matrix fitted to the gear was largely responsible for the injuries sustained. The types of injuries and their extent were species-specific and were related to the fragility and physical characteristics of each species. Our experiments revealed that while some species are highly sensitive to capture, others are capable of surviving the effects of capture

Oddsson *et al.*, 1996
Physiological stress parameters were measured to assess the effects of capture and discarding on the physiology and survival of trawl caught Pacific halibut in the USA NE Pacific trawl fishery. A predictive survival model was then constructed using physiological and fisheries variables. The halibut were kept in sea-cages for up to seven days post-capture to estimate short term survival rates and to measure recovery stress indicator levels. Significant differences in plasma levels of glucose, potassium and sodium were observed between towing durations of 30 and 120 min while survival was significantly lower following 120min tows than after 30min tows. One indicator (potassium) reacted to deck exposure duration (discarding time); levels of potassium increased as duration on deck increased and at a faster pace after the longer towing time. Some stress indicators, such as haematocrit and potassium recovered to baseline levels in 24 h or less. Other factors did not return to baseline values within the observed seven day post capture period.

A cross-validation glim survival prediction model was constructed after a stepwise glim procedure had been used to determine which explanatory variables were significantly related to survival. Survival rates obtained from the predictive model were then compared to observed survival rates of halibut with known fate. Four models predicted individual fate correctly more than 70% of the time. A single variable model with potassium as the explanatory variable is probably the most feasible for management purposes. The methods and results of this study may be used to improve the estimates of discard survival used by management entities and to identify the factors that most significantly impact post-capture survival of Pacific halibut.

Pikitch *et al.*, 1996
Objectives of this research were to refine discard mortality estimates identifying fishing and handling practices that may reduce mortality of discarded individuals and develop a model that can be used to predict halibut discard mortality over a broad range of conditions. A seabed cage methodology was developed to calculate mortality of trawl caught and discarded halibut during 1992–995 in the Gulf of Alaska. Discards were placed in the cages and returned to the sea. These cages were subsequently retrieved one to seven days later for quantification of mortality. We found that 3+ caging days were required to detect most trawl caused mortality and that cage confinement did not adversely affect halibut mortality. Control group halibut was 0% for a period up to 8 days. Factors that significantly affected halibut mortality included tow duration (range 1–3h), amount of time out of water (range 10–40min), body size (range34–113cm) and air temperature (range 3–5 degrees C). One of the most pronounced factors affecting mortality was the condition of the catch. Mortality often reached 100% when substantial amounts of sand were mixed in with the catch. A predictive mortality model using logistic regression applied to data obtained from the sea trials and including factors found to have significant effects on halibut mortality is presented

Redant and Polet, 1994
In June and September 1993 two sampling campaigns were carried out on board a commercial *Nephrops* trawler in the Botney Gut – Silver Pits area to investigate fishermen's selection and discarding of *Nephrops*. The number of *Nephrops* caught landed and discarded varied widely from one haul to another depending on the season, time of day and location

of the hauls. Fishermen's selection curves are presented for male and female *Nephrops* separately. The differences in selection pattern between males and females were related to the occurrence of soft, recently moulted females and to the development stage of the female gonads. Survival experiments on *Nephrops* discards revealed a clear relationship between the type of damage sustained during the catching and sorting process and the immediate mortality rates. A tentative estimate of the long term survival rate of the discards is given.

Salini *et al.*, 2000
The authors state that the use of bycatch reduction devices (BRD) and turtle exclusion devices (TED) will be compulsory in the Northern prawn fishery of Australia by the year 2000. These devices may also benefit fishers by excluding large animals that can damage prawns in the trawl and thereby improve catch quality and hence value. This study measured the reduction in physical damage to prawns caught with BRD –fitted nets compared to a standard codend. The measure of damage was that a prawn one or more of the types of damage that, in commercial fisheries, would condemn it to a less valuable "soft and broken" category. The change in prawn damage ratio was between 6.1% and 34.7% depending on the BRD being used. The total catch weight and weight of large animals (>5kg) were significantly reduced with a grid (excluder device) in the net. The best BRD for retention of prawns and damage reduction was the Super Shooter + Fisheye. The economical value of reducing prawn damage was calculated from a combination of the percentage reduction in damage and the price difference between 10Kg "soft and broken" prawns and higher priced, finger-laid prawns in 1.5, 3.0 or 5.0Kg packs. The increased value of catches from reduced prawn damage in two BRD's that did not significantly affect prawn catches was conservatively estimated to be $735 per week, which is more than the cost of the BRD.

Smith, 1987
American lobsters taken in the commercial trawl fishery in Long Island, USA were inspected for incidence of damage and immediate mortality associated with bottom trawling. Similar sampling was conducted in the pot fishery. American lobsters from trawl and pot catches were held in controlled conditions for 14 days to determine the level of delayed mortality associated with the two fisheries. Trawl caught lobsters were exposed to sub-freezing (-9.5 C) temperatures for periods from 30 – 120 mins. And then returned to seawater to determine the rate of freeze-induced mortality. Major damage rates due to trawling ranged from 12.6–14.0% during molting periods to 0 – 5.6% during intermolt periods. Delayed mortality ranged from 19.2% during July molt to 1% during August and appeared to be related to the incidence of damage, molt condition and temperature. Mortality of American lobsters held in sub-freezing temperatures occurred after 30min exposure and reached100% at 120min exposure.

Thurow & Bohl, 1976
42 experiments were carried out in Nov. 1975 to May 1976. In a multiple correlation, survival was related to 7 variables – total catch weight of cod, towing depth and duration, time on deck, time in tank, cod weight, and fish length. Seasonal effect temperature on deck and area on survival was not evaluated. Only time on deck (T), average fish length (L) and towing depth (D) were found to have a significant effect on survival. It is suggested that survival of Baltic cod could be estimated by means of the formula $S = 14.4 – 0.25D + 1.45L – 0.49T$.

Turunen *et al.*, 1994
Trawling stress and mortality in undersized brown trout were examined at open-water seasons in 1989 and 1990 on the big lakes in Eastern Finland. Large scale trawling on inland waters in this area is a new phenomenon and it has caused conflicts between different fishing groups. It has generally been assumed that undersized trout freed after being caught in trawls do not survive. Blood lactate and glucose concentrations and plasma chloride concentrations were measured from blood samples taken immediately after trawling. The recovery of the fish from trawling stress was also monitored by blood sampling and following the mortality of fish caged for 7 days after capture. The trout were observed to become considerably stressed by trawling. Abundant catch and high water temperature increased stress of the trout. These variables and the duration of trawling haul as well as codend emptying technique explained 72% of the increase of blood lactate. The indicators of stress had not returned to control values by 4h post-capture, but blood lactate showed an abrupt decrease over 2h. Plasma chloride was however still decreasing 4h after the end of trawling. The percentage of caged fish which survived a week was 85.5. Lifting of the codend to the vessel clearly increased the mortality of trout. Without the extra stress connected with caging the proportion of surviving fish would probably have been considerably greater. On the basis of the results, it can be said that if undersized trout were freed immediately by emptying the codend in small portions directly in the water, trawling would not cause them considerable mortality

de Veen *et al.*, 1975
Plaice and sole discard survival was studied in the Southern North Sea off the Dutch coast. Deck exposure time was found to be significant on the survival of both species. Sole mortality was far greater than that of plaice. On average commercial catches are exposed on deck for 15–20mins – plaice and sole survival was estimated at 100% and 14% after this time If the fish were in good condition and after 40 mins, plaice and sole survival was 100% and 0%. Less healthy looking fish had lower survival rates i.e., plaice after 20 and 40min was 52–89% and 7–57%, and sole was estimated at 0–11% and 0%.

Wassenberg and Hill, 1993
The authors studied the survival rates of ten species of invertebrates (n=39–50) and four species of fish (n=50–68) determined from specimens collected from the bycatch of night trawl catches. They were observed in laboratory tanks for 7 days, as these provide better holding conditions than can normally be achieved at sea. Except for the alpheids, crustaceans and echinoids, the invertebrates were more tolerant than the fish - over 70% remained alive after 7 days. Although the species of fish were chosen for their relative robustness, only one species (*Centropogon marmoratus*) had a survival rate above 30% and most deaths occurred during the first 3 days after capture. This result agrees with published data on survival of temperate fish captured in trawls indicating that 4 days is an adequate length of time for experiments to measure survival of animals discarded from trawl catches. Animals returned to the sea may continue to die over a longer period but this cannot be determined in tanks

Wileman *et al.*, 1999
Nephrops escapees and discards were transferred from the vessel to underwater pens containing isolated artificial burrows for each *Nephrops*. Creel caught animals were used as controls and subjected to the same transfer process. Only 0.5% of the controls died. Mean survival rate for discards was 31% (range 19–39%). These were not significantly dependent upon cod end mesh size/ type or *Nephrops* length. The survival rates of discards were significantly lower for females than males. An analysis was made of the relationship between mortality and visual body damage. Mortalities showed a significantly higher amount of visual damage on the abdomen compared to the survivors for discards but not for cod end escapees. Total body water content was measured and found to be reduced for cod end escapees but further reduced for deck discards with the reduction increasing with time on deck. Deck discards showed significant reductions in blood volume and blood pressure compared to controls. *Nephrops* escape using a tail flip mechanism. The number of tail flips that could be elicited, reduced by 53% for cod end escapees and by 90% for discards immersed for 2 hours. Trawling and exposure to air on deck were found to result in high l-lactate levels in the blood and muscle tissues, low muscle glycogen levels, high blood D-glucose levels and high blood ammonia levels.

Trumble *et al.*, 1995
Mortality of Pacific halibut caught as a by catch in groundfish fisheries causes economic losses to both groundfish and halibut fisheries. An experiment on board a factory trawler to sort and discard halibut on deck using a grid over the hold removed 40% by number and 52% by weight of the halibut that previously had all been dumped to the hold. Overall estimates of halibut from hauls sorted and discarded on deck decreased 13% and 24% from two alternate sorting methods that occurred in the factory. Time required to dump the fish to the hold increased from 1–3min for hauls dumped directly to the hold to 10–15min for deck sorted hauls. Reductions in discard mortality of halibut from factory trawl fisheries for Pacific cod and other groundfish could potentially add thousands of metric tons to the groundfish harvest, several hundred tons to the halibut fishery and millions of dollars in revenues. Implementation of a regulation to require factory trawlers to sort on deck is under review. A final decision on deck sorting will require policy makers to prioritise among competing demands for observer duties, recognise incompatibility with existing programme and determine an acceptable level of observer coverage

4.2.1.7 Estimates of Discard Mortality Probabilities – Static Gears

USA
A study was conducted to determine the survival rate of sub-legal cod caught in the longline fishery using 11/0 circle hooks (Milliken *et al.,* 1999). The focus of the research was to assess the rate of mortality of sub-legal catch after the cod were placed in cages for 72 hours. The results of the study showed that there was high mortality (69%) associated with capture using the 11/0 circle hook when the fish were injured by the process of having the hooks removed from their mouths by the crucifier. Furthermore, sublegal cod that had wounds from the dehooking process and were under 39 cm were statistically more likely to die as compared to cod between 38 and 49 cm.

An ancillary set of observations on the predation by sea birds of released sublegal cod was included. Despite low numbers, the findings from these observations show that sea bird predation should be included when estimating the survival of fish caught by a longline.

Pacific cod caught as bycatch in the pacific cod and sablefish longline fisheries. They must be removed carefully by regulation. Kaimmer and Trumble (1998) used a tagged recovery study and found that survival rates of moderately and severely injured fish are one and a half to two times higher that previously thought. It was interesting to note that 26% of the previously recorded dead fish really survived. Ninety-seven percent of fish with minor injuries survived.

The short term survival of lake trout caught by commercial gillnets in Lake Superior was investigated by observation for 48 hours in tanks (Gallinant, *et al.,* 1997). Fishing season, number of night sets, time between capture and holding, and manner of entanglement had no significant effect on survival.

Artificial flies and hook and line with artificial baits, fished both actively and passively were used to understand the post-release mortalities in the catch and release management of rainbow trout (Schisler and Bergersen, 1996). Mortalities were assessed over a three-week period in holding pens. Mortality was determined to be 3.9 % for fly caught fish versus 45.7% for the actively fished hook and line and 78.3% for the passively fished hook and line.

Fishing pressure on freshwater species of fish in the Midwestern United States has resulted in regulations that are attempting to promulgate catch and release fisheries. In 1996, Schisler and Bergersen quantified the differences in mortality associated with capture of rainbow trout (*Onchorhynchus mykiss*) using artificial baits fished both actively and passively versus flies. The results showed that artificial baits fished passively resulted in a 32.1% mortality as compared to actively fished artificial baits which averaged 21.6% mortality and fly caught fish which averaged 3.9% mortality.

Gillnets and hook and line gear were evaluated for their effects on mortality on spotted seatrout, an inshore saltwater fish (Murphy *et al.*, 1995). It was found that 4.6% of the fish caught by hook and line died as compared to 28% of the fish captured by gillnet. Murphy *et al.,* (1995) also found mortality was affect by the location of hook wound.

A tag recapture study was conducted on halibut that had been both gently removed form the longline using a gaff versus those that had received injuries from automated removal from the longline (Kaimmer, 1994). It was found that the survival of automatically removed fish (crucifier) experienced a survival of less than 50%. Those fish that were carefully removed survived 95–98% of the time. Furthermore, fish that removed automatically had significantly reduced growth rates in subsequent years.

A study was conducted to determine the mortality rates of discarded soft and hard shell male Dungeness crabs which incorporated the effects of air exposure (Kruse, *et al.*, 1994). It was found that soft-shell crabs experienced 45% higher mortality than hard shell crabs. Varying air exposures up to 60 minutes had no significant effect on the survival of hard shell crabs. Not enough soft-shell crabs were captured to make any conclusions.

Rutecki and Meyers (1992) found that the mortality of hand-jigged juvenile sablefish was 19% whereas the mortality of trap caught fish was 75%. These results were suspect because of a myxobacterial infection in the held fish. It was hypothesized that fish caught during the summer may exhibit increased survival because of the unfavourably high temperatures toward these bacteria.

Since effort had increased substantially since the 1970’s, fisheries managers concerned about the repeated handling during the fishing season prompted the study of lake whitefish in the trap net fishery in Wisconsin. It was found that 75% of sublegal sized fish survived capture and release. Copes and McComb (1992) used stepwise multiple regression for nine independent variables and determined that sorting time and crowding in the lift bag during sorting contributed the most to mortality.

Norway

Haddock is usually considered a bottom dwelling species, however the seasonal fishery of haddock off the coast of Scandinavian countries target pelagic haddock. Small fish (<44cm) are torn from the hook by various methods and returned to the sea.

At least two studies were conducted where sublegal haddock (<44cm total length) were removed from the longline by crucifier and gaff (Soldal and Huse, 1997). The haddock were transferred to sea pens at the surface. They were monitored for five to eleven days. Mortality was shown to be 34% for fish removed by the crucifier alone and 64% for those torn off using a gaff. In a similar study all fish (18) retrieved from the ocean after being removed by crucifier on a commercial longlining vessel survived for five days.

Canada

The mortality of Atlantic Halibut caught by longline and bottom trawl gear was studied to determine the effect of a proposed minimum size limit of 81 cm. After capture, the fish were placed in holding tanks onboard research vessel before their placement in land-based tanks. Thirty-five percent of the otter trawl catch and 77% of the longline catch of halibut less than 81 cm survived more than 48 hours. Furthermore Neilson *et al.,* (1989) documented the location and severity of wounds caught by both types of gear.

Australia

The mortality rates of sublegal sized spanner crabs were evaluated for four different levels of injury(Kirkwood and Brown, 1998) in an effort to estimate the mortality associated with limb removal sustained during capture and release from baited tangle nets. The results showed that individuals with 1 periopod or cheliped sustained greater mortality than crabs that had no limb damage or one to three dactyli removed. Another sub-study was performed to determine the time of inactivity and reburial rates after release. Crabs remained inactive after release for a period of six seconds to 20 minutes, but the majority (65%) buried themselves within 68 seconds of reaching the substrate.

4.2.2 Escape Mortality

4.2.2.1 Towed Gears

The overwhelming volume of research in this area has concentrated on escape mortality from trawls, both demersal and pelagic. The review highlighted some work on other gears, including: Danish seines (Soldal & Isaksen, 1993); purse seines, as a results of net bursts (Misund & Beltestad, 1995) as well as escapes from selection grids (Beltestad & Misund, 1992); and scallop (clam) dredges (Chapman *et al.*, 1977; and Naidu, 1988). Estimates of mortality defined by these studies are listed in appendix I. Due to the limited time available for the review the author felt it was of most benefit to give a detailed evaluation only of the current knowledge in the most studied fishing gear: trawls.

Escape Mortality from Trawls

It was felt unnecessary in this exercise to review papers assessing the probability of encounter (P^E) for trawl codend escapees, as this area has been investigated comprehensively by many selectivity studies performed over the last century (Wileman *et al.*, 1996). Therefore only work assessing the mortality of escaping fish will be reviewed in this section. Appendix I summarises the references, highlighted by this review process, which report mortality estimates for commercially important species escaping from mobile/towed fishing gears. The results from these references are summarised in terms of species, fishing gear, the category (or mode) of escape from that gear (i.e., via codend meshes or a selective grid, etc), the factors which were shown to influence mortality, the range of mortality seen in each escape category and, finally, the size range of fish seen in each escape category. It was felt necessary to list the range of mortality estimates, as opposed to any averaged mortality estimate, in order to highlight the great viability in mortality estimates seen in many of these studies. The original intention of the review was to list the average estimates of mortality with confidence intervals, however too few of the references included these data.

It is clear from Table #1 that the most studied group of fish are the gadoids, and in particular haddock (13 separate references). Therefore it is not a surprise that the most studied fishing gear is the demersal trawl (16 separate references), in all of its various guises. However considerable work has also been directed at Pelagic Trawls and their target species, in particular Baltic Herring. The most alarming trend highlighted by this review is the great variation seen in mortality estimates for any one species. Indeed the complete range of mortality (0 - 100%) can be seen for a number of species, over the selection of results presented here, and in some cases within individual studies.

The original purpose of many of these studies was from the perspective of gear technology. That is, investigations have either compared the relative benefits of using different selective devices or simply tried to justify the use of such selective techniques by demonstrating that a proportion of the escaping population survive. As such, much of this work has produced promising results, with many species being shown to have relatively high potential post-escape survival estimates (e.g., haddock, whiting, cod &Alaska pollock: up to 100% survival; yellow tail flounder: up to 99%; saithe up to 97.6%; American plaice up to 95%; Baltic herring: up to 90%: *Nephrops norwegicus:* up to 94%). However, some of these same species have also been shown, in extreme cases, to have worryingly low post-escape survival estimates, often by the same studies (e.g., haddock, cod &Baltic Herring: as low as 0% survival; American plaice 41%; whiting: 50%). These are extreme cases though, with most estimates for most species being in excess of 70% survival, but they do highlight the variability in the data. No single study has yet provided a conclusive explanation for this variation. Some of the more extreme examples have been attributed to experimental error and this will be discussed in greater detail later.

In terms of comparing different selective techniques, it has been demonstrated that for a number of species the survival potential of escaping fish increases with increasing mesh size (in trawl codends). This has been shown for Baltic herring (Borisov & Efanov, 1981 and Efanov, 1981) as well as the Gadoids, haddock and whiting (Main & Sangster, 1991; Lowry *et al.*, 1996; Sangster *et al.*, 1996; and Wileman *et al.*, 1999). A change in mesh shape, from the traditional diamond to square mesh, has also been shown to reduce mortality in haddock and whiting escaping through the same mesh size (Main & Sangster, 1990 & 1991). This is thought to be related to the improved selective properties of the square mesh, in particular its improved L_{50}. This was demonstrated further by Main & Sangster (1991), when they compared the different degrees of openness in the same mesh size (90mm, diamond) by altering the number of meshes round the codend. The more open meshes (100 meshes round) showed the better survival potential amongst escaping haddock. This same alteration is known to improve the relative selectivity of the codend (Ferro & Graham, 1998). Comparison of Baltic herring escaping from selective codend grids with various codend mesh sizes and shapes has also been shown to improve their survival potential (Suuronen, 1991 and Suuronen *et al.*, 1996b).

This comparative approach, with respect to different selective devices, has proved of some use to gear technologists, in justifying use of selective techniques, and to fisheries managers in comparing the relative benefits of different fishing gears. However, this work has done little to explain the possible causes of mortality in these escaping fish. It must be remembered that this is not an engineering problem, but a biological one. Moreover, before escape mortality can be fully understood, it must be appreciated that, while a degree of mortality may be seen in a population of fish escaping from a fishing gear, these deaths are absolute events experienced by individual fish. It is the reason that these individual events occur that must be understood, before the mortality in a population can be explained. With this in mind, it is essential that the observed mortality is described in terms of individual biological parameters for the population of escaping fish.

This approach has been taken by a number of researchers. The biological parameters by which individuals in a population can be measured and compared are many, but within fish populations one of the key parameters is size, in particular length. Length has been shown to be indirectly related to mortality for the gadoids, haddock and whiting (Lowry *et al.,* 1996, Sangster *et al.,* 1996 and Wileman *et al.,* 1999) and for Baltic herring (Borisov & Efanov, 1981, Efanov, 1981, Suuronen, 1991 and Suuronen *et al.,* 1996a & b). That is, the larger the individual the greater is its potential for survival. This was a surprise for many workers, as the general presumption was that the larger an individual the greater was its likelihood of injury, and therefore death, during its passage through a trawl codend mesh or other selective device in a fishing gear. In support of this, Borisov & Efanov (1981) and Efanov (1981) showed an increased mortality in the very largest herring, as well as the smallest in the escaping population they observed. For an invertebrate species, *Nephrops norwegicus*, length was shown not to have any effect on escape mortality (Wileman *et al.,* 1999). This maybe true for other species, including some teleost fish, however in general where the size of an individual has been measured it has been shown to have some effect upon escape mortality.

The effect of individual size upon escape mortality was used by Sangster *et al.,* (1996) to partially explain the effect mesh size on mortality in a population of escaping fish. They demonstrated that within any one length classes mesh size had no effect upon mortality. It was argued that the observed mesh effect was in fact the product of length related mortality in the escaping mortality and the varying selective properties of the different mesh sizes. That is, the larger the mesh size the greater is the number of large fish that are able to escape, thus increasing the potential for survival in that escaping population. This may go part way to explaining some of the observed variability seen in the escape mortality estimates for a single species, where the mean size within a population may vary both spatially and temporally.

The importance of size in the mortality of escaping fish, would suggest that age would also have some influence. This has indeed been shown to be true for both haddock and whiting, with the youngest age classes sustaining the greatest mortality (Lowry *et al.,* 1996 and Wileman *et al.,* 1999). Determination of age has however been attempted by few studies, presumably due to the additional laborious effort required to estimate age in aquatic species. This is unfortunate, as most stock assessment models, into which these data could be directed, describe their subject populations in terms age classes, as opposed to length. In addition to separate length and age effects, Lowry *et al.,* (1996) demonstrated that, for haddock and whiting in their observed escaping population, the smallest individuals in any one age class have the lowest survival potential; in particular the 0 and 1 age classes. They further argued that this may be evidence that the physical condition of a fish, prior to its capture by a fishing gear, may predetermine an individual's survival potential. This was also argued for fish escaping static as well as mobile gears (Chopin & Arimoto, 1995) and demonstrated for Baltic herring escaping from a pelagic trawl (Treschev *et al.*, 1975).

The effect of gender on the potential survival of escaping individuals has only recently been investigated (Wileman *et al.,* 1999). These studies showed that for *Nephrops* norwegicus and sexually immature haddock and whiting the gender had no effect upon its survival potential. However, it was shown that female *Nephrops* had a higher mortality than males when discarded (see section 4.2.1.7).

Another important factor, although not strictly a biological one, that individual mortality should be measured by is time; or more precisely the time after escaping from the fishing gear when death occurs. Mortality has generally been shown to be at it peak in the first 24 hours after escape, there is then a steady decline with time, reaching a minimum level after 3–7 days, for haddock & whiting (Lowry *et al.,* 1996; Main & Sangster, 1991 and Sangster *et al.,* 1996) and Baltic herring (Suuronen, 1991 and Suuronen *et al.,* 1995 & 1996a & b). Moreover, Sangster *et al.,* (1996) demonstrated that the small fish in the escaping population died sooner than the larger individuals. The early peak in mortality was described by Breen and Sangster (1997) as the primary mortality and attributed to the effects of escape and possibly captivity. That latter minimum level of mortality was referred to as the secondary mortality and was thought to be the result of secondary infections and most likely the chronic effects of captivity stress.

The period of time during when the fish escape from a fishing gear, particularly a moving trawl, has been thought to have a significant effect on their behaviour and ability to escape (Olla *et al.,* 2000). The effect of this on escape mortality has only been considered once, for vendace, where it was shown that fish escaping of a night had a significantly reduced survival potential over fish escaping during daylight hours (Suuronen *et al.*, 1995b). These researchers also demonstrated that season, and more specifically water temperature, had an effect upon escape mortality in both vendace and Baltic herring (Suuronen *et al.*, 1995b & 1996b).

Other fishing-gear related factors have also been shown to influence the mortality of escaping fish. The length of time that the trawl was towed for was shown to effect the survival of Baltic herring (Treschev *et al.*, 1975). However, towing time was shown to have no effect on haddock and whiting mortality (Wileman *et al.*, 1999), whereas the length of time for which the fish were collected in the codend cover after escaping the trawl, was shown to directly reduce survival potential. The same authors showed that towing speed also had a small influence on the survival of *Nephrops* and whiting. The weight of the catch in a codend, particularly the proportion of abrasive materials, has been shown to have a possible detrimental effect on the survival potential of escaping Baltic herring (Treschev *et al.*, 1975), *Nephrops* norwegicus, haddock and whiting (Wileman *et al.*, 1999).

Causes of Escape Mortality from Trawls

A number of mechanisms have been suggested as possible causes of the observed mortality in escaping fish. The dynamic nature of towed fishing gears, especially trawls, and the abrasive qualities of the materials from which they are constructed has led many to the conclusion that abrasive injuries are the leading source of escape mortality. Secondary infection of these injuries may also account for some of the observed deaths, particularly after the first 3 – 4 days. Observations of the exhausted state of fish herded by trawls, as well as escaping from them, suggests that a physiological imbalance following an excessive build up of lactic acid in the swimming muscles of teleost fish may be a cause (Breen *et al.*, 1997; Suuronen *et al.*, 1995 and Wileman *et al.*, 1999). Finally, the stress of the initial capture and escape may have detrimental effects upon the organisms homoeostasis. Furthermore, many researches have expressed concerns that the experience of captivity during the monitoring of escaped fish may in itself induce injury or a chronic stress response that is sufficient to lead to death.

<u>Laboratory Investigations.</u>
In order to determine the true causes of escape mortality, some studies have attempted to simplify the damaging mechanisms in simulated laboratory experiments. This approach enables the researcher to focus on the mechanism of interest and control all others, thus a simple cause and effect relationship can be established. Most effort has been directed at the potential injury to fish passing through netting meshes or other selective devices (see appendix I). A variety of species have been studied, including sand whiting (Broadhurst *et al.*, 1997), cod (Engås *et al.*, 1990), haddock (Engås *et al.*, 1990) and Saithe (Soldal *et al.*, 1989), and in most the mortality is indistinguishable from the control fish. This clearly demonstrates that the simple passage of a fish through a netting mesh, or other selective devices, does not necessarily inflict fatal injury. However, these findings have sometimes been used to justify the use of such selective mechanisms in full scale trawls. Such a conclusion is worrying as the damaging mechanisms within a commercial trawl are far more complex than the simple laboratory studies and as a result potentially more injurious. In an attempt to address this, some studies have simulated escapes after exhaustive swimming of the fish. For haddock this was shown to induce a significant mortality (Engås *et al.*, 1990 and Jonsson, 1994) which was comparable with some field observations. However, for sand whiting (Broadhurst *et al.*, 1997), yellowfin bream (Broadhurst *et al.*, 1999), cod (Engås *et al.*, 1990 and DeAlteris & Reifsteck, 1993) and scup (DeAlteris & Reifsteck, 1993) no significant mortality was observed. Although even these results, while promising, cannot be extrapolated to the more complex commercial scenario. Soldal *et al.*, (1993) noted differences in the observed mortality rates of their field and laboratory studies and ascribed the higher mortalities of the field experiments to the more complex nature of the protocol. Assuming that at least a proportion of that observed mortality was due to handling in the experiment.

<u>Assessment of Injuries.</u>
An alternative approach in identifying the causes of observed mortality has been investigation of the nature of injuries to fish escaping from fishing gears. As with mortality estimates, such studies have concentrated on teleost fish and trawl fisheries, in particular demersal trawls and the gadoids. The earliest investigations intuitively assumed that abrasion would be the most likely cause of injuries in fishing gears, especially trawls, and hence focussed on estimating the degree of skin damage in escaping fish. Skin damage assessments have usually used visual estimates of the relative area of scale loss to quantify injury, over the whole body or in specific zones (Main and Sangster, 1988 & 1990; Broadhurst *et al.*, 1997 & 1999; Engås *et al.*, 1990; Jonsson 1994; Marteinsson, 1991; Soldal *et al.*, 1991 & 1993; Suuronen *et al.*, 1995a). Alternatively the area of damaged skin tissue has been estimated with a combination of histo-chemical stains and image analysis (Breen and Sangster, 1997; Lehman and Sangster, 1994; Lowry *et al.*, 1996; and Sangster and Lehman, 1994).

The magnitude of skin damage has been shown to vary greatly between individual fish escaping from the same gear. Individual haddock and whiting have been seen with anything between 0% and 100%scale loss after escaping from the codends of demersal trawls (Breen and Sangster, 1997; Lehman and Sangster, 1994; Lowry *et al.*, 1996; Sangster and

Lehman, 1994; Main and Sangster, 1988 & 1990; Jonsson 1994; Marteinsson, 1991; and Soldal *et al.*, 1991 & 1993). Differences between species are also apparent: cod has consistently been shown to suffer less skin damage than other gadoids (Main & Sangster, 1988; Engås *et al.*, 1990; Soldal *et al.*, 1991 & 1993). Although a number have studies have not found any significant difference between the skin damage received by haddock and whiting escaping trawl codends (Main & Sangster, 1990; Breen and Sangster, 1997; Lehman and Sangster, 1994; Lowry *et al.*, 1996; and Sangster and Lehman, 1994). Dab was shown by Ludemann (1993) to have greater scale loss, after discarding, than other flatfishes and this was attributed to its rougher, ctenoid scales; other flatfish having smoother cycloid scales. Also, Farmer et al (1998) found that of nine species examined (*Sardinella albella, Saurida micropectoralis, Arius thalassinus, Apogon poecilopterus, Caranx bucculentus, Leiognathus splendens, Lutjanus malabaricus, Pomadasys maculatum* and *Upeneus sulphureus*) those with 'deciduous' scales (*Sardinella albella, Apogon poecilopteru,* and *Upeneus sulphureus*) that were the most heavily scaled.

A length relationship has been seen by some studies, where the small haddock have been shown to have the greatest skin damage (Breen and Sangster, 1997; Lowry *et al.*, 1996; Marteinsson, 1991; and Soldal *et al.*, 1991 & 1993). This has however not be demonstrated in any other species and Jonsson (1994) observed the greatest scale losses in the largest haddock (>43cm). With respect to the distribution of skin injury on the bodies of fish, various researchers have seen an increase in skin damage towards the tail: in haddock (Breen and Sangster, 1997; Lehman and Sangster, 1994; Lowry *et al.*, 1996; Sangster and Lehman, 1994; Main and Sangster, 1988 & 1990; Jonsson 1994; Marteinsson, 1991; and Soldal *et al.*, 1991 & 1993); cod (Suuronen *et al.*, 1995a; Main & Sangster, 1988) and whiting (Lehman and Sangster, 1994; Sangster and Lehman, 1994; and Main and Sangster, 1988 & 1990). This been attributed to the movement of the tail abrading the skin as it passes through a mesh. However for Yellow Bream the degree scale loss was greatest in the region of maximum girth, adjacent to the first dorsal fin (Broadhurst *et al.*, 1997) suggesting that the skin was abraded most at the point of greatest restriction with respect to the mesh opening.

The size of the meshes through which fish escape has also been shown to effect to degree of skin injury, where fish passing through larger (or more open) meshes are generally seen with less skin damage. This effect has not been observed in all cases (Sangster & Lehman, 1994, Soldal *et al.*, 1991). Also, as with escape mortality, where an inverse relationship with length has been established (as in haddock), it is possible that any observed mesh size effect may simply be the result of a greater probability of injury in smaller fishes and a greater proportion of small fish escaping through smaller mesh sizes, however this has not yet been demonstrated.

Recent detailed studies have expanded damage assessments to included full and detailed external and internal examinations cataloguing all observable injuries (Breen and Sangster, 1997; Farmer *et al.*, 1998; Lowry *et al.*, 1996; Lehman and Sangster, 1994 and Wileman *et al.*, 1999). These have confirmed the earlier assumptions about the importance of skin injury, demonstrating that skin damage (in the form of scale loss, bruising and lacerations) is the most common injury among escaping fish (Breen and Sangster, 1997; Farmer *et al.*, 1998; Lehman and Sangster, 1994; Lowry *et al.*, 1996; Sangster and Lehman, 1994; Suuronen *et al.*, 1995a and Wileman *et al.*, 1999) and that the skin injuries of dead or dying fish are significantly more prevalent and severe than on survivors (Breen and Sangster, 1997; Lowry *et al.*, 1996; Wileman *et al.*, 1999). These observations have also revealed many more injuries, both external and internal: fin damage (Farmer *et al.*, 1998; Wileman *et al.*, 1999); eye injuries (Breen and Sangster; 1997; Farmer *et al.*, 1998; Lowry *et al.*, 1996; and Wileman *et al.*, 1999); mouth and jaw injuries (Farmet *et al.*, 1998; and Wileman *et al.*, 1999); Snout lesions (Breen and Sangster, 1997, Lowry *et al.*, 1996; Suuronen et al 1995a; and Wileman et al 1999); gill disruption and haemorrhage; internal bleeding; bruised liver; (Breen and Sangster, 1997, Lowry *et al.*, 1996; and Wileman et al 1999); and brain haemorrhage and contusions (Wileman *et al.*,, 1999). While some of these injuries are clearly potentially fatal for the subject, their relatively infrequent occurrence among escaping fish means they cannot account for the majority of observed deaths.

While it has been demonstrated that among fish escaping from trawls skin damage is the prevalent injury, it has not been demonstrated conclusively that skin damage is the primary cause of escape mortality. Preliminary histological examination has revealed that the abrasive injuries suffered by the skin of escaping haddock and whiting can result in disruption to all layers of the integument, however it is the epidermis and upper dermis that are most usually affected (Lehman and Sangster, 1994). The breaching of these tissue layers would lead to the loss of two important functions by the skin: as an osmoregulatory barrier and as a protective layer guarding against the invasion of pathogens. It is known that skin damage can result in disruption of the fishes' blood chemistry and osmoregulatory system (Black and Tredwell, 1967; Roald, 1980 and Rosseland *et al.*, 1982). However, this alone has not been demonstrated as a fatal mechanism in fish (Smith, 1993). There is also evidence of infection of abrasive wounds by fungii and other pathogens (Engas *et al.*, 1990; Lowry *et al.*, 1996; Main & Sangster, 1990 and Soldal *et al.*, 1993), but these could not account for the majority of observed mortalities, which occur in the first 2–3 days after the escape. Also, no work has been done to investigate the pathology of these secondary infections.

Early work suggested that the build up of lethal concentration of lactic acid in the blood following exhaustive exercise or stress may be a likely cause of mortality (Black, 1958 and Beamish, 1966). However, the viability of the physiological mechanisms for this have been questioned (Wardle, 1981 and Wood *et al.*, 1983). More recently it has been suggested that a combination of exhaustion and some form of injury, most likely skin damage, is the most likely cause of mortality in escaping fish (Breen and Sangster, 1997; and Suuronen *et al.,* 1995a).

Few physiological assessments have been undertaken to investigate these theories further. Significant disruption in selected blood and tissue parameters have been observed immediately after escape, in Baltic herring (Treschev *et al.,* 1975) and Vendace (Turonen, *et al.,* 1996), and for surviving fish recovery to normal levels was seen in 3–4 days. Although, Turonen et al (1996) concluded that the observed escape mortality was due to more than just the physiology disruption they had seen in escaping fish. More recently Wileman *et al.,* (1999) used measurement of selected blood parameters and behaviour observations to establish the levels of stress experienced by haddock and whiting held captive in survival experiment. They concluded there was no evidence of any chronic stress in the captive population as a whole, but showed that it took the fish 3 – 5 days to acclimatise to captivity; which is the period of time over which the peak mortality was observed in the experiment.

Red king crabs passing under the ground gear of commercial trawls have been shown to sustain remarkably little damage, with estimates for the proportion of damaged crabs varying from 3% (Donaldson, 1990) and 18% (Rose, pers comm). Injuries seen on the crabs included autotomised legs, broken legs, damage carapaces and abdomen; many of which were considered survivable (Rose, pers. Comm.). Scallops passed over by and discarded from a scallop dredge also show remarkable resilience to damage (Breen and Sangster, unpublished data). Damage to the valves, hinge or mantle were seen in only 10.1% of 'escapees' and 5.7% of discards, but only 6% and 2%were considered mortality damaged. A detailed investigation of the Norway lobster (*Nephrops norvegicus*) escaping and being discarded from a demersal prawn trawl showed that these animals could damage or even lose claws, legs and eyes, but it was damage to the carapace or abdomen that was most likely to lead to the death of the animal (Wileman *et al.*, 1999). Physiological assessments during the same investigation revealed that both escapees and discards lost body fluids, had lowered blood pressures, reduced tissue glycogen and elevated Lactate levels in their blood indicating a significant oxygen debt, however in surviving animals these returned to normal levels after 3–4 days. In terms of both injuries and physiological disturbance, its was the discards that faired worst from their experience in the trawl.

4.2.2.2 Static Gears

In an effort to distinguish hatchery reared fish from wild stocks of chinook and coho salmon, all hatchery raised fish were marked and fisherman were required to release any wild stock. Lawson and Sampson (1996) developed a model that suggests that drop-off mortality could be as important as hook and release mortality.

Sockeye salmon that dropped out of gillnets were held for observation for 20 days (Thomson and Hunter, 1971). Approximately half the enmeshed fish escaped entanglement and of those, greater than 80% mortality rate was seen. Multifilament webbing exhibited a higher mortality than monofilament however there was no statistical evidence cited. Of those fish that were exposed to the webbing, 78% of the fish were captured by monofilament and 81% were captured using multifilament.

Many herring captured in the gillnet fishery escape with scale loss because of dropout or non-retaining encounter with the gear. If gillnets cause undetected fishing mortality, Hay *et al.*, (1986) suggest that this undetected mortality should be added to the estimates of total fishing mortality. In order to determine mortality associated with encounters with gillnets, Hay *et al.,* (1986) designed a experimental trap net that retained herring that passed through a gillnet. The results of their test showed no mortality associated with scale loss.

4.2.3 Ghost Fishing Mortality (Fg)

Unaccounted mortality in ghost fishing gear is difficult to quantify. Attempts have been made to do so and most have been met with limited success. First one must determine the amount and type of gear lost in a given fishing area. A measurement of how effective each piece of gear remains is usually advised. Then the task is to systematically quantify the catch over time.

The mortality attributed to ghost fishing gear is dependent on the following factors:

species present
species abundance
species vulnerability
ghost gear effective status

Species present and species abundance, both in regard to mortality, are well-recognised parameters relating to the rate of mortality. Species vulnerability is a less understood parameter.

Species vulnerability is a matter of becoming entrapped, enmeshed, entangled or otherwise caught by the gear. This event results in the species becoming more vulnerable to predation or becoming less able to maintain life functions (e.g., feeding, oxygen exchange, or seeking protection or defence from oceanographic disturbances).

The effective ghost fishing rate of the gear is dependent on what initial fish capture characteristics remain and the level of exposure of the area to the elements.

Synthetic materials have replaced natural materials in many fish capture devices. This includes mobile trawls, gillnets and pots. The result is that much of the ghost gear has a long-lasting life span.

Fish weirs, demersal longlines, and jigging

With fish weirs, demersal longlines and jigging the mortality rate is usually low. This is a function of the gear type, the operation, and the location in regard to active ocean features and elements.

Demersal gillnets

The effective mortality rate of demersal ghost gillnets or pot gear is dependent primarily on the availability of vulnerable species and the lost gear's exposure to environmental incidents such as storms and surge and fouling. Vertical profile and invisibility are the primary characteristics that make gillnet gear effective. Mesh size is also important but less than the former two characteristics.

Other factors relating to the rate of mortality of gillnets are depth and sea bottom type. In protected, near-shore locations where depths are less than 30 meters gillnets may continue to catch fish at a reduced, yet substantial, rate(15% of normal gillnet rate) if roundfish and flatfish are present(Breen, 1980; Carr and Cooper,1987; Brothers, 1992). In rocky bottoms, gillnets may maintain a nearly horizontal configuration (nearly 50 fathoms per net) with some vertical profile (about one meter altitude) as they caught around rocks(Carr, 1988). Dependent on the level of exposure to the elements, however, catch rates can become near zero over a 8 – 11 month period as the nets become destroyed and fouled (Erzini *et al.*, 1997).

Although studies on ghost gillnet gear mentioned above do show a much reduced level of catch, about 15%, over time, initial catches can be high. For example, ten gillnets (50 fathoms each) caught about 20,000 pounds of cod in Placenta Bay, Newfoundland (Brothers, personal communication). These nets were actively fished less than six months before being retrieved as ghost gear.

Fish and crab pots

Fish pots and crab pots are lost through interactions with mobile gear, storm damage, inattention, cut buoy lines, theft or vandalism, and senesce (Smolowitz 1978; Breen 1990;Kruse and Kimker 1993).

The availability and quality of the information for estimating annual trap loss rates varies considerably. Anecdotal reports of lobster pot loss rates off New England, U.S. run as high as 20–30% per year (Smolowitz 1978).). The reported catch of lobster in the ghost lobster pots off the New England coast was 5% of the total lobster landings in 1976 (Smolowitz 1978). Along the Maine coast the pot loss rate is reported in 1992 was 5–10% (Jay Krouse, Maine DMR, personal communication. So, losses vary and information on mortality is lacking.

In a one year study of Dungeness crab pots of British Columbia, Canada, the loss rate of crabs ghost pots was estimated to be 7% of the reported catch (Breen 1987). Another study in a Louisiana, U.S. embayment resulted in a total catch per pots averaging 34.9 blue crabs, 25.8 died and 21.7 escaped per pot (Guillory 1993). No information was available on other species in either study. Most pot fisheries require that pots now have a degradable escape panel to reduce ghost fishing mortality.

Bottom trawl gear

The larger diameter synthetic multifilament twine common to trawl nets is probably the most positive feature of trawls that reduce ghost fishing mortality in lost trawl gear. The material has a larger diameter than the gillnet monofilament and is visible or of such a size that it can be sensed by the fish. Although lost trawl gear ill often be suspended by floats and form a curtain that rises well from the bottom, many of the losses form additional habitat for such organisms as ocean pout, wolfish, and cod and "substrate" for attaching benthic invertebrates such as hydroids, and sea anemone (Carr and Harris 1995).

Diving observations, using SCUBA, submersibles and ROV's (Remote Operated Vehicles) have shown that on deep depth substrate and bottom locations where currents are at a minimum, trawl gear usually has an overburden of silt. The webbing is thus quite visible or detectable.

Trawl netting, though is often found floating or just subsurface. Much of the synthetic twines are buoyant and sometimes the twine buoyancy is augmented by the trawls buoyant floats, that remain attached to major pieces of trawl webbing. This will attract pelagic marine species such as the Carangids(jacks); invertebrates as the attached tunicates and barnacles, and pelagic invertebrates. This webbing, though visible, will attract other marine species that can become entangled(Laist, 1994).

Data on ghost fishing mortality on this gear is minimal.

A review of the general impact of ghost fishing gear was made and is presented in Table 1 (Carr & Harris, 1995). This review categorized the impact by gear type except for pelagic longlines and gillnets.

4.2.4 Predation mortality (F_p)

In addition to the direct unaccounted mortality of discarded (F_d), escaped (F_e) or dropped out (F_d) fish, individuals that initially survive may die as the result of enhanced predation risk (F_p). The magnitude of this mortality is often difficult to define, not least because of lack of methodology.

To my knowledge, only one short report has been published on predation mortality of cod-end escapes. This study (Løkkeborg & Soldal 1995) examined the risk of predation of small cod (*Gadus morhua*) escaping from a small-scale trawl. Trawling was simulated in a circular tank where fish escaping from the cod-end were retained in a cod-end cover and, together with an unstressed control group, and immediately transferred to a tank holding five large cod (predator). The number of fish eaten by the large cod was recorded. The experiments indicated that small cod escaping from a trawl do not have increased risk of predation under these experimental conditions. In a later (unpublished) experiment, a slight increase in predation risk was found among escapees (Løkkeborg & Soldal, unpublished). However, the experimental conditions under which the experiments were conducted were far from commercial trawling conditions.

Consumption of discards is discussed in a few books (Hall 1999) and papers. Furness *et al.*, (1988) and Furness (1990) point out that in certain localities around the British Isles and at certain times of year, adult demersal fish such as cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*) can form the bulk of the diet for some seabird species. This occurs despite the fact that the birds are incapable of diving to the depths at which the fish are usually found and that they do not normally occur in their diet. The only source of demersal fish for these species is from fishing vessels, either scavenged from behind the vessels as they are discarded, or in some cases, stolen from the catch as it is landed. However, the studies only quantify the amount of discards eaten by birds. Most of the discards would have died anyway (part of F_d) and should not be taken as part of $F_{p.}$ The proportion of the scavenged discarded fish that would have survived unless eaten by birds is not known. Hudson and Furness (1988) showed that between 60 and 70 % of the discarded gadoid species were consumed during observation off Shetland, while birds largely ignored flatfish and gurnard species. On the whole, a large fraction of total discards can be consumed, with estimates for the Shetland fishery of up to 75 %. Garthe *et al.*, (1996) estimated the total amount of roundfish, flatfish, elasmobranches and benthic invertebrates discarded and consumed by seabirds in the North Sea.

Australia provides some of the rare examples where an effort has been made to quantify the amounts of discards taken by taxa other than birds. In Moreton Bay, Wassenberg & Hill (1987 and 1990) examined discarding by a prawn trawl fishery. They estimated that 65 % of the discarded material was sinking to the seabed. They state that many crustaceans were still alive and may survive trawling. The authors concluded that about 30% of the diet of the crab *Portunus pelagicus* was made up of discards. But again, F_p cannot be extracted from the data.

One Russian paper (Laptikhovsky & Fetisov, 1999) deals with predation mortality (scavenging) by fish of discarded squids (*Illex argentinus, Loligo sp. and Martialia hadesi)* in the Patagonian squid fisheries. This was done by quantifying the amount of squids in the diet of the main fishing species in the area. Squid is not a normal prey species in the diet of these fishes. However, the investigation does not try to quantify the mortality of discarded squid. Neither does it make any effort to estimate what proportion of the predated squid that might have survived if not eaten, and what proportion would have survived, and does therefore not give any figure of the F_p for the actual species.

A couple of papers also deal with predation mortality of discarded fish by seals (Wickens *et al.,* 1992) and cetaceans (Gulland 1986; Fertl & Leatherwood 1995). However, as in the previous papers the F_ps have not been quantified. They merely give a qualitative description of the problem.

4.2.5 Habitat degradation mortality (F_h)

Habitat degradation mortality (F_h) is the mortality associated with the degradation of an aquatic environment as a direct result of fishing activity. During the last years increasing effort has been put into the study of fishing effects on non-target species and habitats (see e.g., Currie and Parry 1999; Frid 1999; Turner *et al.,* 1999). The author of this chapter will not even try to give a full reference list of publications dealing with habitat degradation, as it is considered to be without the scope of this report.

While the direct effects of the impacts of fishing gears on benthic communities appear obvious, the magnitude of the effects has been very difficult to evaluate. Most work has focused on direct estimates of mortality rates for benthic taxa, and little has been done to quantify effects on population level (see e.g., Hall 1999; Fogarty and Murawski 1998). Habitat degradation can act on mortality in many different ways, both directly and indirectly. Quantification of these effects is, however, a major piece of work that should be looked into in the near future. Thrush *et al.,* (1998) provided evidence of broad-scale changes in benthic communities that can be directly related to fishing. As these changes were identifiable over broad spatial scales, they are likely to have important ramifications for ecosystem management and the development of sustainable fisheries.

Groundfish, in particular, depend on the benthos for their shelter and sustenance; so feedback loops inevitably exist between fish production and the biological community within which fish are both predators and prey. The difficulty for fishery managers is to predict the direction, let alone the magnitude, of fishing-induced changes on these feedback mechanisms. The challenge for habitat researchers is to develop a quantitative predictive capability given a particular management protocol (Langton and Auster 1999).

It is obvious that habitat degradation is important for the juveniles of some species since the additional cover can provide refuges from predation. More complex habitats generally contain much richer faunal communities, and there are sound arguments for believing that they are often of greater functional significance than their real extent suggests, owing to the protection they afford juveniles (se e.g., Tupper and Boutilier 1995). The marked differences between sea grass beds and adjacent sediment areas is a case in point where fish abundances can be many-fold greater in the sea grass (e.g., Jenkins *et al.,* 1997). However, little, if any, effort has been put into quantifying the increased predation mortality due to habitat degradation. The author of this chapter has not been able to track a single publication aiming to quantify unaccounted mortality due to habitat degradation.

4.2.6 Illegal and Misreported Landings (Fb)

This sub-component of fishing mortality was considered by the 1997 Study Group on Unaccounted Mortality (ICES, 1997) as potentially one of the largest sources of unaccounted mortality. However, for practical reasons only mis-reporting and illegal or "black fish" landings by Scottish vessels can be considered in this review.

There is little data collected on the mis-reporting of catches or black fish landings by vessels in the Scottish fishing fleet. Mis-reporting is where catches are caught in one area but are then logged as caught in another, or alternatively they are logged as a different species. "Black fish" landings are landed fish that have no sales slips or official record. Both of these factors can affect the stock assessments for some demersal and pelagic species. Mis-reporting tends to affect the catch allocated to individual stocks and not the overall stock assessment. However "black fish" landings are a more serious problem and can have a significant affect on stock assessment calculations, because an accurate figure for the total landed catch for some species is unknown. The only data on black fish landing currently used for stock assessment purposes is that provided by the Scottish enforcement agency (S.F.P.A.). Each month the agency compiles an assessment of what it considers as the level of black fish is landed into Scottish ports by area. This assessment probably under estimates the true level of black fish landings.

During the early 1990's anecdotal information suggests that the landings of black fish was considerable, possibly up to 40% to 50% of declared landings. However towards the end of the decade black fish landings decreased. One of the reasons for this is possibly the increased quota shared out amongst a smaller fleet because of the removal of vessels by the decommissioning schemes. Also during this period fishing skippers increased their share of the quota by buying additional vessel capacity units (VCU's), allowing them to fish all year round without running out of quota. The level of black fish landings by pelagic vessels is unknown but anecdotal information suggests that there may be many unrecorded landings into foreign ports.

The mis-reporting of demersal catches has been most apparent in the landings of anglerfish and to a lesser extent haddock. The TAC for anglerfish is split between the east and west coast of Scotland at the 4 degree line. The largest TAC for anglerfish is in the waters to the west of the 4 degree line, but a high number of catches have been logged to the east of the 4 degree line. The reason for haddock mis-reporting is unclear, as this stock does not have the same restriction as for anglerfish. For pelagic species, herring and mackerel, mis-reporting causes a smaller problem for stock management. Because there are only three stocks considered in the NE Atlantic mis-reporting does not change the overall catch simply the catch allocated to each stock.

5. A Review and Critique of Current Methods and Techniques

This section will summarise the methods and techniques which have been used to estimate observed mortalities in fish populations encountering fishing gears. ICES (1994) provided summary guidelines for the correct approach to survival investigations. Based on this work and on findings since then, this review will also critically appraise these methods in terms of their husbandry of the subject specimens and the applicability of the protocols to 'normal' fishing conditions.

The first key problem in assessing the survival potential of any organism is ensuring that the monitoring itself does not induce any stress or mortality in the subject population. The monitoring protocol can vary from simple non-intrusive observations of a wild population to the capture of a sub-sample of that population and maintaining it in captivity, while observing the well being of the captive subject. To date, all known work estimating the mortality for any sub-component of F has used some variation of captive observation. The reason for this is simply the impracticalities of non-obtrusive observation in the aquatic environment. Until greater advances can be made in underwater observation, it is necessary to use these more obtrusive techniques, which can be potentially stressful or even fatal for a proportion of the subject population. In order to gain any useful data from these mortality estimates it is essential that they do not induce any additional stress or mortality in the subject population. To promote this ideal a number of general principles should be adopted:-

- The capture and maintenance of specimens should take place without any additional stress or injury to them.
- During the transfer from the site of capture to captivity, specimens should experience a minimum level of environmental change.
- Conditions in captivity should be stable and mimic as closely as possible the ambient conditions in the wild.
- The effects of captivity should be closely monitored. Ideally this should involve a suitable control group of specimens.
- A full description of any mortality occurring within the experiment must be made in terms of all possible explanatory variables, both experimental and environmental.

In addition to the burden of ensuring the well being of the experimental subject, the investigating scientist must also ensure that the conditions which the specimens experience during their interaction with the fishing gear mimic, as closely as possible, the conditions experienced in the 'normal/commercial' scenario. Moreover, 'normal' conditions with respect to any fishing gear are likely to vary in terms of many different parameters: from haul to haul, day to day, season to season, etc. These varying parameters should be recognised by the investigating scientist, quantified and, if possible, controlled to ensure that any observed variation in observed mortality can be fully accounted for. For example, discarded fish are likely to experience variations in the temperature on deck, the time of sorting on deck and the temperature differential between deck and water; while escaping fish are to experience differences in towing speed, towing duration, depth, water temperature and light conditions; and so on.

It is inevitable that while ensuring well controlled, experimental conditions, in terms of the well being of the subject specimens, some compromises may have to be made in terms of 'normal' fishing conditions, and *vice versa*.

5.1 Discard Mortality (Fd)

5.1.1 Estimating Discard Mortality

Discard mortality (*Fd*) can be defined as *the mortality imposed on a stock of fish as a result of death due to being caught and discarded from a catch*. Death may result from (1) injuries suffered while being captured, (2) predation because of the animals increased susceptibility following it's discard, and (3) trauma. If discard data is available and reliable estimates of catch mortality (*Fc*) are known then an estimate of discard survival is required in order to derive *Fd*.

The process of estimating discard mortality (*Fd*) for a particular species must begin with an estimate of discards associated with the target fishery. The estimates are generally based from data collected onboard research vessels, observer programs and log entries made by vessel operators. The quality of the discard data information compiled and estimated will obviously vary depending on the method of data retrieval, scope of information retrieved, sampling procedures and coverage. The basic discard information derived from research vessels is likely to be more derailed than that compiled by observers and or log books. However, it may lack the time and space coverage necessary to make reliable estimates. Observer programs that sample only a small fraction of the fleet and/or sample a small fraction of the catch taken may suffer the same problems.

In the analysis of overall fishing mortality, *F* (at the stock level) the component involving discard mortality *Fd* should not only consider deaths due to the fishing operation under consideration, but also deaths due to discarding in all other fisheries which catch fish from the same stock.

As an example, the halibut stock in the North East Pacific long line fishery is used for illustration. The stock discard mortality as a whole must include halibut discarded from the non-halibut line fisheries, all trawl fisheries, the cod pot fishery and all other gears catching halibut. In this case, the discard mortality associated with the halibut stock (*Fdh)* in the North East Pacific would be:

$$Fdh = Fdslh(t) + Fdlh + Fdht + Fdhl + Fdhp + Fdhog$$

Where:

Fdslh(t) = Mortality resulting from discard of sub-legal halibut in target (t) line fishery

Fdlh(t) = Mortality resulting from discard of legal sized fish in the target line fishery.

Fdht = Mortality resulting from discarding of halibut in all trawl fisheries.

Fdhl = Mortality resulting from discarding of halibut in other line fisheries.

Fdhp = Mortality resulting from discarding of halibut in pot fisheries for other species.

Fdhog = Mortality resulting from discarding halibut in all other fisheries impacting the stock.

In the calculation of *Fd* there is a need to develop estimates of (a) the probability of an individual being discarded and the probability of discarding in other fisheries impacting the stock and (b) the probability of death after being discarded. In the example above, when the *Fd* value being calculated is for the directed fishery only, then only one se of probabilities will be required. However, if the estimate is for the mortality of discarding of the stock, then a set of (a & b) probabilities will have to be established for each fishery contributing to the discard mortality. For the halibut line fishery the *Fd* values for the non-halibut fisheries are in many instances greater then they are in the directed fishery.

In summing the various components of F, the mortalities must be considered in terms of the sector of the population being impacted. In many instances discard mortalities occur on the younger age classes, some of which may not have entered the population for which normal F is calculated.

Fd is most often calculated as the fishing mortality imposed, as a result of discarding by a specified fishery on a particular target species (stock) or as the aggregate discard mortality imposed by fisheries on a stock. However, each fishery will generate discard mortality's for each different species caught and discarded. For those species for which fishing mortality is determined for management purposes an *Fd* will have to be estimated if discard mortality is considered an important element of the consequences of fishing. Although in the above example for halibut provides information on the total impact on line and other fisheries for the halibut stock, the equations do not provide information on impact halibut fishing may have on other stocks (cod, flounders etc) as a result of discarding. A number of species discarded may not be of any commercial interest but may have an ecological value.

The precision of *Fd* estimates rest on the variability inherent in the estimates of discard survival and estimates in the levels of discards. In an observer program precision will be influenced on whether or not the entire catch is sampled or if sub-samples of the catch are required. In many fisheries, if the catch is large the estimate will depend on sub-sampling. In such situations there will be variability between samples within the same catch that should be considered. Furthermore, variability between different catches on the same vessel require different attention as does the variability of discards that may exist between vessels fishing on the same grounds, variability over time and space etc. In retrospect, all the variability involved in sampling the catch for age and size data are replicated in the discard samples plus the variability associated with the survival estimates. The latter will vary dependant on the species under consideration and it's pre-capture physiological state, season, external environmental conditions, fishing gear and on-board handling.

The most important data requirements for estimating discard mortality (*Fd*) are better estimates of discard survival and improved information on the levels of discards in target and non-target fisheries. These are likely to be improved by increased observer and by-catch programs. Hall *et al* (in press) notes that there are only two methods of reducing discard levels. Either the level of fishing effort is cut or the average by-catch caused by each unit of effort is reduced. However, *Fd's* can also be reduced by increasing the survival of discards.

5.1.2 Experimental Critique

Most of the work covered in this review have concentrated on discard survival from trawls, including otter trawls, beam trawls and shrimp trawls. A few other studies focused on *Nephrops* creels, long lines and purse seines.

In order to study discard survival, the experiment has to cover (a) the capture process (from sea bed to deck), (b) the deck handling process (from sampling the catch to its subsequent transfer to the monitoring site) and (c) the survival/mortality assessments of the sampled specimens (from start of monitoring to termination of experiment).

Taking each process in order, the following critical comments are made that have been omitted in many of the papers included in the review and which, ideally, should have been covered to produce a discard estimate with no doubts regarding its accuracy or relevance to commercial fishing practices.

The Trawling Process

- No information on water temperature at the fishing depth
- No controls used
- No information on gear hauling and landing techniques
- Trawl tows were shorter that commercial practices
- No mention of trawling depth
- Tow duration
- Towing speed
- Sea state
- Sea surface temperature
- Number of tickler chains
- Total catch weight

Deck Handling/Sampling and Transfer

- Catch size and composition not specified
- Catch processing conditions not stated
- No information on handling techniques during sampling of catch
- No controls used
- Possible transfer effect from vessel to aquaria
- No assessments of injury prior to monitoring
- Longline caught fish were larger than trawl caught fish, so possible fish length bias when comparing survival of both gears
- **Exposure to sun during deck handling**
- Deck temperature not specified during sampling
- No mention of rate of descent during cage release from vessel to seabed
- Deck handling time during measuring, scaling for age determination and tagging procedures may have influenced mortality
- Controls used, only controlled the survival of riddled and non riddled fish during mechanical sorting
- Time on deck sampling not given
- Deck sampling times different from commercial discarding practices

Monitoring and Mortality Assessment

- Method of containment not stated
- No controls used
- No mention of specific monitoring protocols

- Probable overcrowding in tanks leading to spread of secondary infection
- Monitoring period not stated
- Method of inspection during monitoring not given
- No information on how death was assessed
- No post mortems to assess actual cause of death
- No precise cause of death made
- No mention of retrieval techniques
- No mention of temperature at monitoring site
- No mention of cage ascent/descent rate during monitoring
- No mention of monitoring depth
- Possible cage effect during suspension from a floating pontoon
- Controls that were used, were only for stress analysis comparisons

5.2 Escape Mortality (Fe) - Towed Fishing Gears.

Most work estimating escape mortality from towed fishing gears has focused on trawls, and in particular escapes from trawl codends and other selective devices. This review of protocols will therefore concentrate on these techniques.

5.2.1 Experimental Technique & Potential Sources of Inaccuracy

In investigating escape mortality from trawls two very different approaches have been taken. The first has been using escapes from simulated codends or selective devices under laboratory conditions. The second has been to capture or 'sample' fish after they have escaped from a trawl and then to monitor their survival for a limited period afterwards, while they are kept in captivity. Within this general scheme, there have been many variations on how to capture or 'sample' the fish post-escape, how best to maintain them in captivity and how to monitor the specimens while in captivity. The one unifying aspect of these methods is that they have investigated only the escapes from trawl codends or selective devices attached to codends. While this is not an unreasonable approach, as most fish entering a trawl are thought to pass into the codend, it highlights the fact that few workers have considered escape from any other part of the trawl. Walsh et al (1989) did develop a cover for collecting fish passing under the ground gear of a trawl, but this has never been used or adapted to estimate the mortality of those escaping fish. Rose (pers com) and Donald (1993) have used this technique to describe the injuries to Red King Crab and from these observations an incidental estimate of mortality was made.

To overcome the first problem of minimising unintentional experimentally induced mortality some researchers have conducted simulated escapes in controlled laboratory conditions. Broadhurst et al (1997) listed a number of advantages to this approach. Firstly, the cost of small scale laboratory studies is far less than the logistically cumbersome field trials. Secondly, the controlled environment of the laboratory means that the researcher can avoid much of the inherent variability in conditions observed during field experiments. This means that fewer specimens are required to produce a 'significant' result. Also, the specimens used will be acclimatised to captivity and so will not be exposed to the acute stress responses that wild fish will experience immediately post-capture. Any stress responses observed will be due solely to the simulated 'escapes'. Finally, it is far easier to monitor the well-being and behaviour of the subjects in the laboratory, and the recording of more detailed behavioural and physiological parameters is made less complex.

There are disadvantages to this approach however. Firstly, the fish are being held in captive conditions that are unavoidably detached from their natural ambient conditions. This is likely to induce a chronic stress response in the captive fish (Wardle, 1981), which could affect various factors important to their well being, including their behaviour, swimming ability and immune response. One notable exception to this was work by DeAlteris and Reifsteck (1993) who used a Towed Codend Simulation Apparatus (TCESA) into which individual fish placed and towed behind a research vessel. After escaping from the simulated codend, fish were transferred to the vessel and then into seabed cages. However, this required considerable handing of the fish and as a result a small but significant control mortality was observed (10%). The second disadvantage, and most important, was that simulated escapes bear little resemblance to escapes from a full scale trawl. Therefore, the results from such experiments cannot, and should not, be used to estimate the likely mortality in real fisheries. Where their strength lies is in investigating the impact of specific potentially injurious mechanisms, for example mesh penetration and exhaustion, by simplifying and controlling the complexities of the trawl codend environment.

When studying escapes from full scale trawl codends and other selectivity devices, the most common method of capturing or 'sampling' escaping fish is with a codend cover. In survival experiments these are usually designed of a soft netting material (to minimise abrasive injury), with small mesh size (to retain small fish and minimise any detrimental water flow inside the cover) and with supporting hoops or frame (to prevent the cover collapsing on the fish within). Early covers had to be closed at the beginning of the tow and release at or near the surface at the end of the tow (Main & Sangster, 1990 & 1991, Lowry *et al.,* 1996, Sangster *et al.,* 1996, Soldal *et al.,* 1991 and Suuronen *et al.,* 1991). This meant that the 'sample' of fish was taken over the whole haul, but that the haul duration was generally limited to ensure the cover was not overfilled. Moreover, bringing the cover to the surface could induce mortalities through decompression injury and so tows were usually confined to shallow waters. Latest designs now allow the cover to be closed and released remotely (Lehtonen *et al.,* 1998, Suuronen *et al.,* 1996 and Wileman *et al.,* 1999), so that escaping fish can be 'sampled' and released at any time during the tow.

The greatest problem with using covers in a survival experiment is the potential for this technique to inflict injury and mortalities in the subject specimens. Early observations by divers suggested that fish within the cover were 'comfortable and unaffected by flow' (Main and Sangster, 1991). However, subsequent direct observations of fish in covers have revealed that some fish, particularly smaller ones, struggle to maintain position within the cover and are often forced against the netting at the back of the cover (Soldal *et al.*, 1993, Suuronen *et al.*, 1995 and Wileman *et al.*, 1999). Recently it has been shown that the period of time for which the escaping fish are 'sampled' and forced to swim behind the trawl ('Sampling Time') has a significant effect on their subsequent survival (Breen *et al.*, 1998 and Wileman *et al.,* 1999). Moreover, it has been suggested that this 'cover mortality' is intrinsically linked to the swimming ability of the captive fish. Therefore the inverse length related mortality seen in some studies (Lowry *et al.*, 1996, Sangster et al 1996, Suuronen *et al.,* 1996a and Erikson *et al.,* 1999) could in fact be the result of this induced cover mortality (Breen *et al.,* 1998 and Wileman *et al.*, 1999).

Work is urgently required to develop a technique to overcome this cover mortality problem. It will not be sufficient in most cases simply to reduce sampling time, because for many fisheries this would mean that insufficient numbers of the target species would be collected in the cover. Reduction in towing speed would also be unwise as this would be a significant alteration from 'normal' fishing practices. Alternative methods to the codend cover have been utilised in survival experiments, but on the whole have been even less satisfactory. Main and Sangster (1988) used divers to capture fish, in polythene bags, immediately after escape from the codend. The authors felt this method was introducing an experimental bias to the results, in that the divers were in general only able to capture the slowest and probably most moribund of the escaping fish. Zaferman and Serebrov (1989) used a manned submersible to make direct observation of escaping fish. They followed the track of the trawl and estimated the number of dead haddock on the seabed. This method only gives an approximate incidental estimate of instantaneous escape mortality and is unable measure important biological parameters such as length, age, and injuries.

Once the specimens have been collected, they must be transferred into a safe and stable environment where they can be monitored. This transfer should involve a minimum of environmental change. Dramatic changes in hydrostatic pressures are known to kill some fishes, through various decompression injuries (Feathers and Knable and Tytler and Blaxter, 1973). More recently Wileman et al (1999) showed that haddock transferred over a relatively small hydrostatic range (90 to 20m: 7 bar) may have experienced over-pressurisation of their swimbladders which could have accounted for some of the observed mortality in the experiment. Dramatic changes in temperature have also been shown to effect the survival of some species (Olla *et al.*, 1998). Researchers should also be aware of changes in dissolved oxygen content, water movement, light levels, turbidity and salinity. Any changes in these parameters, both during transfer and while in captivity, may induce a mortality in the observed population and should be avoided.

The mode of captivity varies considerably between experiments. Laboratory based experiments invariably use aquaria or tanks to hold specimens. While providing stable environmental conditions, this method as discussed earlier is very detached from the fishes 'normal' environment. This form of artificial confinement is known to induce chronic captivity stress (Wardle *et al.,* 1981) and as such may influence the results of any survival experiment.

To overcome this problem, many field experiments endeavour to keep the 'sampled' fish in or as close to the same area as they were caught. These fish are held in fish cages which can be suspended in the water column or placed on the seabed. These cages often form an integral part of the cover and can be detached, with the captive fish contained within. Suspended cages are best used with pelagic species (Suuronen, 1991; Suuronen *et al.*, 1995b, 1996a & b), but have also been used with demersal species (Soldal & Engås, 1997; Suuronen *et al.*, 1995a and Thorsteinsson, 1995). The major disadvantage with this system is they are very mobile and can drift for considerable distances making monitoring difficult and resulting in changes in environmental conditions. In addition, wave action can lead to considerable vertical movement in the cages leading to further stressing of the captive fish. Finally, the use of an essentially pelagic containment system with demersal species is questionable. Demersal species normally have the seabed as a reference point for at least part of their day and are likely to find much of their food there. Therefore isolation from it could lead to additional captivity induced stresses. Seabed cages have been used to contain a variety of demersal species (e.g., for Cod: Robinson *et al.,* 1993; DeAlteris & Reifsteck, 1993 and Main & Sangster, 1993; and for haddock: Lowry *et al.,* 1996; Sangster *et al.,* 1996 and Wileman *et al.,* 1999). The main disadvantage with this system is that the cages usually need to be constructed or placed in sheltered conditions, which means transporting the fish from the fishing grounds to the cage site. Transporting normally involves towing the codend cover or detached cage at slow speeds to the site. This can induce further stresses akin to the sampling induced mortality discussed earlier. As a solution to this Towed Underwater Fish Transporters (TUFT) have been devised (Lowry *et al.,* 1996; Sangster *et al.,* 1996 and Wileman *et al.,* 1999)). In corporation with divers, the cover (with captive fish) is collected and placed in a protective container. This container can then be towed to the inshore caging site, while protecting the contained fish from any excessive water flow.

The effect of captivity on a population can be assessed with careful use of 'controls'. Here a group of fish of the same species are held in captivity along side the test groups and their survival is assessed in the same way. If captivity is having no lethal effect on the captive fish, there should be no observed mortality in the control group. The difficulty with control groups, particularly with respect to complex experiments like these, is what aspect of the experiment they are indeed acting as a control for. Ideally, the population of fish acting as controls should be representative of the population of fish in the test groups in all ways, except for the test variable; in this case escape from a trawl. Also, the method of capture of the control fish should not induce any mortality, as this would be misinterpreted as an experimentally induced mortality. A number of researchers have been self critical of their use of control fish. Soldal et al (1993) used an open codend to allow haddock from the trawl to enter the codend cover, without passing through codend meshes. They found an equivalent mortality in the control and test groups and concluded that the fishing process was the main cause of mortality and not passage through the codend meshes. They added that their use of controls was incorrect for the experiment. Lowry et al (1996) used control fish caught on handlines and barbless, as opposed to in a trawl, and as such measured only the effect of captivity in the seabed cages. They found a no mortality in these control fish, but stated that they too though their control inadequate because they differed in length range from the test population and had not experienced aspects of the experiment (i.e., confinement in the cover and transfer to the cage site). In fact, both types of control should have been employed to determine both the effects of captivity and the effects of capture and transfer in the experiment. This approach was taken by both Suuronen et al (1996) and Wileman et al (1999), and both found lower mortalities in the control assessing just the effect of captivity.

Unfortunately just looking for the lethal effects of captivity in control groups does not reveal all of the detrimental effects of captivity. The stresses induced by captivity can be sub-lethal but sufficiently large that, in combination with the injuries and stresses of escaping the trawl, they could detrimentally effect the survival potential of the test fish. This would therefore over estimate escape mortality. Wileman et al (1999) recently assessed for sub-lethal evidence of chronic captivity stress in haddock and whiting in a survival, using physiological and behavioural parameters. They found no conclusive indications of chronic captivity stress, but did observe that the period of acclimatisation in captive fish coincided with the period of peak mortality.

Once in captivity the progress of the test and control populations must be monitored. The period over which this monitoring takes place can have a great influence on the observed mortality. As discussed earlier the rate of mortality in survival experiments has been shown to vary with time for a number of species (for haddock & whiting (Lowry *et al.,* 1996; Main & Sangster, 1991 and Sangster *et al.,* 1996) and Baltic herring (Suuronen, 1991 and Suuronen *et al.,* 1995 & 1996a & b)), with the peak in mortality occurring in the first few days. Thus survival assessed over just a few hours will be greater than a survival potential measured over a few weeks. This was clearly demonstrated by Suuronen et al (1996), who showed that caging duration had a significant effect on mortality. How the monitoring is performed and how often can also determine the type and quality of data taken from the experiment. For example, using cameras every few days, it may be possible to count the number of dead fish in a cage and possibly even determine their species; whereas using divers to monitor the cage daily, the researcher can get an accurate record of mortality with time, as well as retrieving the dead specimens which can give valuable detailed information such as length, age, injuries, etc.

5.2.2 Relevance to Commercial Fishing Gear and Conditions

Despite work in the field attempting to emulate real/commercial fishing condition, few protocols genuinely succeed. The first problem is that most techniques use some form of codend cover. Just with respect selectivity the use of codend covers is thought to have an effect on water flow in and around the codend, as well on the behaviour of escaping fish (Wileman *et al.,* 1996). How this may effect the survival potential of escaping fish is unclear. As already discussed, the use of codend covers has often dictated the towing duration of a trawl and, as a result, the weight and contents of the codend catch. Recent developments in technique have overcome these restriction by enabling the cover to be closed and released at any point during the tow (Lehtonen *et al.,* 1998 and Wileman *et al.,* 1999). Thus the sampling period can be precisely controlled and the sample taken at point in the haul. Wileman et al (1999) used this techniques to demonstrate that haul duration had no effect upon the survival of haddock and whiting. However, they did show that the catch weight and contents (particularly abrasive materials) may influence escape mortality for haddock, whiting and *Nephrops*.

Restriction of fishing to shallow water depths is also a common criticism of escape mortality protocols. With the advent of remotely controlled covers, in conjunction with good decompression procedures or deep water monitoring protocols, this problem should now be solvable. Reduced towing speeds was noted in a number of studies. While protecting fish in the codend cover from exhaustion and injury, this approach could also seriously effect any true survival estimates. Changing speed will alter the water flow within the trawl. This is likely to have significant effects upon the behaviour of the fish, their degree of exhaustion, the probability of injury, the likelihood of escape, as well as the species composition and length range of fish in the catch.

Fishing operations are inevitably associated with greatly varying conditions with respect to many physical parameters, including: the time of day, light conditions, temperature, season, weather conditions, tidal state and water current. The population being fished may also vary greatly with respect to area, biological parameters (length age and), from year to year, etc. As scientists it is necessary in the design of a good experiment to recognise these variables and account for them, by controlling them or by measuring and assessing for them. As a result many of these possible influences upon escape mortality remain un-investigated. Thus even for the most studied of species (e.g., haddock and Baltic herring) our estimates of mortality are very restricted with respected to the conditions by these fishing during normal fishing conditions. Moreover these estimates of mortality, despite being encouragingly high, are mostly made in shallow water, during summer months and in good weather conditions. They could therefore be greatly underestimating true escape mortality.

5.2.3 Quality of Mortality Estimates - survey results

As part of the review process, a case study was performed were all available work on escape mortality in trawls was assessed to identify any escape mortality estimates that may be applicable for incorporation in stock assessment models. This revealed that of 28 separate studies only 43% were considered useful estimates of escape mortality, in terms of: the parameters in which mortality is described, the relevance of the work to real fishing conditions and accuracy of the mortality estimate (Figure 5.1). To be considered usable, the work had to describe mortality with respect to at least one biological parameter (e.g., length, age, condition, etc) which enabled the data to be applied to a population model. In addition, the work had to be considered accurate in terms of its estimate of mortality in experimental terms or in its reproduction of real fishing conditions, but not necessarily both. A lenient approach was taken here because only one piece of work was considered to have been accurate in both attributes. This means the available estimates of mortality take two forms: one is a best case scenario, where the accuracy of the mortality estimate is good in experimental terms but is poor in with respect reproduction of real fishing conditions; the other is *vice versa*, providing a worst case scenario.

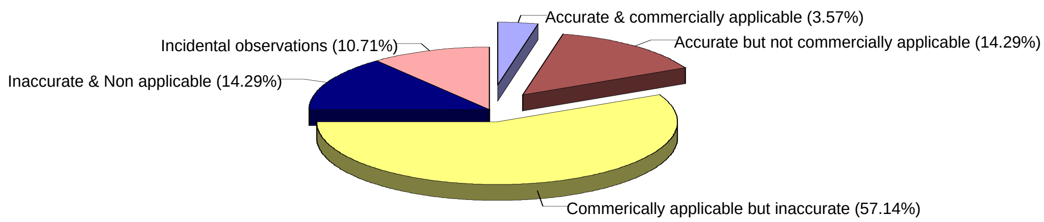

Figure 5.1: The proportion of accurate and commercially applicable escape mortality estimates.

Moreover, of all the publications describing work which has estimated escape mortality from trawls, only 9 (27.3%) have been published in reputable scientific journals (figure 5.2). The remaining 24 (72.7%) are hidden in grey literature, as internal project reports or were never published, making it difficult for researchers to even find the data, let alone use it.

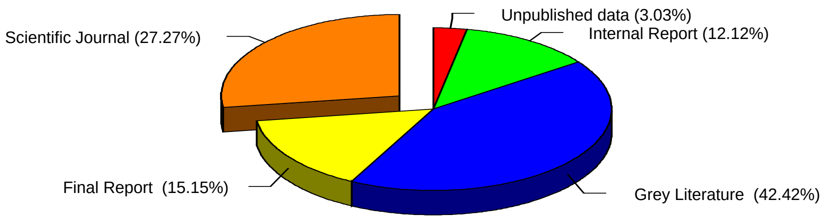

Figure 5.2: Types of publications for escape mortality estimates.

The outcome of this, is that survival data has seldom been applied to stock assessment models or included in any fisheries management decision making processes. In fact, only Efanov (1981), Lowry et al (1996), Sangster et al (1996) and Wileman et al (1999) have applied their survival estimates to a population model to demonstrate the impact of various technical measures.

5.3 Predation mortality (F_p)

As discussed in the previous chapter, the amount of work carried out to estimate the extent of predation mortality (F_p) has been negligible. Almost no effort has been put into developing specific experimental techniques for this purpose. One investigation (Løkkeborg & Soldal 1995) tried to simulate trawling stress in a circular water tank, and thereafter transferring the stressed fish (cod, *Gadus morhua*) together with unstressed controls to a separate water tank containing predators. However, the experimental conditions were very far from commercial trawling. The fish were not totally physically exhausted, and their predation risk was tested under laboratory conditions where the predator could easily capture both stressed and control fish. The authors conclude that the predation risk should be tested under conditions that are more representative of actual fishing operations.

The other studies cited in the former chapter have not worked specifically at quantifying predation mortality. They have focused on estimating the amount of discards eaten or scavenged by different species. However, no effort has been put into separating the predation component from the total discard mortality. The problem has merely been discussed in general.

No experimental methods have been developed to estimate the predation mortality component of F_e, F_d, and F_o, and new technology is required to look into these problems. In the same way as for estimating the other components of unaccounted mortality, one of the main challenges will be to develop methods that are representative for commercial fishing operations.

5.4 Habitat degradation mortality (F_h)

Little, if any, effort has been put into quantifying the possible increased unaccounted mortality due to habitat degradation (F_h). Quantification of F_h on a population level will, as far as the author of this chapter is able to predict, demand a multi-species modelling of the interactions between habitat, benthos and fish at the different trophic levels, as well as marine mammals. Among other things it requires a quantitative mapping of the different habitats in the investigated area, as well as an assessment of their degradation. The road to a full understanding of this mortality segment is long and winding. At the moment we are just at the starting point.

6. The "Unaccounted Mortality Problem" – a discussion

6.1 The 1997 Unaccounted Mortality Study Group Conclusions and Recommendations Revisited

In 1997 the ICES Study group on Unaccounted Mortality in Fisheries made the following conclusions and recommendations:

Conclusions

- *The Study Group reaffirms the recommendations made by the 1994 ICES Sub Group On Methodology of Fish Survival Experiments and the 1995 Study Group an Unaccounted Mortality in Fisheries.*
- *The Study-Group on Unaccounted Mortality in Fisheries recognises;*
- *a continuing need to increase the awareness of fisheries managers, fisheries scientists and the fishing industry to the potential importance of Unaccounted Fishing Mortality;*
- *little or no data exists on the magnitude of each sub-component of fishing mortality as defined by 1995 Study Group an Unaccounted Mortality in Fisheries;*
- *illegal, misreported and unreported landings (F_B) and discards (F_D) are likely to be of most importance in the majority of fisheries. With respect to fisheries using mobile gears escape mortality is also likely to have a significant impact.*
- *while advancements have been made in the development of techniques to investigate the magnitude of some sub-components (namely, discard, escape and ghost fishing mortalities), further investment in the development of these techniques, and those for previously un-investigated areas, are required if accurate estimates of fishing mortality are to be achieved.*

Recommendations:

- *A concerted effort is undertaken to raise the awareness and understanding of Unaccounted Mortality in Fisheries among fisheries managers, scientists and the fishing industry.*

Action: The Study group on the use of Selectivity and Effort Measurement in Stock Assessment (SGSEL) (co-chair: Dr R. M. Cook, UK and Dr D. A. Somerton, USA) discussed the need for further work on unaccounted mortality (reliable estimates of survival, wider range of species and stocks, effect of changes in mesh size). They recommended that Fishing Technology and Resource Management Committee engaged in a dialogue to discuss the future direction of the Group, but so far nothing have happened.

- A data base should be constructed, co-ordinated by the FTFB Working Group, to collect and collate any available data on all sub-components (except landed catch, illegal, misreported or unreported landings) of fishing mortality *and used to identify future research priorities. This would be made available to the Methods Working Group and to the Stock Assessment Working Groups of ICES.*

Action: In 1998, WGFTFB, there was a Suggested Work item: investigate the feasibility of compilation of a survival database (Action: M. Breen, UK). The database structure that was recommended in this feasibility study depended heavily on reviewers who would screen and summarise the data to be used. This was considered too great a task and potentially controversial.

- *The mortality due to illegal and misreported landings has been identified by the Group as causing particular concern. It is recommended that immediate action be taken to estimate its magnitude and account for it in the relevant fisheries.*

Action: None

- *In addition to estimating the magnitude of mortality in all the sub-components of F. The Group strongly recommends identification of the causes of mortality in each case. Such knowledge is essential if the fatal mechanisms are to be identified and mitigated.*

Action: It is evident from recent publications highlighted by this review that this recommendation has been acted upon by a number of researchers. However there is still a continuing need to express the importance of this work.

It is clear from this review of the 1997 conclusions and recommendations that little effort has been made to enact the Study Groups' recommendations. This raises an important question concerning the usefulness of these Study/Topic groups and the value of conclusions and recommendations made by them, in the current ICES framework.

6.2 What is the Problem with Unaccounted Mortality?

The problem of unaccounted sources of potential fishing mortality in commercial fisheries has been recognised for a number of years now (Ricker,1976; ICES, 1994, 1995 & 1997; Chopin *et al.*, 1996). However the single biggest problem is that these sources of mortality remain **unaccounted** for, despite repeated recommendations for work by ICES (ICES, 1994, 1995 & 1997) and other authors (Alverson & Hughes, 1996; & Chopin *et al.*, 1996). Furthermore, it is clear from the review of current knowledge (section 4.0) that considerable effort has been directed at this problem both within and outside ICES.

So why, despite these efforts, does the magnitude of these additional sources of mortality remain unquantified for the vast majority of fisheries ?

This Topic Group has identified a number of possible causes:

<u>1. Scale of problem</u> - the first and most obvious reason, is the shear scale of the "Unaccounted Mortality Problem". Sections 2.0 and 3.0 of this report revealed the large amount and complex nature of the data required to estimate a single sub-component of F for one species in just one fishery. This must then be repeated for the other nine possible sub-components of F in that fishery. Finally we must then multiply this effort by the many thousands of commercially important species and fisheries in the world today.

<u>2. Finding the Data</u> - The nature of the work in unaccounted mortality investigations is very varied. That is, many different vertebrate and invertebrate species have been studied, with respect to a great variety of gears used to capture them. Some workers have just considered the likely outcome of fish interacting with a fishing gear (Pe); and other consider the potential of individuals to survive these encounters (Pm); while some attempt to define the actual causes of mortality following encounters with fishing gear. These very different approaches and fields of research mean that there is likely to be little interaction between these groups of scientists and thus little transfer of information and data. This is further exacerbated by the nature of the publications from these researchers. A quick read of the enclosed bibliography (appendix I) will reveal to the reader the many different publications in which this work is presented. Moreover, as demonstrated in section 5.1.3, much of this work appears in grey literature, making it very difficult to locate. Thus even if work is being done, it is generally unavailable to the fisheries managers who may wish to use it.

<u>3. Quality of Data</u> - The review of techniques used to estimate mortality of fish encountering fishing gears highlighted that the majority of mortality estimates contain errors with respect to either: their relevance to commercial fishing gears and conditions or to the accuracy of the experimentally derived estimates. Furthermore, much of the data is described in terms of simple proportions, with no attempt to define variations in mortality with respect to different parameters in the observed population (e.g., length, age, etc) making the data unsuitable for application to stock assessments.

<u>4. Lack of co-ordination/direction</u> - Many of the problems described in points 2 & 3 could be overcome with better co-ordination and direction in this field. This is clearly lacking, as is evident from the short term, *ad hoc* and simple comparative nature of much of the work. Very few of the most commercially important species have been investigated. There appears to be little direction from fisheries managers as to their key concerns with respect to "Unaccounted Mortality" and to which fisheries concerted efforts should be directed. Amongst Unaccounted Mortality researchers themselves there has been little effort directed towards standardising experimental protocols and eliminating sources of error in the methodologies.

<u>5 Complexity & Cost</u> - the complex nature of many mortality investigations can make them very costly in terms of resources and manpower, as well as financially. This can prove prohibitive to many institutes. For example a recent investigation into the discard and escape mortality of *Nephrops* and round-fish from demersal trawls required the concerted efforts of six different institutes and other parties, from five different countries (Denmark, Norway, Sweden, UK and USA), at a cost of 1.9 million Euros.

<u>6. The "Uncertainty Principle" and Pragmatic Management</u> - Finally, as discussed in section 3.0, many stock assessment modelling techniques implicitly include or compensate for unaccounted mortality without any accurate estimates of those mortalities. Based on this, and the knowledge that direct mortality estimation is often costly and is sometimes inaccurate, it proves difficult for fisheries managers to justify the investment of scarce resources in the direct estimation of unaccounted mortality. However, this approach precludes the fisheries manager from the considerable advantages, in

terms of informed decision making and the effective utilisation of an exploited stock, provided by the detailed and accurate estimates of the various sub-components of unaccounted mortality in that fishery.

7. Conclusions and Recommendations

7.1 Conclusions

1. A review of the available literature highlighted methods to calculate sub-components of F. Three different approaches to include these sub-components in the VPA are: 1) modifying catch at age; 2) estimating an instantaneous F in a probabilistic fashion; and 3) additional survival term in expression of total removals. The choice of method will depend on the type of information available.

2. This report has reviewed 110[♦] papers on 54[•] species with details accounts of sub-component estimates. This review has provided an important summary of available data (Appendix 1). However, it is recognized that this work is not definitive and more references may be available in the literature.

3. Critical analysis of current methods has highlighted a number of potential sources of error which are common to many estimates of mortality. Two areas of particular concern are errors due to experimentally induced mortality and poor replication of commercial conditions.

4. A bibliography was compiled and many of the references were in grey literature, e.g., only 27% of references estimating escape mortality were published in scientific journals.

5. The conclusions and recommendations from the 1997 Study Group report on unaccounted mortality were reviewed and considered to still be relevant. It is recognised that the following progress has been made:

    - The Study Group on the use of Selectivity and Effort Measurement in Stock Assessment (SGSEL) met and considered how to incorporate post selection mortality for haddock and whiting in assessments. They recommended a dialog be pursued between fishery technology and resource management committees. There has been no further progress.
    - This recent review of the literature has provided new information on the importance of unaccounted mortality. Appendix 1 is an initial form of the required database.
    - More data has been collected on escapement mortality from mobile gear. Illegal, misreported and unreported landings and discards are still considered to be of more significance than other sources of unaccounted mortality in many fisheries.
    - Significant improvement of techniques has been achieved, which should reduce experimentally induced mortality, improve the replication of commercial conditions and aid the identification of causes of mortality.

6. It was discussed why many potential sources of fishing mortality still remain unquantified or unaccounted for. This report identifies a number of possible causes, including: the scale of the unaccounted mortality problem; finding relevant data; the quality of data; lack of co-ordination and communication among researchers and fisheries managers; the complexity & cost of mortality investigations; and pragmatic management amongst fisheries managers.

7.2 Recommendations

1. A joint meeting, by 2001, should be organized between gear technology and stock assessment experts to perform pilot assessments using real and simulated unaccounted mortality estimates with a particular emphasis on the sensitivity of stock size estimates. (Convener ?)
2. A Theme Session on unaccounted mortality in fisheries should be held at the Annual Science Conference in 2002. (Convener ?)
3. Members of the working group should consider acquiring the expertise in stock assessment to be able to evaluate the effect of unaccounted mortality on stocks and hence to justify further work in this field.

[♦] Preliminary estimates

4. Focus future research on this topic on a) the justification of the mesh regulations and b) expanding understanding of the factors causing variance in mortality estimates, e.g., fish condition, seasonal variation, fishing method and experimental technique.

Appendix Ia – Discard Mortality (Towed Gears) Review Summary

Species	Fishing Gear	Category	Mortality Factors	Mortality %	Size Range	Reference
Sole	Beam trawl	Deck discards	Number of tickler chains; Duration of stay in codend; Total catch weight	>90%	20–28cm	van Beek *et al.*,1989
Plaice	Beam trawl	Deck discards	as above	>90%	20–30cm	Van Beek *et al.*, 1989
Dab	Beam trawl	Deck discards	None	0%	<MLS	Bergman *et al.*, 1989
Plaice	Beam trawl	Deck discards	None	90%	<MLS	Bergman *et al.*, 1989
Whiting	Shrimp trawl	Deck discards	Species, length, catch weight and processing conditions	100%	9.5–15.5cm	Berghahn *et al.*, 1992
Sculpin	Shrimp trawl	Deck discards	as above	9 %	10–20cm	Berghahn et al 1992
Hooknose	Shrimp trawl	Deck discards	as above	11%	7–16cm	Berghahn *et al.*, 1992
Eelpout	Shrimp trawl	Deck discards	as above	8%	13–20cm	Berghahn *et al.*, 1992
Plaice	Shrimp trawl	Deck discards	as above	91%	4.5–9cm	Berghahn *et al.*, 1992
Various teleost species	Australian otter prawn trawl	Deck discards	Tow duration, deck exposure time	~ 100%	not given	Hill and Wassenberg 1990
Pacific halibut	Otter Trawl	Deck discards	Catch size, fish length, time on deck	Average 50%	<61 - >100cm	Hoag, 1975
Atlantic cod	Otter trawl	Deck discards	Air temperature, deck time, fish length, tow duration, catch weight	49% spring, 91% summer, 64% winter	< MLS	Robinson *et al.*, 1993
American plaice	Otter trawl	Deck discards	Air temperature, deck time, fish length, tow duration	34% spring, 60% summer, 100% winter	< MLS	Robinson *et al.*, 1993
Yellowtail flounder	Otter trawl	Deck discards	Tow duration and deck time	23% spring, 33% summer, 50% winter	< MLS	Robinson *et al.*, 1993
Plaice	Otter trawl	Deck discards	Poss. secondary infection to trawling injuries, towing speed, poss. quality and quantity of catch, effect of tagging	Average 10% (October), 20 - 37 % (April),	< MLS	Millner *et al.*, 1993
Atlantic halibut	Otter trawl	Deck discards	Handling time, fish length, catch weight, tow duration, secondary infection, scale loss	65% after 48h	< 81cm	Neilson *et al.*, 1989
Atlantic halibut	Longline	Deck discards	Fish length, less damage	23% after 48h	< 81cm	Neilson *et al.*, 1989
Plaice	Shrimp trawl	Deck discards	Haul duration, catch size, catch composition, fish length, and deck handling	49%	<MLS	von Kelle, 1976
Sole	Shrimp	Deck	as above	43%	<MLS	von Kelle,

Species	Fishing Gear	Category	Mortality Factors	Mortality %	Size Range	Reference
	trawl	discards				1976
Dab	Shrimp trawl	Deck discards	as above	74%	<MLS	von Kelle, 1976
Atlantic cod	Otter trawl	Deck discards	Thermocline, deck temperature, stress, handling practices	88% in June, 49% in April	<MLS	Carr *et al.*, 1992
American plaice	Otter trawl	Deck discards	as above	56% in June and 34% in April	<MLS	Carr *et al.*, 1992
Chinook salmon	Purse seine	Deck discards	Capture injuries, stress and landing duration	77% after 24h	> 50cm	Caddy *et al.*, 1996
Nephrops norvegicus	*Nephrops* trawl	Deck discards	Wounds from cod end catch, bleeding, temperature, light	60% after 8–9 days	< MLS	Chapman, 1981
Nephrops norvegicus	Creels	Deck discards	Damage from gear, bleeding, temperature, light	97% after 8–9 days	< MLS	Chapman, 1981
Plaice	Shrimp beam trawl	Deck discards	Deck sorting system, tow duration, catch composition, weather, length	0–32%	<MLS	Graham 1997
Atlantic cod	Shrimp trawl	Deck discards	Air temp., tow duration, depth, catch weight, avian predation	36.1%	< MLS	Hokenson and Ross, 1993
Pollock	Shrimp trawl	Deck discards	as above	21.7%	< MLS	Hokenson and Ross, 1993
Witch flounder	Shrimp trawl	Deck discards	as above	29.4%	< MLS	Hokenson and Ross, 1993
Winter flounder	Shrimp trawl	Deck discards	as above	0.8%	< MLS	Hokenson and Ross, 1993
Yellowtail flounder	Shrimp trawl	Deck discards	as above	5.1%	< MLS	Hokenson and Ross, 1993
American plaice	Shrimp trawl	Deck discards	as above	19.4%	< MLS	Hokenson and Ross, 1993
Plaice	Beam trawl	Deck discards	Species, air temp. and deck handling	61%	<MLS	Kaiser & Spencer 1995
Dab	Beam trawl	Deck discards	as above	76%	<MLS	Kaiser & Spencer 1995
Dragonet	Beam trawl	Deck discards	as above	68–97%	All	Kaiser & Spencer 1995
Cuckoo Ray	Beam trawl	Deck discards	as above	41%	< MLS	Kaiser & Spencer 1995
Lesser Spotted dogfish	Beam trawl	Deck discards	as above	10%	All	Kaiser & Spencer, 1995
Pacific halibut	Bottom trawl	Deck discards	Plasma levels (Glucose, K, Na.), tow duration, deck exposure time	Significant diff. due to tow duration	all as bycatch	Oddsson *et al.*, 1996
Pacific halibut	Bottom trawl	Deck discards	Tow duration, in air exposure, length,	47% with little sand	all as bycatch	Pikitch *et al.*, 1996

Species	Fishing Gear	Category	Mortality Factors	Mortality %	Size Range	Reference
			temperature, with/without sand in catch	in catch, 87% with excessive sand in catch		
Nephrops norvegicus	*Nephrops* trawl	Deck discards	Sorting process damage, season	33.2% after 1hour; 60% long term	20–40mm	Redant and Polet, 1994
Tiger prawn *(Penaeus* spp.)	Australian prawn trawl	Deck discards	Catch weight and composition, excluder devices	Not given specifically only comparison with/without excluder devices	Not given	Salini *et al.*, 1999
American Lobster	Bottom trawl	Deck discards	Season, shell, condition/damage, molt condition, temperature	1% in Aug 2.2%May 6.3% Nov 21.3% Jul	All as bycatch	Smith & Howell, 1987
Baltic cod	Bottom trawl	Deck discards	Total catch tow duration, stress from handling, crowding in tanks, fish length	Not actually stated but from graphs 65–75% after 20hours	18–39	Thurow & Bohl, 1976
Plaice	Beam trawl	Deck discards	Deck exposure & tow duration	Range 43–48%	7 –29cm	de Veen *et al.*, 1975
Sole	Beam trawl	Deck discards	as above	86–100%	9 – 26cm	de Veen *et al.*, 1975
Centropogon marmoratus (Aus.)	Aust. shrimp trawl	Deck discards	None	16% after 7 days	6.4cm (SD 1.05)	Wassenberg & Hill, 1993
Pagrus (Spp.)	Aust. Shrimp trawl	Deck discards	Poss. Swimbladder damage	92% after 7 days	11.4cm (SD.91)	Wassenberg & Hill, 1993
Paramoacanthus (Aus.)	Aust. Shrimp trawl	Deck discards	as above	73% after 7 days	7.5cm (SD.92)	Wassenberg & Hill, 1993

Species	Fishing Gear	Category	Mortality Factors	Mortality %	Size Range	Reference
Pelates (Spp.)	Aust. Shrimp trawl	Deck discards	as above	74% after 7 days	13.4cm (SD.94)	Wassenberg & Hill, 1993
Nephrops norvegicus	*Nephrops* trawl	Deck discards	sea state	69% (range 61–81%)	21–45mm CL	Wileman *et al.*, 1999
Pacific halibut	Bottom trawl	Deck discards	Deck handling procedures	Mortality decreased by 13 & 24 % by using two alternative sorting methods	All sizes in bycatch	Trumble *et al.*, 1995
Sablefish	Bottom trawl	Deck discards	fishing depth, tow duration, deck exposure, temperature	>95% for short/shallow tows, small catches and short deck exposure time20–30% for low treatment levels, low deck exposure and low tow time	All sizes <MLS	Erickson *et al.*, 1999
Brown trout	Bottom trawl	Deck discards	Lifting in codend, poss. cage effect, temperature diff., cage depth	14.5% after 7 days	< 40cm	Turunen *et al.*, 1994
Winter flounder	Shrimp trawl	Deck discards	Novel gear design	17%	< MLS	Kenney *et al.*, 1991
Silver hake	Shrimp trawl	Deck discards	Novel gear design	95%	< MLS	Kenney *et al.*, !991
King crab	Bottom trawl	Deck discard	Shell age, body damage, vitality	79%	all sizes in bycatch	Stevens 1990

Species	Fishing Gear	Category	Mortality Factors	Mortality %	Size Range	Reference
Tanner crab	Bottom trawl	Deck discard	Shell age, body damage, vitality	78%	all sizes in bycatch	Stevens 1990
Nephrops norvegicus	*Nephrops* trawl/twin trawl	Deck discards	mesh size/grid spacings	70–80%	all sizes in bycatch	Valdemarsen, 1997

Appendix Ib – Discard Mortality (Static Gears) Review Summary

Species	**Gear**	**Method of assessment**	**Unaccounted Mortality**	**Mortality**	**Size Range**	**Reference**	**Comments**
Atlantic Cod (*Gadus morhua*)	Bottom Set Longline	Hook Injury vs. No Injury, placed in bottom set cages	Released Sub-legal Bycatch	26% (72 hours)	< 49 cm (Sublegal in NW Atlantic - USA)	Milliken, Farrington, Carr and Lent 1999	Mention of sea bird predation
Pacific Halibut (*Hippoglossus stenolepis*)	Bottom Set Longline	Assessing condition codes	Released Unwanted Bycatch and Escapees	3% minor injuries 24% moderate 74% severe	34 – 191 cm	Kaimmer and Trumble, 1998	Difficult interpretation
Spanner Crabs (*Ranina ranina*)	Baited tangle nets	Observation in holding cage	Released Unwanted Subleagal Bycatch	Control-5% 1Dactylus-20% 3 Dactyli-25% 1 Periopod-55% 1 Cheliped-90%	70–100 mm	Kirkwood and Brown, 1998	Only 20 crabs in each treatment. Differences in burial time were also noted.
Lake Trout (*Salvelinus namaycush*)	Gillnets	Observation in holding tank	Released Unwanted Bycatch (>TAC)	23–32% (48 hrs)	None given	Gallinat, *et al.*, 1997	
Haddock (*Melanogrammus aeglefinus*)	Bottom Set Longline	Observation - on board holding tank	Released Sub-legal Bycatch	0% (five days)	Sublegal off Northern Norway	Soldal and Huse, 1997	Bait, sinking speed and hook design studied
Pacific Salmon (*Onchorynchus* ssp.)	Hook and Line	Model incorporating marked and unmarked fish	Drop-offs and Non-catch	NA	All	Lawson and Sampson, 1996	
Rainbow Trout (*Onchorhynchus mykiss*)	Artificial Bait (lures) and Flies	Observation	Released with Wound Assessment	32.1% Passive capture-artificial baits (3 weeks)	20–40 cm	Schisler and Bergersen, 1996	Other capture techniques-fly and actively fished artificial bait
Spotted Seatrout (Cynoscion nebulosus*)*	Hook and Line Gillnets	Observation in net pens	Released Unwanted Bycatch	Hook and line 4.6% Gillnets 28% (48 hours)	Hook and line - 186–465 mm TL Gillnet - 276–575 mm TL	Murphy *et al.*, 1995	Good References. Hook location affect mortality.
Pacific Halibut (*Hippoglossus stenolepis*)	Bottom Set Longline	Tag and recapture (hook stripper vs. gentle handling)	Released Unwanted Bycatch	50% or greater	< 82 cm > 82cm	Kaimmer, 1994	Estimation from recapture
Dungeness Crab (*Cancer magister*)	crab pots	Tag and recapture	Released Unwanted Sublegal Bycatch	Soft-shell crabs 45% greater mortality than hard shell crabs	> 6.5 inch males only	Kruse, *et al.*, 1994	No difference in mortality found with up to 60 minutes air exposure
Sable Fish (*Anoplopoma fimbria*)	Traps bushel basket shaped (151x29cm)	Held in tanks	Released Unwanted Bycatch?	75% (1st week) 96% (35 days)	22–30 cm	Rutecki and Meyers, 1992	Compared with hand jigging Problem with myxobacteria

Species	**Gear**	**Method of assessment**	**Unaccounted Mortality**	**Mortality**	**Size Range**	**Reference**	**Comments**
Lake Whitefish (*Coregnous clupeaformis)*	Trapnet	Observations in net pens	Released Sublegal Bycatch	25% (24 hours)	Sublegal < 432mm	Copes and McComb, 1992	Multivariate and stepwise multiple regression analyses
Atlantic Halibut (*Hippoglossus hipoglossus)*	Bottom Set Longline	Live holding on research vessel	Released Sublegal Bycatch	23% (48 hr)	< 81 cm	Neilson *et. al.*, 1989	Compared with trawl caught halibut

Appendix Ic – Escape Mortality (Towed Gears) Review Summary

Species	**Fishing Gear**	**Escape Category**	**Mortality Factors**	**Mortality %**	**Size Range**	**Refernce**
Alaska Pollock	Pelagic Trawl	Codend (Mesh size 83.3 & 101mm diamond)	None	0 – 8	24 – 48cm	Efanov & Istomin 1988
American Plaice (*Hippglossoides platessoides*)	Demersal trawl	Codend (Mesh size: 20.3cm diamond)		5 – 59		Carr (pres comm) & Robinson *et al.*,, 1993
Capelin (*Mallotus villosus*)	Demersal Shrimp trawl	Codend (Mesh 36mm diamond)	None	95 – 100	?	Thorsteinsson 1995
		Codend (Mesh 36mm square)		97 – 100	?	
		Control		55 – 100	?	
Cod (*Gadus morhua*)	Demersal trawl	Codend (Mesh size: 20.3cm diamond)		4 – 6		Carr (pres comm) & Robinson *et al.*,, 1993
Cod (*Gadus morhua*)	Demersal Trawl	Codend (Mesh 145mm diamond)	None	0		Jacobsen 1994 (Cf Jacobsen 1992)
		Control		0		
Cod (*Gadus morhua*)	Demersal Trawl	Codend (Mesh 90mm diamond; 120 meshes round)	Mesh size, mesh shape, & number of meshes round	0 – 9	?	Main & Sangster 1991
		Codend (Mesh 90mm diamond; 100 meshes round)		0	?	
		Codend (Mesh 90mm diamond; with square mesh window)		0	?	
Cod (*Gadus morhua*)	Demersal (Shrimp) Trawl	Deflecting Grid	None	0	?	Soldal & Engas 1997
		Controls		0	?	
(Baltic) Cod (*Gadus morhua*)	Demersal Trawl	Codend (Mesh 105mm diamond with square mesh lateral panels)	None	2.5	24–40 cm	Suuronen *et al.*,, 1995a
		Codend (Mesh 95mm diamond with square mesh windows)		10	26–38 cm	
		Control		0	25–50 cm	
Cod (*Gadus morhua*)	Demersal Shrimp trawl	Codend (Mesh 36mm diamond)	None	50 - 100	?	Thorsteinsson 1995
		Codend (Mesh 36mm square)		0 - 100	?	
		Control		0 - 75	?	
Cod (*Gadus morhua*)	Simulated codend - TCESA	Control	None	0	?	DeAlteris & Reifsteck (1993)

Species	Fishing Gear	Escape Category	Mortality Factors	Mortality %	Size Range	Refernce
		120 - 126mm Diamond mesh		0		
		120 - 126mm Square mesh		0		
Cod (*Gadus morhua*)	Tank experiment	Control	None	0	35–40cm	Engas *et al.*, (1990)
		Post exhaustion		0		
		Exhaustion and net injury		0		
		Exhaustion and induced injury		6.3		
Haddock (*Melanogrammus aeglefinus*)	Demersal Trawl	Codend (Mesh 145mm diamond)	None	15		Jacobsen 1994 (Cf Jacobsen 1992)
		Control		1		
Haddock (*Melanogrammus aeglefinus*)	Demersal Trawl	Codend (Mesh 70mm diamond)	Mesh size, length and length at age (condition?)	35.6– 46.5	8–32 cm	Lowry *et al.*,, 1996
		Codend (Mesh 90mm diamond)		14.5– 20.4	10–34 cm	
		Codend (Mesh 110mm diamond)		4.5 – 19.1	9–41 cm	
		Control (Captivity only)		0	17–34 cm	
Haddock (*Melanogrammus aeglefinus*)	Demersal Trawl	Codend (Mesh 70mm single)	None	33	?	Main & Sangster 1988
		Codend (Mesh 80mm single)		82	?	
		Codend (Mesh 80mm double)		100	?	
		Codend (Mesh 70mm square)		25	?	
		Control (Captivity only)	None	0	?	
Haddock (*Melanogrammus aeglefinus*)	Demersal Trawl	Codend (Mesh 90mm diamond)	Mesh Shape	26 – 33	?	Main & Sangster 1990
		Codend (Mesh 90mm diamond)		6 – 8	?	
		Control (Captivity only)	None	0 – 3	?	
		Control (Tagged fish in test cage)		0 – 10	?	
Haddock (*Melanogrammus aeglefinus*)	Demersal Trawl	Codend (Mesh 80mm square; 120 meshes round)	Mesh size, mesh shape, & number of meshes round	3 – 14	?	Main & Sangster 1991
		Codend (Mesh 90mm diamond; 120 meshes round)		14 – 57	?	

Species	Fishing Gear	Escape Category	Mortality Factors	Mortality %	Size Range	Refernce
		Codend (Mesh 90mm diamond; 100 meshes round)		3 – 7	?	
		Codend (Mesh 90mm diamond; with square mesh window)		18 – 28	?	
		Codend (Mesh 100mm diamond; 120 meshes round)		3 – 17	?	
Haddock (*Melanogrammus aeglefinus*)	Demersal Trawl	Codend (Mesh 70mm diamond)	Length, Length with time & mesh size (?)	33 – 52	16 – 32 cm	Sangster *et al.*,, 1996 (Cf. Sansgter & Lehmann, 1994 and Lehmann & Sangster, 1994)
		Codend (Mesh 90mm diamond		18 – 21	17 – 38 cm	
		Codend (Mesh 100mm diamond		17 – 27	16 – 36 cm	
		Codend (Mesh 110mm diamond		11 – 17	15 – 35 cm	
		Control (Captivity only)		0	23 – 34 cm	
Haddock (*Melanogrammus aeglefinus*)	Demersal Trawl	Codend (Mesh 135mm diamond)	None	0.9 – 6.5	11 –70 cm?	Soldal *et al.*,, 1991
		Codend (Grid 55mm bar space)		5.4 – 10.5	11–70cm?	
		Controls		8.9 – 32.2	?	
Haddock (*Melanogrammus aeglefinus*)	Demersal (Shrimp) Trawl	Deflecting Grid	None	0	17 – 31 cm	Soldal & Engas 1997
		Controls		0 – 100	17 – 31 cm	
Haddock (*Melanogrammus aeglefinus*)	Demersal Shrimp trawl	Codend (Mesh 36mm diamond)	None	0 – 100	?	Thorsteinsson 1995
		Codend (Mesh 36mm square)		0 – 100	?	
		Control		2	?	
Haddock (*Melanogrammus aeglefinus*)	Demersal Trawl	Codend (Mesh 70mm diamond)	Catch (dogfish), monitoring time, fish length	9.4 – 37.5	11 – 21 cm	Wileman *et al.*,, 1999
		Codend (Mesh 100mm diamond)		6.6 – 22.2	10 – 26 cm	
		Controls (Captivity only)		0.0 – 5.6	20 – 37 cm	
Haddock (*Melanogrammus aeglefinus*)	Demersal Trawl	Codend (mesh 100mm diamond) 1 hr tow & 15 min sample	Sampling time, fish length, monitoring time	5.4 – 10	9 – 33 cm	

Species	Fishing Gear	Escape Category	Mortality Factors	Mortality %	Size Range	Refernce
		Codend (mesh 100mm diamond) 3 hr tow & 15 min sample		3.5 – 4.3	9 – 25 cm	
		Codend (mesh 100mm diamond) 3 hr tow & 30 min sample		31.9	9– 25 cm	
		Control		5.4	9–28 cm	
		Control (Captivity only)		0	18–29 cm	
Haddock (*Melanogrammus aeglefinus*)	Purse Seine	Codend - at surface		3.2 – 6.8		Soldal & Isaksen (1993)
Haddock (*Melanogrammus aeglefinus*)	Tank experiment	Control	None	0	35–50cm	Engas *et al.*, (1990)
		Post exhaustion		0		
		Exhaustion and net injury		20		
		Exhaustion and induced injury		12.5		
Haddock (*Melanogrammus aeglefinus*)	Simulated codend	155mm diamond mesh	“stress”	50–70	46–70cm	Jonsson (1994)
Herring (*Clupea harengus*)	Purse Seine	Net Burst 1000m^3 net	(Skin damage?)	95	34cm mean	Misund & Beltestad (1995)
		Control 1000m^3 net		12		
		Net Burst 30m^3 net		100		
		Control 30m^3 net		98		
(Baltic) Herring (*Clupea harengus*)	Pelagic Trawl	Codend (Mesh Size: 24, 28 & 36mm, diamond)	Length Mesh Size	10 – 100	6 – 13cm	Borisov & Efanov 1981
(Baltic) Herring (*Clupea harengus*)	Pelagic Twin Trawl	Codend (Mesh: 24mm diamond)	Mesh Size Length Scale Loss	35.3	6 – 13 cm	Efanov 1981 (Cf. Borisov & Efanov 1981)
		Codend (Mesh: 28mm diamond)		15.6		
		Codend (Mesh: 32mm diamond)		10.1		
		Control		?		
(Baltic) Herring (*Clupea harengus*)	Pelagic Herring Trawl	Rigid Grate	Monitoring time, Selection method, Length (?)	17.7– 73.0	6 – 19 cm	Suuronen 1991
		Square Mesh Panel		7.0 – 84.1	7 – 17 cm	
		Control		6.5 – 39.4	6 – 24 cm	
(Baltic) Herring (*Clupea harengus*)	Pelagic Herring Trawl (@ Night)	Codend - small fish (<12 cm); (Mesh 26 & 36mm diamond)	Caging duration & Fish length	9 – 82	6–11 cm	Suuronen *et al.*,, 1996a

Species	Fishing Gear	Escape Category	Mortality Factors	Mortality %	Size Range	Refernce
		Codend - small fish (>12 cm); (Mesh 26 & 36mm diamond)		0 – 17	12–17 cm	
		Control (Captivity only)		9 – 13	12–17 cm	
(Baltic) Herring (*Clupea harengus*)	Pelagic Herring Trawl (@ evening & night)	Codend - small fish (<12 cm); (Mesh 36mm diamond & Grid)	Fish length, fish length with time, Selective device (?), season,	96 - 100	6 - 11 cm	Suuronen *et al*.,, 1996b
		Codend - small fish (>12 cm); (Mesh 36mm diamond & Grid)		77 – 100	12–17 cm	
		Control (Captivity only)		9 – 55	5 – 18 cm	
(Baltic) Herring (*Clupea harengus*)	Pelagic Trawl	Codend	Condition, trawling time, catch of sticklebacks	59.5	?	Treschev *et al*.,, 1985
		Control		71.6	?	
Mackerel (*Scomber scrombus*)	Purse Seine	Sorting grid		44 – 82	31 – 45cm	Beltestad & Misund (1996)
		Control		5 – 55	30 – 45cm	
		'Meso scale' sorting grid		0.5 – 1.6		
		Control		0.7 – 1.8		
Norway Lobster (*Nephrops norwegicus)*	Demersal *Nephrops* Trawl	Codend (mesh 60mm square)	Codend type, catch (dogfish/total abrasive), depth and towing speed.	5.2 – 22.9	20 – 46mm	Wilemen *et al*.,, 1999
		Codend (mesh 70mm diamond)		15.5 – 23.2	20 – 46mm	
		Codend (mesh 100mm diamond)		12.6 – 27.1	20 – 46mm	
		Control		0.0 – 1.1	20 – 46mm	
Saithe (*Pollacius virens*)	Demersal Trawl	Codend (Mesh 145mm diamond)	None	2.4 – 4.0		Jacobsen 1994 (Cf Jacobsen 1992)
		Control		0.0 - 4.0		
Saithe (*Pollacius virens*)	Simulated codend	Control	"secondary infection"	4.1	?	Soldal *et al*., (1989); cited in Soldal *et al*., (1993)
		Anaesthetic control		5.8		
		Net damaged		1.7		
		Induced Damage		13.7		
Saithe (*Pollacius virens*)	Purse Seine	Sorting grid		0 - 3		Beltestad & Misund (1996)

Species	Fishing Gear	Escape Category	Mortality Factors	Mortality %	Size Range	Refernce
		Control		0		
Sand Whiting (*Sillago ciliata*)	Simulated codend	60mm square mesh - only	None	3	10–18cm	Broadhurst *et al.*, (1997)
		60mm sq mesh - post exhaustion		0		
		Controls		0		
Scallops (*Pecten maximus*)	Scallop dredge	"escapes"	mortality based on damage observations	6		Breen & Sangster (unpublished)
		discards		3		
Scallops (*Pecten maximus*)	Scallop dredge	"escapes"		0 – 6.7	53–149mm	Chapman *et al.*, (1977)
		discards		0 – 25	62–144mm	
		Controls		0 – 6.9	65–140mm	
(Iceland) Scallop (*Chlamys islandica*)	Scallop dredge	Inshore Digby dredge	(Indiect mortality estimates)	17		Naidu (1988)
		Heavy offshore Bedford dredge		31		
Scup (*Stenotomus chrysops*)	Simulated codend - TCESA	Control	None	0–11	?	DeAlteris & Reifsteck (1993)
		120 - 126mm Diamond mesh		0–3		
		120 - 126mm Square mesh		0–6		
Sebastes viviparus	Demersal Trawl	Codend (Mesh 145mm diamond)	Length (?)	6 – 100		Jacobsen 1994 (Cf Jacobsen 1992)
		Control		6 – 75		
Shrimp (*Pandalus borealis*)	Demersal Shrimp trawl	Codend (Mesh 36mm diamond)	None	0.5 – 42.9	?	Thorsteinsson 1995
		Codend (Mesh 36mm square)		1.7 – 6.9	?	
		Control		1.2 – 14.9	?	
Vendace (*Coregonus albula*)	Pelagic Pair Trawl	Codend (evening & night)	Holding time, time of day, season & temperature	60 – 80	5 – 10 cm	Suuronen *et al.*,, 1995b
		Codend (afternoon)		30 – 40	5 – 10 cm	
		Control		2 – 23	5 – 10 cm	
Walleye Pollock (*Theragra chalco-gramma*)	Pelagic Trawl	Codend escapes	Length, (escape route?)	46 – 84	?	Erikson *et al.*,, 1999
		Extension escapes		47 – 63	?	
		Controls (Seine caught)		2 – 59	?	

Species	Fishing Gear	Escape Category	Mortality Factors	Mortality %	Size Range	Refernce
Whiting (*Merlangius merlangus*)	Demersal Trawl	Codend (Mesh 145mm diamond)	None	7		Jacobsen 1994 (Cf Jacobsen 1992)
		Control		0		
Whiting (*Merlangius merlangus*)	Demersal Trawl	Codend (Mesh 70mm diamond)	Mesh size, length and length at age (condition?)	14.2 – 21.3	10 – 30 cm	Lowry *et al.*,, 1996
		Codend (Mesh 90mm diamond)		14.2 – 21.7	10 – 32 cm	
		Codend (Mesh 110mm diamond)		7.3 – 16.5	10 – 33 cm	
		Control (Captivity only)		0	17 – 25 cm	
Whiting (*Merlangius merlangus*)	Demersal Trawl	Codend (Mesh 90mm diamond; 120 meshes round)	Mesh size, mesh shape, & number of meshes round	3 – 17	?	Main & Sangster 1991
		Codend (Mesh 90mm diamond; 100 meshes round)		14 – 30	?	
		Codend (Mesh 90mm diamond; with square mesh window)		0 – 12	?	
Whiting (*Merlangius merlangus*)	Demersal Trawl	Codend (Mesh 70mm diamond)	Length, Length with time & mesh size (?)	40 – 48	17 – 31 cm	Sangster *et al.*,, 1996 (Cf. Sansgter & Lehmann, 1994 and Lehmann & Sangster, 1994)
		Codend (Mesh 90mm diamond		22 –27	18 – 35 cm	
		Codend (Mesh 100mm diamond		33	19 – 33 cm	
		Codend (Mesh 110mm diamond		14 – 17	20 – 34 cm	
		Control (Captivity only)		0	23 – 34 cm	
Whiting (*Merlangius merlangus*)	Demersal (Shrimp) Trawl	Deflecting Grid	None	0	15 – 34 cm	Soldal & Engas 1997
		Controls		0	15 – 34 cm	
Whiting (*Merlangius merlangus*)	Demersal Shrimp trawl	Codend (Mesh 36mm diamond)	None	N/A	?	Thorsteinsson 1995
		Codend (Mesh 36mm square)		0 – 50	?	
		Control		0	?	
Whiting (*Merlangius merlangus*)	Demersal Trawl	Codend (Mesh 70mm diamond)	Mesh size	0.6 – 3.6	11 – 26 cm	Wileman *et al.*,, 1999
		Codend (Mesh 100mm diamond)		5.4 – 9.9	12 – 29 cm	

Species	Fishing Gear	Escape Category	Mortality Factors	Mortality %	Size Range	Refernce
		Controls (Captivity only)		2.4 – 10.0	18 –- 29 cm	
Whiting (*Merlangius merlangus*)	Demersal Trawl	Codend (mesh 100mm diamond) 1 hr tow & 15 min sample	Sampling time, fish length, monitoring time	0 – 7.3	9 – 27 cm	
		Codend (mesh 100mm diamond) 3 hr tow & 15 min sample		1.7 – 3.0	10 – 29 cm	
		Codend (mesh 100mm diamond) 3 hr tow & 30 min sample		9.9	9 – 25 cm	
		Control		11.8	7 – 28 cm	
		Control (Captivity only)		0 – 10.8	15 –- 25 cm	
Winter Flounder (*Pseudopl-euronectes americanus*)	Simulated codend - TCESA	Control	None	0	?	DeAlteris & Reifsteck (1993)
		120 - 126mm Diamond mesh		0–5		
		120 - 126mm Square mesh		4–15		
Yellowfin Bream (*Acanthopagrus australis*)	Simulated codend with Nordmøre-grid guiding panel	Passage through guiding panel	None	2	?	Broadhurst *et al.*, (1999)
		Hook & Line		0–100		
		Control		0–100		
Yellow Tail Flounder (*Plueronesctes ferrugineus)*	Demersal trawl	Codend (Mesh size: 20.3cm diamond)		1 –10		Carr (pres comm) & Robinson *et al.*,, 1993

Appendix Id – Escape Mortality (Static Gears) Review Summary

Species	Gear	Method of assessment	Unaccounted Mortality	Mortality	Size Range	Reference	Comments
Pacific Halibut (*Hippoglossus stenolepis*)	Bottom Set Longline	Assessing condition codes	Released Unwanted Bycatch and Escapees	3% minor injuries 24% moderate 74% severe	34 – 191 cm	Kaimmer and Trumble, 1998	Difficult interpretation
Pacific Herring (*Clupea harengus pallasi)*	Experimental Gillnets	Scale loss and survival observation	Swim-through escapees	2% (2 weeks)	< 21 cm	Hay, *et al.*, 1986	Unique design using experimental trap net
Sockeye Salmon (sp)	Gillnets	Observation in floating enclosure	Escape	80%(monofilament) 95% (multifilament) (20 days)	None given	Thompson and Hunter, 1971	

Appendix Ie – Ghost Fishing Mortality Review Summary

Gear Type	Location	Major Cause of Loss	Impact on Target Population	User Conflict	Reference
Trawls	US, Canada, Australia	1, 4	A, 1	Medium to high	High 1985; Low *et al.*, 1985
Traps	US Atlantic & Pacific Coasts, Caribbean, Canada	1, 2, 3, 4	B, 2	High	Breen 1987 & 1990; High & Worland, 1979: Kruse & Kimker1993; Muir *et al.,;* 1984; Smolowitz, 1978.
Gill Nets	US, Australia, East Coasts – UK, Irish Sea, North & Baltic Seas, Atlantic Canada	1, 2, 3	Inshore: c, 3 Offshore: b, 2	High	Breen, 1990; Brothers, 1992; Carr, 1988; Carr *et al.,*, 1985; High, 1985; Wileman, pers com.
Longlines	US (NW Atlantic & NE Pacific), Canada.	2, 3 (Degree of operational Loss is unknown)	A, 1	Low	High, 1985
Weirs	US (New England)	3	?	Low	

Appendix II - Bibliography

General

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ANNEX 2 – USING GEAR TECHNOLOGY TO UNDERSTAND AND REDUCE UNINTENDED EFFECTS OF FISHING ON THE SEABED AND ASSOCIATED COMMUNITIES: BACKGROUND AND POTENTIAL DIRECTIONS

Report of a WGFTFB Topic Group

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1. Introduction

The effects of fishing gear on the seabed and associated communities have received increased attention over the last several years. Several major research efforts (Lindeboom and de Groot 1998, Prena *et al.*, 1999), reviews (Kaiser and de Groot 2000, Auster *et al.*, 1996, ICES 2000) workshops (Dorsey and Pederson 1998) and symposia (ICES Marine Science Symposium, Benaka 1999) on the topic have been recently completed. However, this accumulation of knowledge is being outpaced by increasing demands for an even greater level of understanding to support specific policy decisions. This includes the need to distinguish combinations of fishing gear and seabed communities that result in equivocal or marginal effects from those that generate enduring and severe effects. It is also necessary to recognize where and when the later combinations occur and identify the most efficient way of mitigating such effects.

A number of factors influence the effect of fishing gear on a benthic ecosystem and the characteristics of the fishing gear may be as significant as those of the physical habitat or the community of organisms affected. While the effects of different fishing gear components on benthic ecosystems may be similar in type, variations in particular gear characteristics, such as force of bottom contact, and component dimensions, could cause profound differences in the severity of such effects. Operational choices by the fishers, such as towing speed and scope ratios, can cause similar gears to have different effects. Characteristics of the benthic habitat, such as sedimentary composition and complexity also affect the interactions between different gear components and the ecosystem. Likewise, the vulnerability of organisms to gear components is determined by an interaction of their structure and behaviour and the characteristics of the component that they encounter.

Effective study of the effects of fishing gear on benthic ecosystems should include interaction between those who study fishing technology and those who study the benthic ecosystem. This document will begin to explore the appropriate role of gear researchers in addressing these problems and start collecting relevant concepts derived from previous work. Much of the relevant information gathered by those who study fishing gear and related fish behaviour has been collected incidental to studies with other goals, and their application to seafloor effects may not be rigorous at this point. For example, while studying what determines the spreading force of a trawl door or the reactions of fish to the sand clouds that the door generated, observations may have been collected that shed light on how the door affected the

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seabed. However, that knowledge may not have been analysed or published in a form that allows objective interpretation. Using such observations to generate revealing studies on understanding and reducing seafloor effects will be an important task in moving forward in this field.

While incentives have long been present for designing fishing gear to capture fish more effectively and selectively, the need to minimise interactions between the seabed and the fishing gear has been mostly limited to avoiding damage to the gear. With the option available of using more robust materials, the resulting gear has not necessarily been tuned to be gentle on the seabed. An appropriate role for researchers of fishing technology will be to identify changes in the use and construction of fishing gear that significantly reduce seabed effects. It will also be important to quantify any associated losses in fishing effectiveness. There is no gain where the effects of fishing on the seabed are halved, but twice the effort is necessary to catch the same number of fish.

Few studies of seabed effects have directly identified the mechanisms by which fishing gear interacts with the substrate and organisms. For studies based on historical fishing effort and open vs. closed areas, the fishing gear can often only be identified by broad classes such as beam trawl, otter trawl or scallop dredge, preventing examination of which components caused the effects and what characteristics of those components determine the severity of the effects. Even when controlled trawling is used, the seabed sampling is usually not designed to distinguish such differences. Such knowledge would be useful in developing or evaluating gear-specific measures to reduce effects. Fishing technology researchers should develop tools and studies to make and quantify such distinctions.

This paper will categorise and describe the effects of fishing which have been identified, noting which characteristics of fishing gear components are likely to affect the severity of each effect. We will describe the main components of each class of fishing gears and relate them to the above significant characteristics. The final section will list the methods available to study such effects. It is not the intent of this paper to provide a rigorous evaluation of the evidence supporting each effect, which would be largely redundant with recent work of the ICES WGECO (ICES 2000), but rather to describe the effects that have been indicated and relate them to the structure and function of different fishing gears.

2. Effects of Fishing

The direct and intended effect of using fishing gear is the removal of selected organisms from the ecosystem. Improving the effectiveness and selectivity of this harvest have been the principal goals of fishing gear research. Assessing the effects of this removal is one of the primary applications of populations dynamics and multispecies modelling. Neither these effects nor those resulting from incomplete selectivity (bycatch) are included in this paper, which will focus instead on the indirect effects of fishing gear on the seabed and associated communities.

In terms of the effects of fishing gear on the seabed habitat, mobile gears can be considered different collections of objects being pulled across the seabed. This includes components of some passive gears, such as pots and longlines, during setting and retrieval. Beginning with this basic similarity, however, one must recognise that the effects of such different objects can vary from undetectable to long-lasting and severe. The characteristics of these objects, their contact with the seabed, the area of seabed that they encounter and the composition of the substrate itself all influence the severity and extent of effects. The longevity of effects is related to the rate at which the affected seabed features are produced. Effects will be less persistent where features which are constantly being renewed (high energy environments). Hydrographical parameters such as tidal currents and effects of storms will influence the longevity of seabed disturbance, especially in shallow waters.

2.1 Sedimentary substrates

Most of the ocean floor is covered with sedimentary substrates, consisting of different combinations of clay, mud, sand and gravel. The percentages of these components and the degree of consolidation are principal determinants of resistance of the seabed to suspension, compression and penetration. Sediments may have surface bedforms, such as sand waves or burrows, caused by wave, current or biological actions.

Components of the surface layer of sediments can be suspended into the water column even by close passage of a towed object of sufficient size. A vortex formed behind a moving object can suspend the lighter fractions of the sediments off of the seabed. Suspension of sediments becomes more pronounced with direct contact and greater still when the sediments are penetrated and disrupted. Suspended sediments temporarily increase local turbidity and redistribute these finer sediment fractions across the seabed. Divers and video have observed sand clouds produced by trawl gear (Main & Sangster 1981). Pilskaln *et al.*,(1998) found that the occurrence of infaunal worms in midwater sediment traps was correlated with bottom trawling activity in the area. Churchill (1989) found a similar correlation with increases in turbidity detected by a series of transmissometers.

Component characteristics that would intensify vortices and hence increase sediment suspension include; larger cross section perpendicular to the direction of travel, higher towing speed, less hydrodynamically efficient shapes and closer proximity to the seabed. Penetration of the seabed would make more sediment vulnerable to suspension.

With direct contact of sufficient force, sediments can be compressed or penetrated and scoured by fishing gear components. This can flatten existing surface features (Currie and Parry 1999, Tuck *et al*., 1998, Schwinghamer *et al.,* 1998), create new features (Friedlander *et al,*. 1999, Gordon *et al.,* 1998, Service and Magorrian 1997), collapse or cover burrows, or break up sedimentary layering (Lindeboom and de Groot 1998).

The gear characteristics likely to have the most influence on the degree and extent of penetration or compression of sediments are the force with which the component contacts the seabed and the area over which that force is distributed. Light force over a large area may only produce some minor compression and flattening, while heavy force over a small area will penetrate the sediment, causing displacement and disruption (Gilkinson *et al.,* 1998).

2.2 Emergent structures

While surface sediments make up the vast majority of seabed habitats, the most densely populated and diverse habitats are associated with emergent structures. Their origins may be geological (boulder piles or bedrock), biogenic (coral or worm tube colonies), or anthropogenic (shipwrecks and artificial reefs). Important characteristics of emergent structures that determine their vulnerability to fishing gears include height, shape, flexibility and how they are joined together and to the substrate. Effects of fishing gear on emergent structures may include overturning of boulders (Freese *et al.,* 1999) and reduction of reef height (Lenihan *et al.,* 1998).

Encounters of fishing gear with emergent structures can take several courses. If the component is towed from a point that is high relative to the encountered object, it will tend to go over it. This could result in harmless passage, breakage or displacement, depending on the contact force, the fragility of the object and its weight or attachment to the substrate. Components with a low towing point relative to an encountered object can cut through or under it, tip it over, move it, become fast or suffer gear damage. Higher towing forces and smaller diameters of components make undercutting and gear damage more likely. Higher tension in a linear gear component will make it more resistant to upward displacement, applying more force to emergent objects. An unattached object can be dragged along the seabed for some distance if gear components make contact near its center or it gets caught in the gear.

2.3 Organisms

The same forces that fishing gears apply to the substrates also affect organisms living on and within them. Similarly, the resulting effect can range from none (Kaiser *et al.,* 1999) to displacement or injury (Kaiser 1996, Robinson and Richardson 1998), including mortality, depending on the vulnerability of the organism and the characteristics of the encountered gear component. Types of injuries include abrasion, laceration and breakage of shells and skeletons (exo- or endo-). Mobile epifauna may be able avoid the gear, depending on the speed of approach and their sensory abilities, while sessile species may be more vulnerable (Hall-Spencer *et al.,* 1999). Organisms that provide habitat for others may be caught in the gear and removed. Suspension, compression or penetration of sediments can affect the infauna. Small invertebrates may be suspended with the sediment (Pilskaln *et al.,* 1998). In addition to direct injuries, collapse and covering of burrows, exposure and stress can increase energetic and predatory vulnerability (Ramsay and Kaiser 1998). As with emergent structures, emergent epifauna are vulnerable to being undercut and separated from the substrate, or run over by the gear. (Collie *et al.,* 1996, Freese *et al.,* 1999).

Gear characteristics related to effects on infauna and epifauna should be similar to those that determine effects on sedimentary and emergent structures. Species specific differences in mobility, fragility, size, structure and relation to habitat will produce differences in vulnerability.

2.3.1 Ghost fishing

Another category of fishing gear effect is the entrapment and eventual mortality of organisms from encounters with lost gear, so-called “ghost fishing”. This is mainly an issue with gears that are left on the seafloor, the so-called ‘passive gears’, such as pots, gill nets and traps, though active gear can become derelict when separated from the towing vessel. Mesh from active is unlikely to entangle fish due to its high visibility and its relative rigidity. Factors related to ghost fishing include the ability to relocate and retrieve gear and the ability of the gear to continue capturing fish for periods longer than the normal deployment. An important tool for reducing ghost fishing mortalities is effort management to reduce loss in the first place. Once lost, it is possible to mitigate the effects through the use of devices to disable gear after some period in the water (e.g., biodegradable panels). Derelict gear can have a positive effect for some organisms by providing complex structure in their environment.

2.4 Community Effects

Any of the above effects on the fauna and habitat components of an ecosystem can affect the interactions of the biological community. Changes in the composition of infaunal (Tuck *et al.,* 1998) and epifaunal (Kaiser *et al.,* 1998, McConnaughey *et al.,* 2000, Prena *et al.,* 1999) communities have been indicated. Significant changes in the abundance of individual species, either through displacement or mortality could affect food web dynamics. Several studies have indicated that scavenger population may benefit from injured or discarded organisms (Ramsay *et al.,* 1996,1998,Kaiser and Ramsay 1997). Loss or reduction of sheltering structures and organisms may affect both predator-prey interactions and the energetic needs of individuals (Sainsbury 1987, Auster *et al.,* 1996, McConnaughey *et al.,* 2000).

Most of these indirect effects are difficult to trace, measure and attribute significance, involving complex interdependencies that are obligatory to varying degrees. The dynamic nature of communities and ecosystems also makes it difficult to distinguish changes due to fishing effects from the natural background. However, ecosystem level effects are the basis for many of the concerns regarding the effects of fishing gear on seabed communities, including loss of habitat-dependant populations, increased mortality of juveniles of commercial species and shifting of food web structures (ICES 2000). While this is not an area where gear technology is likely to directly contribute, improved understanding of ecosystem effects will be necessary to correctly direct the development of mitigation methods.

3.0 Components of fishing gear and their characteristics

3.1 Otter Trawls

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

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

Trawl door marks are the most recognizable and frequently observed effect of otter trawls on the seabed (Caddy 1973, Friedlander *et al.,* 1999). Doors travel across the seabed oriented at an angle to the direction of travel. The resulting marks consist of an area scoured by direct contact and a berm of sediment displaced toward the trawl centerline (Gilkinson *et al.,* 1997). Of the major components of a trawl, doors affect the smallest area of seabed, usually producing two swaths totalling a few meters in width. The downward force exerted by the door on the seabed and the width of that contact affect the extent of these marks. The weight of the door is partly cancelled by the upward force from the cables attaching it to the towing vessel. The vertical attitude of bottom trawl doors is generally adjusted so that hydrodynamic forces have a small downward component, increasing the force of seabed contact (Seafish *et al.,* 1993).

The design of the door can influence the degree of contact significantly. The v-door traditionally used in many *Nephrops* fisheries in Europe is designed with a hinged bracket to which the warp is attached. The door is designed to have only light contact with the seabed because it is used on muddy grounds where digging in must be avoided. The hinge also allows the main plate to swivel when an obstruction such as a large boulder is encountered. However, because of its inefficient hydrodynamic shape seabed material is put into suspension by the vortices behind the main plate. The dimensions of these trailing clouds of suspended matter behind some types of otterboards are reported in Main and Sangster (1981).

Bridles are cables that connect the trawl doors to the trawl net and may be in contact with the seabed for part of that distance. The selection of length of these cables and their angle of attack, which determine the area of seabed that they sweep, will be based on the herding characteristics of the target species. Flatfish trawls may be fished with bridles longer than 200 m, while shrimp trawls usually have short bridles. Sometimes, bridles are covered with hose or strung with a contiguous series of rubber disks (cookies), up to 15 cm diameter, to protect the cables and to increase their herding effectiveness. The length of bridle wires is also dependent on seabed type. On rough ground where there is a high risk of snagging on boulders or other obstructions, only short wire lengths are feasible.

When using long bridles to target herdable species, the bridles contact more seabed than any other trawl component. The force of contact of these sections with the seabed results from their weight (in water) per length. Unless chain is used, or supplementary weights are added, this limits their action to skimming the surface of the seabed. Small scale vertical features on soft substrates can be flattened by this action. Emergent structures and organisms can be vulnerable to penetration or undercutting by bridles, especially where the bridles have a small diameter. The ease with which wires travelling across the seabed can be displaced upwards by these structures will be reduced as the tension in the wire increases.

Footropes are the components of a trawl that are directly attached to the lower, leading edge of the net and contact the seabed. They have two, often conflicting, functions of separating the target species from the seabed and raising the netting far enough above the seabed to prevent damage. Large diameter footropes protect the netting more effectively, but may inhibit fish from passing back into the net and allow more opportunities for escape under the net. Footropes are constructed similarly to bridles, with a cable or chain that may be covered with protective material. Diameters are commonly larger than bridles (up to 1 m) and often vary along the length. Thus only part of the footrope may be in direct contact with the seabed.

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

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

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

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

3.2 Demersal seines

These include Danish anchor seines, Scottish fly-dragging seines and pair seines. There are similarities between demersal seines and otter trawls in that a funnel shaped net with a protective groundrope is hauled by a system of wires or ropes which contact the seabed. The differences are described below.

Otterboards are not used with demersal seines. The net and groundrope are generally of lighter construction because the long lengths of rope used ahead of the net are vulnerable to snagging on rough ground. Therefore, the seine gear is therefore used generally on relatively clean seabed.

The wires or ropes are in contact with the seabed over much greater lengths, typically several hundred meters compared to the 100 m or less for otter trawls. These wires are made of synthetic rope (not wire rope) and have a lead core for extra weight. The seine operation involves laying the ropes in a triangular shape with the net in the middle of one side of the triangle. The two rope ends are then hauled simultaneously towards the vessel by winches or rope reels. During this hauling process the ropes gradually close and for much of the time the rope has a component of velocity along its axis. The rate of closure is relatively slow, possibly allowing more time for animals to avoid the rope rather than being overrun. The rope may cut into the substrate due to the longitudinal velocity and the stranded form of the rope that displaces material as it moves. The greater the tension in the rope, the deeper the cut which is made and also the more difficult for the rope to be displaced by an object or conversely the greater the force exerted on an object which the rope passes over.

The speed of advance of the net is very slow at first, gradually quickening to a maximum of perhaps 2–2.5 knots as the rope speed is increased towards the end of the set. The lighter construction of the net and the lower speed of hauling the net through the water, even at the end of the haul, generate lower tensions in seine ropes than in trawl sweeps and bridles. Thus, they are less rigid and more able to conform to substrate features instead of cutting through them.

3.3 Beam trawls

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

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

The pressure from the tickler chains or matrix chain elements is substantially lower than that exerted by the trawl heads, in the order of 0.5 $N.cm^{-2}$ (Paschen *et al.,* 1999), although the area covered is significantly greater.

During the passage of a gear component the pressure in the sediment at a certain point will gradually increase up to a maximum and then gradually decrease. Model tests have shown that, irrespective of the weight of the gear, the reaction pressure is reduced to 10 % of the near-surface value at a depth of 10 cm and unchanged at depths greater than12.5 cm (Paschen *et al.,* 1999). Whether benthic infauna can detect this change in pressure whether they would consequently react is unknown at present.

When towing a tickler chain or a chain matrix over the seabed, sediments will be transported and pass through and/or over the links and resettle after passage. Smaller particles will go into suspension and may be transported away by currents or resettle in the track of the trawl. Local variations in morphology such as ripples will be flattened out. The effect of an array of chains running consecutively over the seabed is that the increase in penetration depth become less and the additional effect is smaller with an increasing number of chains. The passage of the first chain compacts the sediment, diminishing the effect of elements passing later. After about seven passages the increase in penetration is hardly noticeable (Paschen *et al.,* 1999).

Fluctuations in the pressure exerted on the seabed indicate that beam trawls are not in a steady contact with the seabed (Fonteyne 2000). Both variations in seabed morphology and vessel movements may cause a variable bottom contact of the gear. As a consequence the penetration depth is not constant along the track. Recent measurements showed penetration depths between 1 and 8 cm (Paschen *et al.,* 1999). The penetration depth depends on the sediment type. The largest values were noticed on very fine to fine muddy sand with an average of 5.3 cm.

As for the otter trawls, the composition of the groundrope depends on the seabed condition. The tickler chain beam trawls, used on clean grounds, are simple and rather light. The groundropes of chain matrix beam trawls, for use on rough grounds, are equipped with bobbins.

Beam trawls leave detectable marks on the seabed. The duration that the beam trawl marks remain visible depends on the upper sediment layer and on the hydrographic conditions. On a seabed consisting of medium to coarse sand, tracks have been observed to remain visible for up to 6 days. On sediments with mainly finer particles a corresponding figure of 37 hours was observed (Fonteyne 2000, Paschen *et al.,* 1999).

3.4 Dredges

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

3.4.1 New Bedford drag

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

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

3.4.2 Scallop dredge

Towed, toothed dredges, are typically used in U.K. waters for the capture of the scallop, *Pecten maximus* and the queen scallop, *Chlamys opercularis* (Strange, 1981). These animals are usually found recessed in sediments comprised of sand and silt. The dredges are constructed from a triangular frame, the ‘base’ of the triangle consisting of a toothed bar. A retaining bag is attached to the rear of the toothed bar. This consists of a belly section constructed from steel rings with a heavy netting top and rear section to form a bag. Dredges with the toothed bar rigidly attached to the frame are used primarily on fine ground where there is little risk of gear damage. On harder substrates, damage to the toothed bar is minimized by attaching it to the frame via two shock absorbing springs, which ‘give’ during impact. The teeth of the dredge are typically 80–90mm long, constructed from ~20mm thick steel bar. Each dredge is generally 0.8m wide, with each bar having approximately 9 teeth per bar. During operation, depending on substrate and tooth sharpness, the teeth will penetrate the substrate by 20 – 50 mm (Lart 1999). Each fully rigged dredge may weigh approximately 150–175kg in air. Multiple dredges are attached to a single wheeled towing bar or beam. Typically a vessel will operate two beams towing from either side of the vessel. Depending on the vessel size and power, up 18 dredges per side may be operated, however, this is relatively rare, and for most U.K. vessels, 7–8 per side is more normal. With the beam weight and associated hardware, the combined weight for each side may reach well in excess of two tonnes (in air).

3.4.3 Italian rake (Rapido Trawl)

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

3.4.4 Portuguese clam and razor dredge

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

3.4.5 Benthic effect of mechanical dredges

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

3.4.6 Hydraulic dredges

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

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

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

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

3.5 Longlines

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

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

3.6 Gillnets

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

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

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

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

3.7 Pots and traps

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

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

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

4. Methods of measuring effects

The studies that have looked at the effects of fishing gear on seafloor communities have used a range of experimental designs and methods to measure each type of effect. The following section will describe the characteristics of these designs and measurement tools. Of particular interest from a gear technology perspective is how specifically these experimental methods allow any observed effects to be ascribed to a particular gear type, gear component or even characteristic of that component. Methods that allow more direct connections to be made will be more useful in understanding the mechanisms that generate effects and, hence, finding ways to reduce them. Helping studies to be more specific in this regard may be a useful contribution for gear researchers.

4.1 Study designs

Some studies look for evidence of the effects of fishing gear in historical changes in benthic communities over some time while they are subject to fishing pressure (Philippart 1998, Greenstreet *et al.*, 1998, Hill *et al.*, 1999). A significant challenge for these studies is separating the fishing effect from other influences on the benthic environment. Pre fishing baseline data, while rarely available, is very useful to such studies. Historical studies can only provide gear specific knowledge if there exists detailed knowledge of the gears used and the distribution of effort. They are unlikely to provide information on component specific effects.

A related and rarer type of study only looks at the recovery of the benthos after closure of a heavily fished area (Sainsbury *et al.*, 1997). This provides valuable information on the persistence of effects, but less useful for finding ways to avoid them.

The third type of study takes advantage of area where something (e.g., regulations, shipwrecks) prevents fishing in one area, while leaving an adjacent, comparable area open (Collie *et al.*, 1996, Engel *et al.*, 1998, McConnaughey *et al.*, 1999, Thrush *et al.*, 1998). To the extent that the areas are otherwise comparable, differences detected in the benthic communities are attributed to the fishing effort. These studies measure the effects of the cumulative effort in the fished area. If only one type of fishing gear is used in that area, such effects can be considered gear specific.

A more tightly focused study design involves fishing a delimited area within a larger area that is closed to fishing (Currie and Parry 1996, Schwinghamer *et al.*, 1998, Kaiser *et al.*, 1998, Freese *et al.*, 1999, Tuck *et al.*, 1998). Thus the effect of a known and usually acute fishing effort is measured. The seafloor communities within the affected area is then compared to a nearby control area. Often such sites will be revisited over time to assess recovery. These studies are certainly gear specific, because a particular gear has to be selected for the fishing. With adequate tracking and location of the gear and the sampling, it can also provide component specific information.

4.2 Measurement methods

The sediment suspended by fishing gear can be measured directly by a transmissometer (Churchill 1998), which measures the passage of light through the water or a turbidometer, which measures light reflected from particles in the water. Suspended sediments can also be directly observed by divers or with *in situ* video, commonly preventing observation of anything else until the sediment settles. Sediment traps collect suspended sediments (and associated organisms, Pilksan *et al.*, 1998) as they return to the seabed. The RoxAnn acoustic system for characterising seabeds apparently detected sediment suspension as the parameters measured (density and roughness) changed during trawling, but returned to the near-original state in a few hours (Fonteyne 2000).

Effects on sedimentary substrates may be measured by monitoring a number of sediment characteristics. Grain size distribution can be measured from core samples or grabs to indicate loss of suspended fractions. Changes in pore water pressure, measured by pressure sensors inserted in the seabed, may indicate compaction or fluidisation. The depth and texture of different sedimentary layers can be measured from core samples or by Sediment Image Profiling (Lindeboom and de Groot 1998). A penetrometer, measuring the resistance of the sediment to penetration, can also indicate changes in compaction.

Small scale changes in surface topography can be detected by video or direct observation. To improve quantification of these observations in lab studies, laser lines are used. An acoustic system (DRUMS) has been developed to make quantitative field observations. Larger scale features can be detected by side scan acoustic imagery. Systems that use analyse echo sounder returns (Roxann, QTCView) integrate a number of these sedimentary and topographical factors into unitless parameters that can be used to identify differences in sediment composition and structure.

Measuring the effects of fishing on the fauna generally involves collecting or observing the affected animals. Observation or collection can be done by divers in shallow water, but remote tools are needed deeper. Video or photographic cameras have been deployed on sleds or other arrangements (Collie *et al.,* 1996, Gordon *et al.,* 1998, Freese *et al.,* 1999). Epibenthic sleds, dredges or trawls have been used to collect epifauna (McConnaughey *et al.,* 1999, Collie *et al.,* 1996, Gordon *et al.,* 1998), while grabs or corers are used to collect infauna (Currie and Parry 1996, Thrush *et al.,* 1998, Engel and Kvitek 1998). Collected specimens may be examined for injuries or other signs of stress (Kaiser 1996, Gilkinson *et al.,* 1998). Observed injuries or stress can be related to mortality by holding the individuals or by lab experiments with specimens having similar injuries.

4.3 Quantification of gear contact

The above study designs and methods are not specifically designed to identify component-specific effects or to find and test ways to limit them. Methods to measure effects on a small scale will be needed to ascribe observed effects to particular components of the fishing gear. These would allow studies that identify and measure the characteristics of those components that determine seabed effects. The following section describes studies that quantify the parameters of the gear / seabed interactions.

One way of quantifying gear contact is measuring the pressure of the gear or gear elements on the seabed. There are two approaches to the problem viz. *in situ* measurements or measurements on models in a tank.

4.3.1 *In situ* measurements

The pressure exerted on the seabed by beam trawls was calculated from the underwater weight of the gear elements in contact with the seabed and the upward force or lift generated by the warp (Fonteyne 2000). The lift can be deduced from the warp load measurements.

The pressure exerted by gear elements can be measured more directly by incorporating load cells into the gear element. An example is the instrumented trawl head (Fonteyne 2000). The instrumented trawl head has a loose sole plate that is connected to the trawl head by means of two measuring axles. Strain gauges on the axles measure the forces in the towing direction and in the direction perpendicular to the sole plate. The forces perpendicular to the sole plate are a measure for the pressure exerted on the seabed. The forces in the towing direction are a measure for the friction between the sole plate and the seabed. Analysis of the recorded forces allows detailed description of the mechanical performance of the trawl head and the beam trawl.

Instruments mounted on scallop dredges were used to quantify the angle and depth of tooth penetration and impact forces on the seabed and on animals in the dredge (Anon. 2000).

4.3.2 Tank experiments

Tank experiments have been performed at the Institute of Naval Architecture and Ocean Engineering of the University of Rostock to quantify the physical effect of a beam trawl on the seabed (Paschen *et al.,* 1999).

The tank experiments were performed on single elements (trawl head model, curved stiff and flexible full scale chain segments). The superposition principle was used to predict the resistance of chain sub-elements and by extension of the entire gear systems. The measurement equipment consisted of a test tank (5.0 x 0.52 x 0.5 m water depth), mobile device carrier, 3 component balance for drag measurements, laser distance measuring units, video cameras, adjustable pressure and mounting system, force measuring sensors embedded in the sediment layer, auxiliaries to determine coefficients of static and sliding friction and displaced sediment volume.

The following measurements were made:

- measurement of drag and transverse force at towed elements and sub-systems
- measurement of actual penetration depth of gear elements during towing
- estimation of track depth and shape after towing
- estimation of displaced sediment volume by means of a laser technique and soil mechanical analysis of sediment movements
- measurement of pressure changes within the sediment, resulting from fishing gear elements running over the bottom.

Gilkinson *et al.*, (1998) performed instrumented tank tests with a simulated trawl door, making similar measurements to those above and observing the fate of clams implanted in the path of the door.

An additional type of tool which will permit the generalisation of results from studies like those above are numerical models of full gear systems (e.g., Vincent 2000). Optimisation of gear can be sped when calculations of the ground contact forces associated with alternative configurations can be modelled and calculated before the gear is made and tested.

5. Summary

This paper has categorised and summarised the known effects of fishing gear components on seabed and associated communities, noting which characteristics of fishing gear components are likely to affect the severity of each effect. The main components of each class of fishing gears were described and related to the above significant characteristics. We also listed the methods available to study such effects noting their applicability to the search for gear-specific modifications to reduce or eliminate effects.

Table 1 provides a summarisation of some of the relationships between characteristics of gear components and different types of effects of fishing gear on benthic communities. Unfortunately, many of these values do not have directed research to back them up and are only subjective estimates based on *ad hoc* observations. The research to develop and further specify more supportable values and categories for such a table would greatly improve our understanding and ability to reduce unintended effects of fishing on the seabed and associated communities. A key requirement for such studies will be tools to measure the effects on a scale applicable to individual gear components.

The categories of effects used here do not exactly match those used in the recent WGECO report (Table 2) (ICES 2000). Particularly in considering effects on species, they took a broader perspective, while this report has focused on effects that can be described in terms of the direct encounters of fishing gear with habitat and organisms. In comparing two sets of effect categories, it is noted that the three physical effects in the WGECO report (remove physical features, reduce structural biota and reduce complexity) relate primarily to the emergent structures and biota effects cited here. As sediment structures can be flattened or created through the sediment compression and penetration effects, there is also a connection between these and the physical feature and complexity effects. Some of the WGECO biological categories can be related to the direct effects discussed here (relative abundance, depth of burrowing, scavengers, fragility, sub-lethal effects). Others relate to the spatial (fragmentation and range reduction) and temporal (high vs. low turnover species) distributions of effects.

Researchers of fishing technology have and will continue to improve our understanding of the mechanisms by which fishing gear components affect seabed ecosystems. Such knowledge should be useful in planning and interpreting other research on the benthic effects of fishing gear. In a similar manner, studies focused on mechanisms need to be informed by knowledge of the benthic ecosystem to correctly interpret the correspondence between physical effects and vulnerabilities of the benthic communities. Knowledge of the mechanisms of benthic effects should also be applied to developing and evaluating gear-specific measures to mitigate effects. Determining which mitigation measures can achieve reductions in seabed effects while also maintaining effective capture of target species will require the fish behaviour research that has been an integral part of modern fishing technology research.

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Table 1 - Generalised concepts of the relationships[1] of several characteristics of fishing gear components on different effects of the fishing gear on seabed habitat and organisms.

Characteristic of Component	Sediment suspension and microinfauna	Sediment compression and infauna	Sediment penetration and infauna	Emergent structure and organisms - undercut	Emergent structure and organisms - rollover
Downforce	1	2	2	0	2
Horizontal contact area	0	-2	-2	0	0
Vertical cross section	2	0	0	-2	-1
Rigidity [2]	0	1	1	2	2
Towing force	0	0	0	2	2
Speed	2	0	0	1	1
Height of tow force	0	0	0	-2	1

1 – Associations (positive (+) or negative(-)) between characteristics of fishing gear components and categories of seabed effects.

–2 (strong negative relation), -1 (weak negative relation), 0 (little or no relation),

1 (weak positive relation), 2 (strong positive relation)

2 – Flexible objects may have high 'rigidity' if under tension

Table 2 – Categories of effects of fishing gear and benthic ecosystems used in this paper and in a review of the IMPCAT II report (ICES 2000).

ICES (2000)	**This paper**
Remove physical features	Sediment suspension and microinfauna
Reduce structural biota	Sediment compression and infauna
Reduce complexity	Sediment penetration and infauna
Sub-lethal effects	Emergent structure and organisms – undercut / detach
Fragment populations	Emergent structure and organisms - rollover
Reduce species range	
Change relative abundance	
Affect fragile species more	
Surface vs. deep burrowers	
Favour scavenging species	
Increase high turnover species	
Decrease low turnover species	