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Calculating Indices of Ecological Disturbance based on Fishing Effort Data

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CONTENTS

1. INTRODUCTION

Community level changes in both demersal fish and benthic invertebrates have occurred in the North Sea over the last century (For review see Greenstreet *et al.*, 1999; Clark & Frid, 200; Kröncke & Bergfeld, 2001). It is certain that the disturbance caused by fishing has contributed to these changes and in some cases the mechanistic link between a change (such as a decrease in dominance of species with particular life history characteristics) and a direct effect of fishing (such as size selective mortality) may be clear (see Jennings *et al.* 1998, 1999a). However, in most cases it is difficult to differentiate community level changes that could be the result of a combination of climatic effects, a variety of anthropogenic disturbances and biotic or physical changes as a result of natural variability.

In order to further our understanding of how fishing contributes to community level changes it is vital that we first understand the actual direct ecological disturbance that occurs as a result of fishing. This is the mortality of animals and the change in habitat that occurs in the path of the fishing gear. It is also important that we are able to map the distribution of the activity of fishing in time and space at scales that are relevant to fish and invertebrate communities. In a previous review of the ecological disturbance of fishing to demersal fish and benthic invertebrate communities, the different sources of disturbance were described (Robinson, 2003 – MAFCONS Deliverable 3). At the same time, the availability of data and literature to quantify and qualify these direct effects was also considered.

In summary, the main effects of fishing to demersal fish communities include:

1. Changes in competition and predation due to the removal of large numbers/biomass of target and bycatch fish (and in some cases invertebrates) from the system.
2. Changes in the availability of food resources due to the mortality of fish and benthic invertebrates (decreases due to the removal of targets and bycatch from the system and increases due to discards/escapees and moribund material on the seafloor due to gear contact).

3. Changes in habitat structure important to fish, due to the physical contact with gear and the mortality of habitat modifying invertebrates.

The main effects of fishing disturbance to benthic invertebrates include:

1. Changes in competition and predation due to the removal of large numbers/biomass of target and bycatch invertebrates and fish from the system (increases and decreases in competition and predation possible).
2. Changes in the availability of food resources due to the mortality of benthic invertebrates and fish (decreases due to the removal of targets and bycatch from the system, increases due to discards/escapees and mortality on the seafloor following gear contact).
3. Changes in habitat structure important to benthos, due to the physical contact with gear and the mortality of habitat modifying invertebrates (benthic invertebrates have close associations with the physical habitat throughout their life cycles and thus habitat change is likely to be more important to benthic invertebrate communities than to fish).

To improve our ability to resolve where these changes are occurring we must first be able to quantify the actual ecological disturbance that occurs. Certainly, if we are ever to predict the community level response to a change in fishing practice, we should know the level of mortality experienced by the species making up that community given a particular amount and type of fishing activity. We ought to also account for any other direct effects, such as mortality to other components of the ecosystem or changes in habitat that might also affect the overall response. In this report, the development of a number of potential indices of ecological disturbance due to bottom fishing is described.

2. DESCRIPTION OF INCIDES

Ideally an overall index of fisheries disturbance should include a quantification of the total mortality (landings, discards and other) induced by all fishing activities in a given area, over a given time period with weighting for the associated alteration of habitat that occurs (ICES, 2004). Until now, indices of fisheries disturbance have been derived directly from the fishing effort data with no weighting for how factors such as gear type will cause variation in mortality. Fishing effort data should, however, be available for all countries fishing in the North Sea and the number of hours fishing will act as the basic input data for all indices except those that are based only on the landings data. It is considered that two separate but complimentary approaches are required for benthic and demersal fish communities, because their movement rates mean that they are distributed on different scales and because the mortality they sustain due to fisheries is mainly in the catch for fish but mainly on the seafloor for invertebrates. At this time, indices described are not inclusive of habitat alteration.

In predicting the level of fishing disturbance to demersal fish communities all direct mortality of the species making up that community should be accounted for (including landed fish, discarded fish and fish that die due to damage sustained in contact with the gear). For commercial species such as cod and plaice, landings and discards data should be available from all countries fishing in the North Sea. However, discards data are only available for a sample of each fleet and so mortality based on discards would need to be raised to the scale of the fleet. Data on non-target species are less available and in these cases mortality may need to be estimated based on the assumption that non-target species will have the same catch rates as non-target species with similar characteristics and of the same size class. In this report an index for fisheries disturbance to the North Sea demersal fish community is described based on such an approach (section 2.2).

In predicting the level of fishing disturbance to benthic invertebrate communities, ideally, as with fish, all direct mortality of the species making up that community should be quantified. However, there are a lot less data available for the mortality of invertebrates in the catch at the fleet and regional scale. Landings and discards data exist for some commercial species but these make up a very small number of the species that are actually caught and either landed or discarded in North Sea fisheries (see Robinson, 2003 for detail). For non-target species of the benthic community it will be more difficult to predict the mortality sustained in the catch. It is known that a large biomass of non-target invertebrate species is discarded from North Sea demersal fisheries and using the results of a number of small scale studies of the discards of invertebrates it may eventually be possible to weight invertebrate mortality from discards.

The majority of the invertebrates that are killed by demersal fishing die as a result of contact with the fishing gear as it passes over the seafloor (towpath mortality) (see Robinson, 2003 for detail). This mortality is not recorded in the catch data because the animals are killed on the seafloor and not caught in the net. In this report a modelling approach is described that will be used to predict the overall mortality of a community based on the composition of the species found, the pattern of distribution of fishing effort, the quantity of fishing effort in a described area and the mortality of species per unit of fishing effort (see section 2.3). Benthic invertebrate communities operate on much smaller spatial scales than do fish communities. Thus the microscale distribution of fishing effort can have important consequences on the overall mortality of the community at the scale at which the effort data are available - the ICES rectangle scale (approximately 30x30 nautical miles). The modelling approach described is dynamic in space and time, which importantly allows for the exploration of how the distribution of fishing effort affects overall mortality of the benthic community.

2.1 Basic Input data – International Fishing Effort

2.1.1. Updating the international database

Actual data for fishing effort (i.e. the number of hours or days fished by a given gear in a given area) exist for all countries fishing in the North Sea area. An international fishing effort database was constructed for the years 1990-1995 by Jennings *et al* (1999b) and updated for 1998 by Callaway *et al.* (2002). This included all demersal effort for vessels fishing in the North Sea area and landing in either the UK (England, Wales, Northern Ireland and Scotland), The Netherlands, Germany, Denmark or Norway. In this report the international database has been updated and the results are presented here for the years 1997-2002. All demersal effort for vessels landing in the UK, The Netherlands, Germany and Norway are included. It is hoped that the effort data for vessels landing in Belgium will be provided in the near future, but there are currently ongoing problems with access to the basic effort data for landings in France and Denmark. The most resolved differentiation of effort by gear common to all fleet data is that of otter trawl and beam trawl. Thus, all effort data were aggregated to total hours fished due to either otter trawls or beam trawls. Since data are collected at the scale of the ICES rectangle this is the spatial scale at which the distribution of effort for each year is presented (Figures 1-3).

In compiling the new international dataset, a number of problems with the original database have been identified. Most notably it has been found that since at least 1997 the Scottish fleet effort data for ‘hours fished’ are no longer reliable. Traditionally the number of hours fishing was estimated on the basis of the number of days fishing per trip and the skipper’s verbal report of his daily fishing activity. In the absence of the latter, the number of hours spent fishing per day was estimated based on the inspector's knowledge of each particular fishery. This became more formalised in the early 1980s with the introduction of a logbook system, but notification of the actual number of hours spent fishing was still not compulsory, although most skippers did provide this information. Where these data were missing, fisheries inspectors continued to estimate them following the original procedures (Greenstreet *et al.*, 2004 - MAFCONS Deliverable 12a).

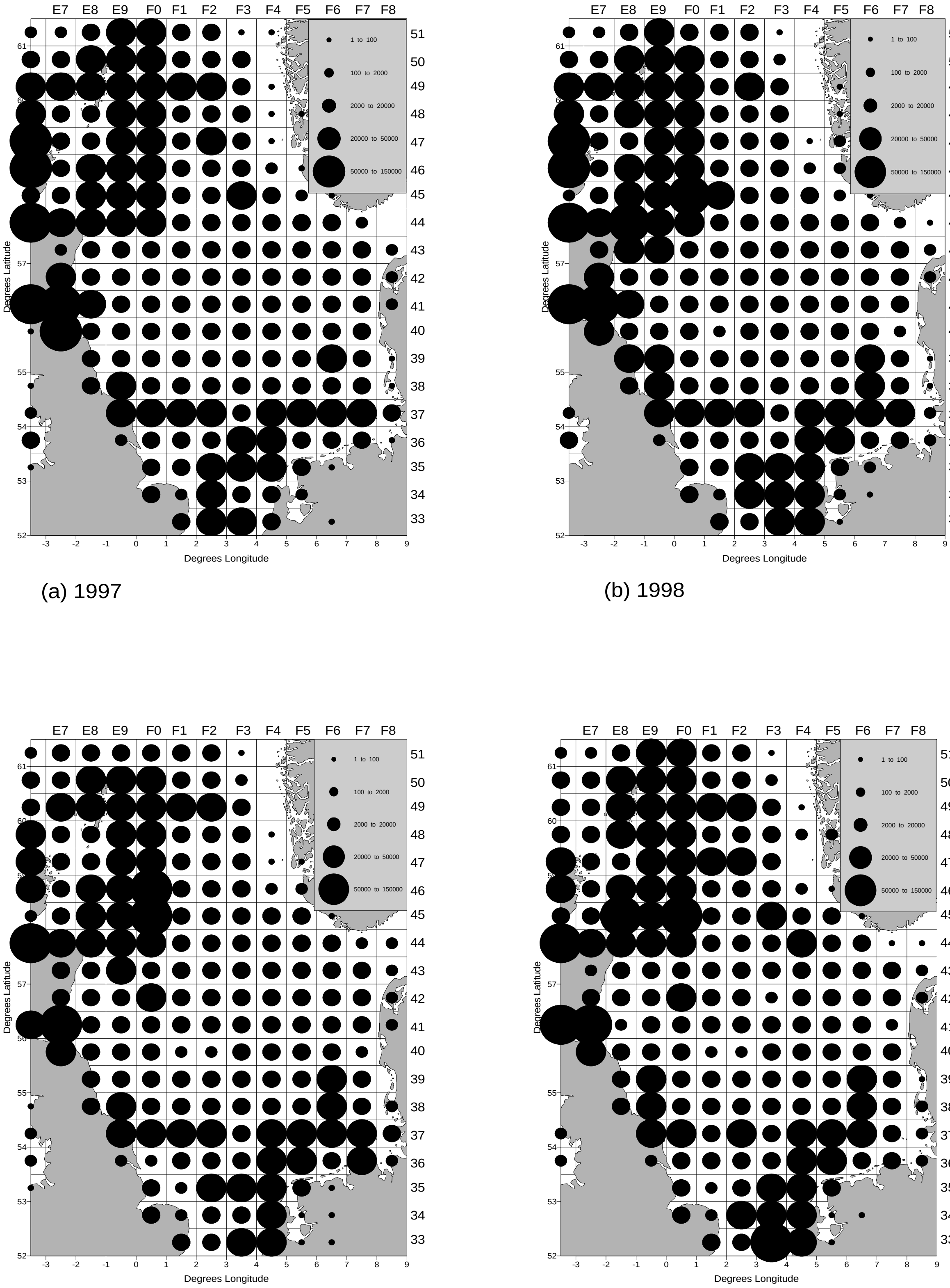
Over the last 10 years, the processing of logbook reports for the Scottish fleet has become more centralised and the inspectors responsible do not have the same experience of the local fishing fleets. As such, rather than entering hours fished based on a “best guess” they have stopped entering hours fishing entirely and so, where no record has been made by the fisherman in the logbook, the effort assigned to that particular trip is zero (*pers comm.*, Aileen Shanks, 2004). Thus, based on the Scottish effort records alone, there is a major underestimation of fishing activity. As a result of this, all Scottish effort for the updated international dataset presented here are derived from the landings data, based on the number of days at sea per trip multiplied up to the number of hours fishing by assuming an average 17-hour day fishing (Piet *et al.*, *submitted*). In the landings records the total number of days fishing per trip and the ICES rectangles visited per trip are recorded. At this stage it has been assumed that the effort is spread evenly across all rectangles visited. The Dutch data are also based on 'days at sea' records and effort has been converted to hours fishing based on the same assumption of the number of hours fished in an 'average fished day'. However, the Dutch effort per trip has been distributed in space *pro rata* based on the quantity of landings per ICES rectangle visited. This assumes even catch per unit effort (CPUE) but may be more realistic than simply distributing total effort evenly across all rectangles visited.

2.1.2. Distribution of international effort

There are clear patterns in the distribution of both Otter and Beam trawl effort and of total demersal effort for each of the years 1997-2002 and there is little interannual variation in these patterns (Figures 1-3). For total effort of all demersal gears, the majority of the North Sea has been fished with between 2000 and 20,000 hours per year. However, in the southern North Sea and the northwest North Sea effort exceeded 20,000 hours per year. In all years there were also a number of ICES rectangles along the northeast coast of the United Kingdom where effort exceeded 50,000 hours per year. Although the northwest North Sea has mainly been fished in excess of 20,000 hours per year, there is an area directly north of Scotland (between 1.5 and 3 degrees west) where effort was consistently lower (Figure 1).

Otter trawls account for most of the effort in the northern North Sea and along the eastern coast of the UK, and overall, their distribution is consistent across years (Figure 2). Beam trawl effort is mainly found in the central and southern North Sea with the highest effort concentrated along the continental coast of Europe. Some beam trawling has taken place in the northern North Sea but this is very low in quantity in comparison with the amount of otter trawling that takes place in that region (Figure 3).

Figure 1 **The distribution of total fishing effort of all demersal gears for the years 1997-2000 (based on the international dataset compiled for this report – see Section 2.1).**



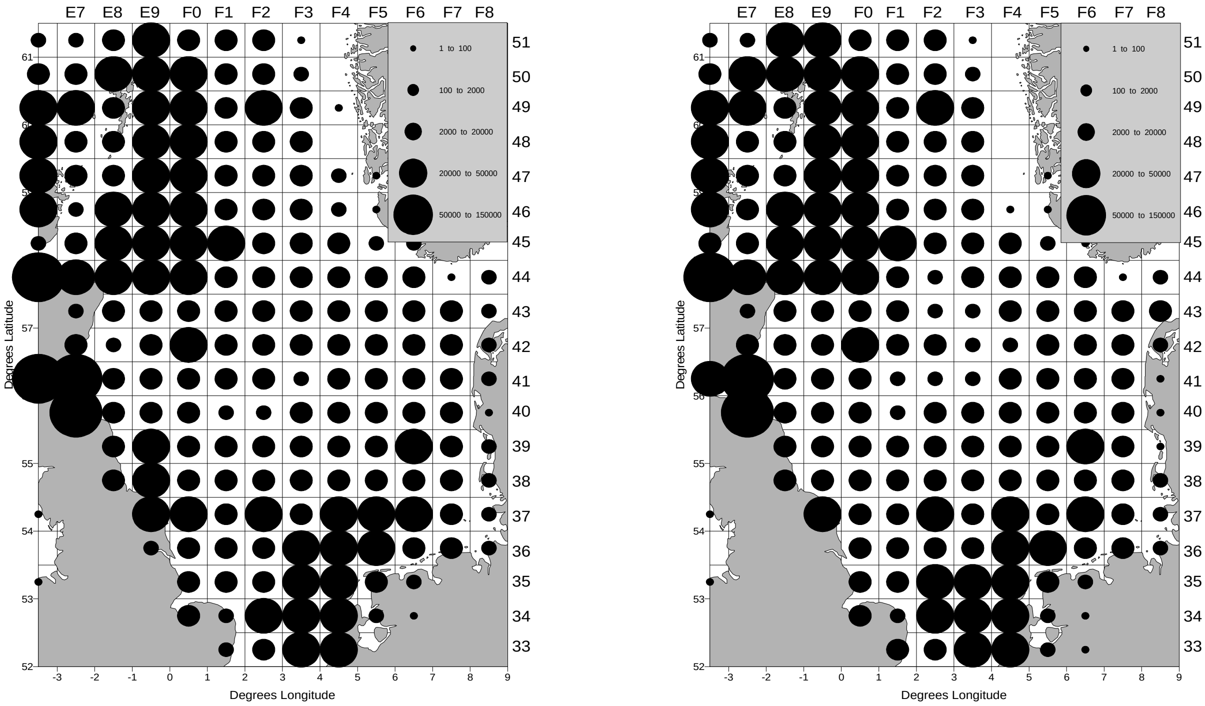
(a) 1997

(b) 1998

(C) 1999

(d) 2000

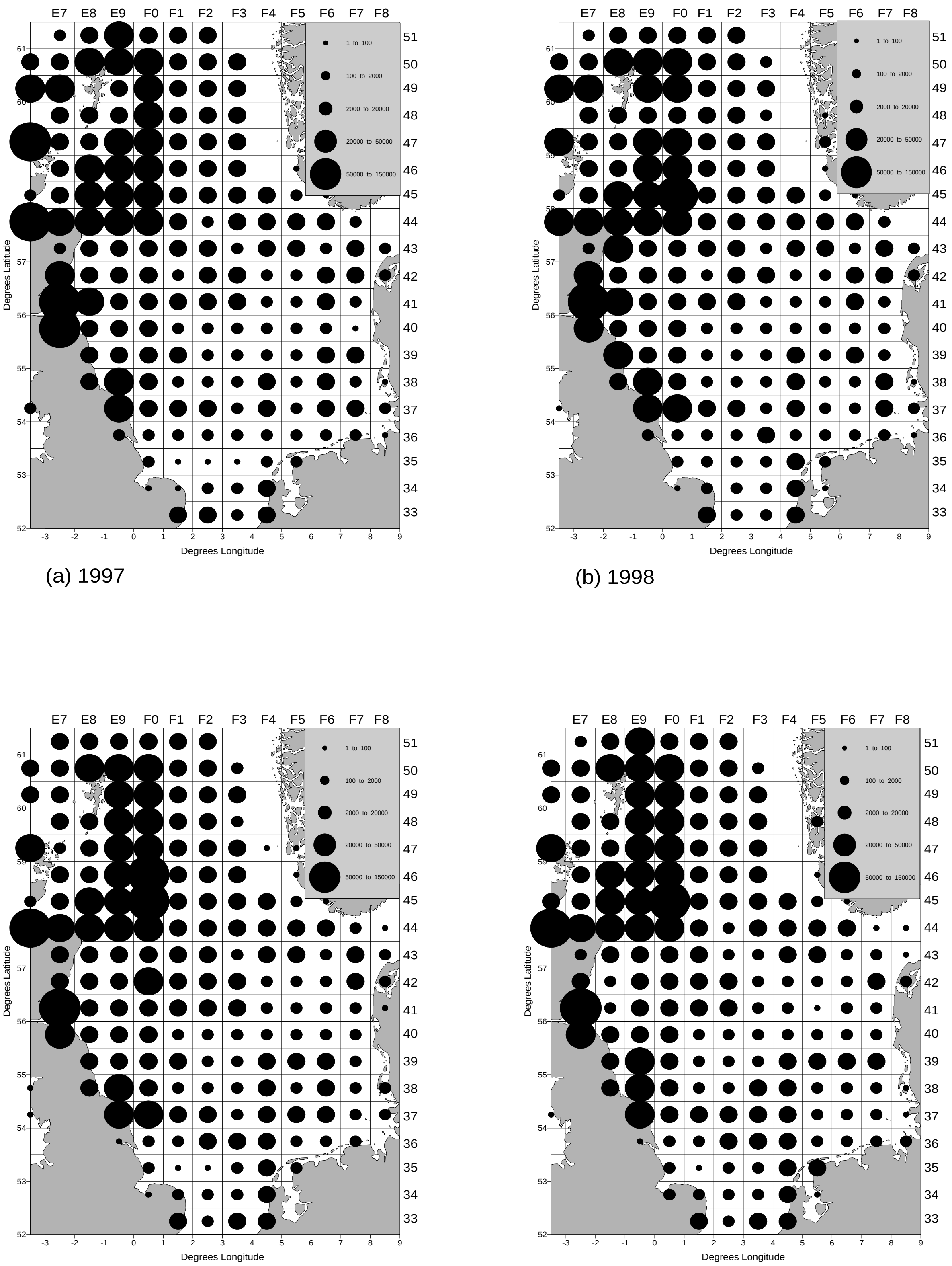
Figure 1 **The distribution of total fishing effort of all demersal gears for the years 2001 and 2002 (based on the international dataset compiled for this report – see Section 2.1).**



(e) 2001

(f) 2002

Figure 2 **The distribution of total fishing effort by Otter trawls for the years 1997-2000 (based on the international dataset compiled for this report – see Section 2.1).**



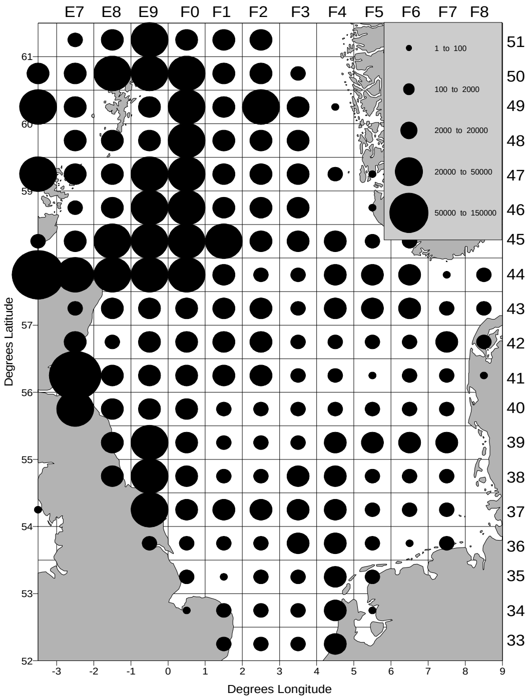
(a) 1997

(b) 1998

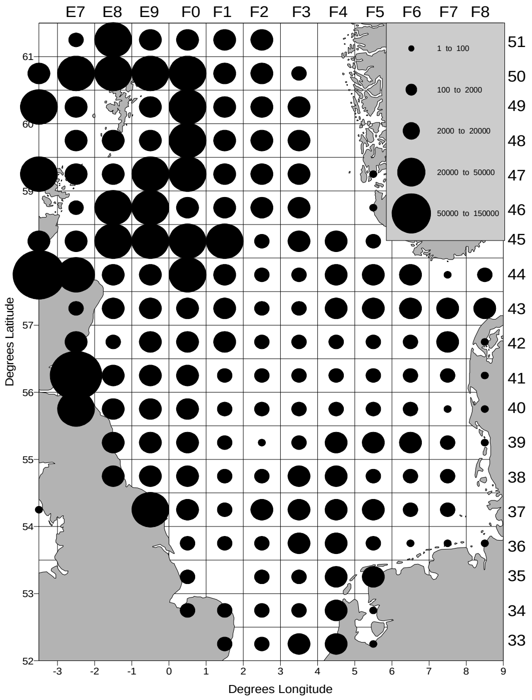
(c) 1999

(d) 2000

Figure 2 **The distribution of total fishing effort by Otter trawls for the years 2001 and 2002 (based on the international dataset compiled for this report – see Section 2.1).**

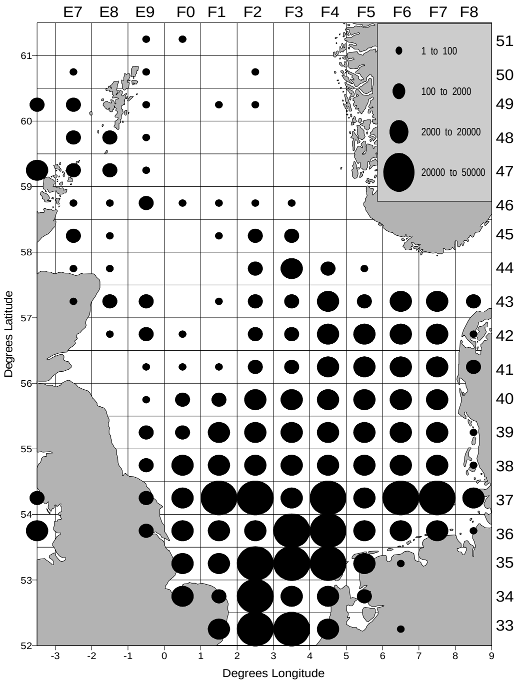


(e) 2001

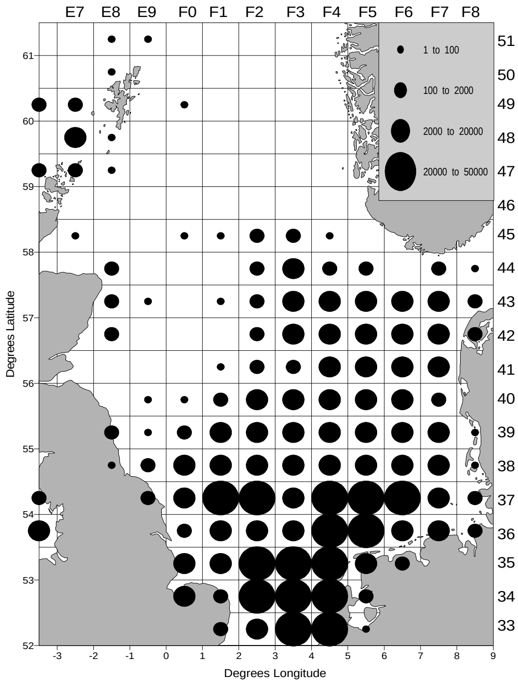


(f) 2002

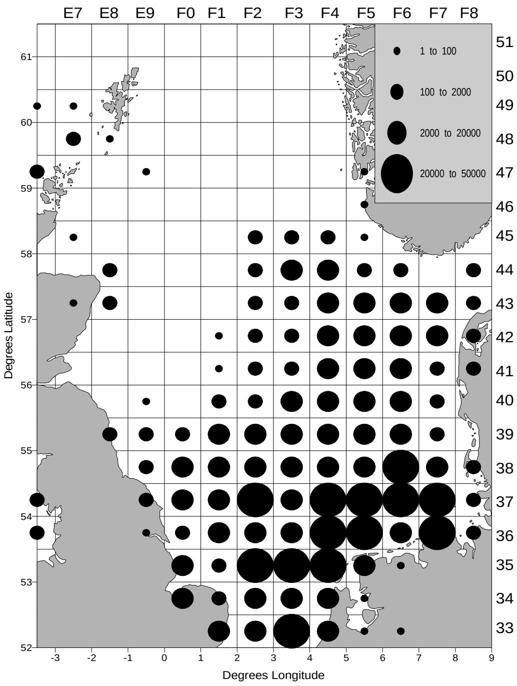
Figure 3 **The distribution of total fishing effort by Beam trawls for the years 1997-2000 (based on the international dataset compiled for this report – see Section 2.1).**



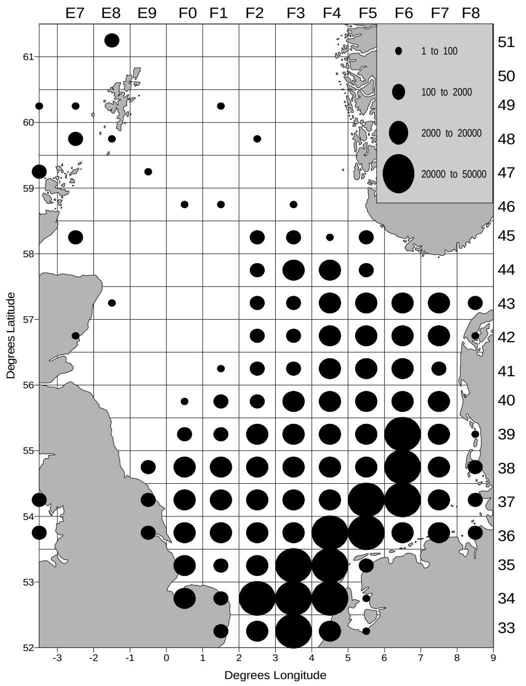
(a) 1997



(b) 1998

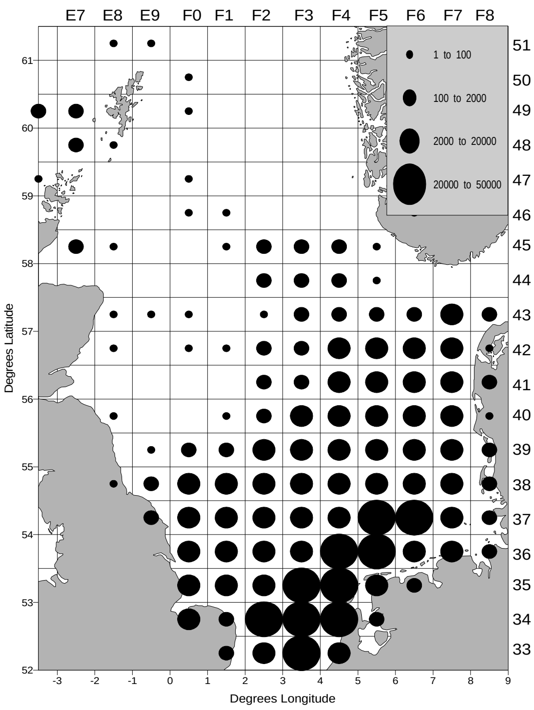


(c) 1999

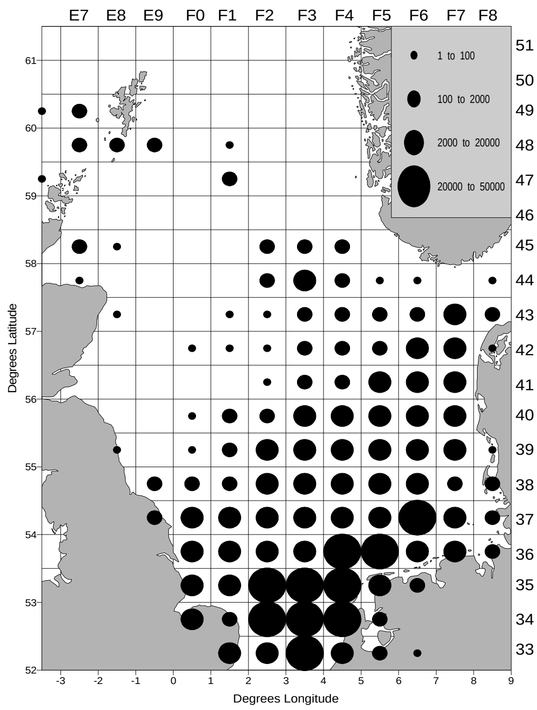


(d) 2000

Figure 3 **The distribution of total fishing effort by Beam trawls for the years 2001 and 2002 (based on the international dataset compiled for this report – see Section 2.1).**



(e) 2001



(f) 2002

2.1.3. Conclusions and future work

In comparison with the distribution of international effort presented by Callaway *et al*. (2002) for the year 1998 there appears to be a lack of effort in the northeastern North Sea for the years presented here. It is possible that this is due to a change in fishing practise in recent years, but more likely due to the lack of Danish data in the updated database; data that were included in the 1998 database. None of the international databases of effort (Jennings *et al.,* 1999b; Callaway *et al.,* 2002 and this report) have included French or Belgian data but Jennings *et al*. (1999b) suggested that this may translate to an underestimation of fishing effort in some areas of the southern North Sea by over 50%. Further attempts will be made to access the Danish, Belgian and French data before the database is finally updated to include international effort for 2003 and 2004.

For the Scottish and Dutch data, effort is recorded as 'days at sea' and the number of hours fishing has been estimated here using an 'average fished day' of 17 hours. This was based on information about the Dutch beamtrawl fleet operating in the southern North Sea, as there are more readily available information on the detailed fishing practises of this fleet (Rijnsdorp *et al.* 1998; ICES, 2004; Piet *et al.*, *submitted*). For the purpose of this report it has been assumed that the Scottish fleet behaves in a similar fashion to the Dutch beamtrawl fleet. Work will now be undertaken to investigate the availability of information on the fishing practices of the Scottish fleet and where necessary adjustments will be made to the hours fished by that component of the international effort. At the same time, the spatial distribution of hours fished by the Scottish fleet within single trips will be investigated, as it has been assumed to be even across all ICES rectangles visited in a trip at this stage. Finally, once data have been fully verified and updated to the most recent years, they will be used as input data for the two indices described below.

2.2 Index 1: Ecological Disturbance based on Fisheries Mortality to the Demersal Fish Community

2.2.1. Approach

Fishing mortality estimates for the North Sea are available for 10 commercial fish species that are assessed routinely to provide annual advice on Total Allowable Catches (TACs) (ICES 2002, 2003). The principal method used is the Virtual Population Analysis (VPA), which requires reliable estimates of the age composition of the total international catches and allows an evaluation of the historic development of fishing mortality and stock numbers by age group up to the present day. While this method yields converged parameter estimates for year classes that have reached the end of their life, estimates for recent years will vary to some extent during subsequent assessments, because of uncertainty about the proportion still surviving. To obtain the best possible estimates, a variety of statistical methods have been developed that use additional information on catch per unit of effort (CPUE) derived from commercial and/or research vessel data to tune initial estimates of fishing mortality (Shepherd 1999). Based on these methods it is possible to calculate total fishing mortality to these commercial species across the North Sea area.

To provide an overall index of disturbance at the community level the same information is required for all other species making up that community. For non-target species, however, the data necessary to run VPA-type models are usually not available and other approaches are therefore required. For benthic invertebrate species, such approaches exist and typically involve a combination of data on the abundance of the biota (based on spatially disaggregated, absolute density estimates), fishing effort and the impact of a unit of effort (i.e. a single pass of a trawl) on these biota (Piet *et al*. 2000; Duplisea *et al*. 2002) (see Section 2.3). In this report a similar approach is described for non-target fish species where the direct effects of fishing are expressed as the mortality of a specific fish species. In contrast to benthos, quantitative estimates of the impact of a unit of effort are not available for non-target fish. Therefore methodology aimed at delivering this type of information has been developed by Piet & Star (working paper, 2005) and this is described here.

For each ICES rectangle the mortality of each demersal fish species is determined by the integration of:

- The absolute abundance of that species; i.e. the number of fish present in an ICES rectangle. As this abundance is based on survey data that are stratified according to ICES rectangles, this is the spatial resolution used in the model (this is also the spatial resolution of the fishing effort data).
- The frequency with which the spatial unit is trawled; this is a measure for the amount of fishing effort in an area derived from the basic fishing effort input data.
- The impact of a single pass of a gear. Here this is expressed as the fraction of the total abundance retained by the gear; this is the catch efficiency of a trawl gear. Catch efficiency ranges from 0 (no effect) to 1 (maximum effect). Catch efficiency is influenced by many factors, ranging from environmental and biological factors to gear specific factors such as mesh size and gear type (Wardle 1988; Wileman 1991).

Total mortality of a species in the North Sea is the sum of the mortalities over all spatial units and total mortality at the community level can then be calculated by summing all single species values.

2.2.2. Calculating absolute abundance in a given area

To estimate the abundance of each species a slightly modified version of the method developed by Sparholt (1990) will be applied. Based on Sparholt's method the abundance of each species is estimated by combining MSVPA-based abundance estimates of target species with survey catches that include both target and non-target species and this is further improved by including a size component. MSVPA provides the stock abundance in the North Sea of each commercial species-at-age at the start of the year (ICES, 2002). It is assumed here that this estimate is the most accurate available. The catch rate of each commercial species-at-age in the North Sea is known from the IBTS (international bottom trawl survey) survey. The catch rate is usually very variable between different hauls, and so it is important to use the mean catch rate of many hauls to reduce this variability.

Availability is calculated as MSVPA abundance (n) divided by IBTS catch-rate (n/hr). For the commercial species, availability can be determined per age group and then each species can be divided into 5-cm length groups up to forty centimetres, above which availability is assumed constant. Within such a length group the proportion of fish of a particular age is calculated using age/length keys (e.g. a specific size group may consist of 83% of age 1 and 17% of age 2) and the availability of that size-group is the weighted average of the age-based availabilities. Following Sparholt (1990) the commercial species are divided into seven groups: (1) cod, haddock, whiting, (2) Norway pout (3) herring and sprat, (4) sandeel, (5) mackerel, (6) plaice and (7) sole. If more than one species is present in a single group (e.g. group 1), the availability of each species is taken as an average by using the unweighted mean. All other species caught are allocated to one of these seven groups, and it is assumed that a non-target fish of equal size as a commercial fish in a particular group also has an equal availability. Abundance per species is then calculated by multiplying the IBTS catch rate (n/hr) with the availability of that species. If for a particular Sparholt/size-group there is no value for availability in a particular year then the mean availability of that size-group can be used and if that is also missing, the availability of the Sparholt group can be used to calculate abundance.

2.2.3. Frequency of fishing for a given area

In Piet *et al.* (submitted) the frequency with which an area is trawled is suggested as the most appropriate measure of the fishing impact. Piet *et al.* (submitted) also provide quantitative data on relevant fishing parameters (e.g. the proportion of the day actually spent fishing, fishing speed) and gear characteristics (e.g. width of the gear), which allows for the transformation of the conventional measures of fishing effort into trawling frequency. In the initial exploration of this method (Piet & Star, working paper 2005), the international otter- and beam trawl effort data for 1990-1995, as compiled by Jennings *et al.* (1999b), were used to calculate fishing frequency. This will be updated to include the more recently compiled fishing effort data once any queries related to these have been rectified (see Section 2.1 above).

Trawling frequency (F_t) is calculated as:

$$F_t = Eff_w \times T_F \times S \times S_{ICES}^{-1}$$

Where:

F_t = Frequency trawled

Eff_w =Effective width (m)

T_F =Time Fished (s)

S=Speed (m/s)

S_{ICES}=Surface of ICES rectangle (m^2)

2.2.4. Calculating the mortality of each species: catch efficiency

Two potential methods to estimate mortality rates are (1) an extension of Jones's (1981) length cohort analysis and (2) an approach based on estimates of swept areas from fishing fleets (Pope *et al.*, 2000). The latter method may be easier to use as, unlike the length cohort analysis method, the swept area method does not require sampling of commercial by-catches and the required data on the distribution and abundance of non-target species are often available from surveys (Kunitzer *et al.*, 1992; Knijn *et al.*, 1993).

In the approach described by Piet & Star (working paper, 2005) the direct ecological disturbance of a fishery on each fish species has been determined according to Pope *et al.* (2000), with improvement made with regard to the assumption of a 100% catch efficiency. The interaction between fish and bottom trawls is a complex issue and it is determined by fish behaviour in relation to gear characteristics, making the catch efficiency of a gear hard to quantify (Wardle, 1988; Dickson, 1993). Based on the available literature (Engås and Godø, 1989; Weinberg *et al.* , 2002), a conceptual framework in which catch efficiency is determined by four factors has been developed.

These four factors are:

- Positioning of the species in the water column
- Herding behaviour of the species
- Escape below footrope
- Retention in the net

There are numerous other factors that may effect catch efficiency. For example, vessel noise (Dickson, 1993), visibility, fishing speed, density-dependent catchability, diel variation and mesh shape (Robertson *et al.* 1988; Wardle, 1988; Godo et al., 1999; Weinberg *et al*., 2002; Benoit and Swain, 2003). However, the lack of quantitative data on these factors has prevented their incorporation in the method described here.

Positioning in the water column of fish relative to the gear determines the likelihood that they will enter the mouth of the net. As there are no quantitative data on this, it has been assumed (based on professional experience, Piet *pers comm*., 2005) that 80% of roundfish are positioned such that they will not succeed in escaping over the headline of the otter trawl. As a beam trawl has a markedly lower vertical opening, the proportion of roundfish entering the mouth of the gear is reduced to only 30%, with the assumption that 70% will succeed in passing around the gear. It has been assumed that flatfish are not able to pass over the top of either type of gear.

Not all fish species swimming between the boards of otter trawls (otter boards) are herded towards the mouth of the net (Wardle, 1986; Engås & Godø, 1989; Dickson, 1993; Ramm & Yongshun, 1995). For roundfish, Engås & Godø (1989) compared the catches of cod and haddock between gears with different sweep lengths. With increasing door-spread, a significant increase was found in catches for cod and haddock, especially for larger fish lengths (Engås & Godø, 1989). In this approach, herding is assumed to be related to difference in door-spread between gears. From Engås & Godø (1989) an average herding effect per meter door-spread of 0.067 has been used. It has been assumed that a standard otter trawl has a sweep-length of 40m, a door-spread of 58m, a net opening of 19m, and a difference of 39m in width between door-spread and net opening (Engås and Godø 1989). As a net opening equal to the door-spread (i.e. 58 m) has been assumed the correction factor for the proportion of fish that do not reach the mouth of the net is calculated as $(39*19*0.067)/58=0.86$. No quantitative data on herding were found for flatfish. According to Winger (1999) larger flatfish should be capable of reaching the net opening. However, Winger (1999) assumed a towing speed markedly lower than that of the fishing fleet in the North Sea and as Wardle (1988) showed that the endurance rapidly decreases with increasing speed a correction factor of 19/58 (i.e. no herding) for flatfish has been assumed.

The proportion of fish passing below the footrope is dependent on species, size, fishing speed and gear construction (Engås and Godø 1989; Dahm, 2000; Weinberg *et al*., 2002). Estimation of the proportion passing below the footrope results in an efficiency of 0.95 for roundfish while for flatfish a footrope factor of 0.5 for smaller (< 0.25cm) flatfish and 0.85 for larger (≥ 25cm) flatfish has been assumed (Weinberg *et al*. 2002).

The values for the positioning, herding and footrope (Small/Large fish) factors are assumed constant and these factors are multiplied to result in a final efficiency factor. The results of the initial calculation of efficiency by Piet and Star (working paper, 2005) are shown in Table 2.2.4.1 below. Thus a beam trawl is more selective than an otter trawl for flatfish (1 versus 0.12 for small and 0.21 for large flatfish) and less selective for roundfish (0.3 versus 1 for roundfish).

Table 2.2.4.1. Factors used in the disturbance index for calculation of catch efficiency for beam trawl (BT) and otter trawl (OT) and two different fish types, roundfish (RF) and flatfish (FF).

SMD indicates the factor is fish- and mesh-size dependent. The footrope factor is divided in a factor for smaller (S, < 25 cm) and a factor for larger (L, ≥ 25 cm) fish. The overall factor (S,L) is calculated by multiplying the positioning, herding and footrope factor.

Gear	Fish type	Factor						
		Positioning	Herding	Footrope (S)	Footrope (L)	Overall (S)	Overall(L)	Mesh
BT	RF	0.3	1	1	1	0.3	0.3	SMD
BT	FF	1	1	1	1	1	1	SMD
OT	RF	0.8	0.85	0.95	0.95	0.65	0.65	SMD
OT	FF	1	0.3	0.4	0.7	0.12	0.21	SMD

The final efficiency factor will allow for the calculation of the proportion of each species that are caught by either gear. However, many fish are considered to escape from the cod-end of the gear (Wileman *et al,*. 1996; Millar & Fryer 1999) and therefore it is also important to include gear selectivity in the final calculation of catch efficiency. Gear characteristics such as mesh size, cod-end extension length, cod-end diameter or mesh-shape have a significant influence on the selection of fishing gears (Robertson *et al.*, 1988; Beek *et al.*, 1981, 1983; Reeves *et al.*, 1992; Zuur *et al.,* 2001). The proportion of fish that are retained in a net is calculated as a function of mesh size using cod-end selectivity data. Wileman (1991) summarised several gear selectivity studies carried out over a period of more than 30 years. Several species in two types of gear were distinguished: seven species in the otter trawl (OT) and two in the beam trawl (BT) (Table 2.2.4.2).

Table 2.2.4.2. Gear selectivity parameters, selection factor and selection range for different species and species groups.

Two types of gear have been used. OT=Otter trawl, BT=Beam trawl. Mean values for roundfish and flatfish species have been calculated. Note that the mean value for flatfish does not include sole.

Species	Gear type	Selection factor	Selection range (cm)
Cod	OT	3.0	7.2
Haddock	OT	3.1	6.6
Whiting	OT	3.5	6.6
Saithe	OT	4.3	5.7
Dab	OT	2.5	1.9
Plaice	OT	3.3	1.6
Sole	OT	3.4	4.1
Dab	BT	2.2	4.1
Plaice	BT	2.2	3.6
Sole	BT	3.2	3.9
Roundfish	OT	3.5	6.5
Flatfish	OT	2.9	1.8
Flatfish	BT	2.2	3.9

A logistic curve is used to describe the relationship between the length of a fish and the proportion of a population that is retained in a net (Casey 1996):

$$S_L=\{(3^{(L50-(L+\Delta L/2))/(L50-L25)})+1\}^{-1}$$

Where:

S_L = The proportion of the population of length L and class width Δ L that is retained.

L50 = The length of which 50 percent of the population entering the net is retained (cm)

L25=The length of which 25 percent of the population entering the net is retained (cm)

L50 and L25 are calculated from the selection factor (SF) and selection range (SR) according to Wileman (1991) and Wileman *et al.* (1996).

L50 = SF * M

L25 = L50-(SR/2)

Where:

SF= Selection Factor

M= Mesh size (cm)

SR=Selection range (cm)

Sufficient quantitative information to determine cod-end selectivity are only available for a number of commercial species (Maclennan *et al*., 1992) and so, Piet and Star (working paper, 2005) determined generic roundfish and flatfish selectivity parameters and applied those to the non-target species.

2.2.5. Modelling the total fisheries mortality to the demersal fish community

At this stage, work is still being undertaken to refine the main input variables as described above. Initial calculations of total fisheries mortality by Piet and Star (working paper, 2005) were compared with validation data sources such as MSVPA mortality estimates, landings data and discards monitoring data and for some species large differences were found between the modelled outputs and the validation data. Investigations into these discrepancies are currently being undertaken in order to improve the accuracy of the input variables where possible. Following this, the model will be updated with recent data for fish abundance and frequency of fishing in each rectangle in order to generate fishing disturbance data for the total fish community.

2.3 Index 2: Mortality of Benthic Invertebrates in the Towpath of Demersal Gears

2.3.1. Approach

Fishing mortality estimates based on routine ICES stock assessment are only available for a very small number of benthic invertebrate species and the methods used for these species (e.g. *Nephrops*) are thought to be inappropriate because they rely on assumptions that are more suitable for finfish stocks (Marrs *et al*., 2000; Marrs *et al*., 2002; see detail in Robinson, 2003). In this report, an approach to estimate fisheries mortality of the whole benthic community based on the same principles as that described for the fish community disturbance index (section 2.2.1) is described. The approach involves modelling the interaction of a given distribution of fishing effort with a particular community of invertebrates, with overall mortality being dependent on the motility of the animals and the proportion of animals killed by a single pass of the gear for the species making up that community. This approach builds on previous models (Piet *et al*., 2000; Duplisea *et al*., 2002) by moving to a dynamic framework in both time and space.

The three main input variables are:

- The absolute abundance of animals in each species; i.e. the species composition and total abundance for each ICES rectangle.
- The distribution of fishing effort across and within individual ICES rectangles.
- The impact of a single pass of a gear expressed as the proportion of each species killed in a single pass of the gear (encounter mortality). As gear design does affect this, encounter mortalities will be calculated for both otter trawls and beam trawls.

2.3.2. Calculating absolute abundance in a given area

Routine assessments of abundance, such as the international bottom trawl survey (IBTS) for demersal fish, are not undertaken for benthic invertebrates across the North Sea. However, a number of large-scale studies have been undertaken in recent years (e.g. the North Sea Benthos Project – surveys in 1986 and 2000/2001 and the EC

MAFCONS and BIODIVERSITY project surveys). For each ICES rectangle the total number of individuals of each species for that area will be calculated based on all the data available from the infaunal and epifaunal samples taken in each year. Where possible, catchability coefficients will be applied to account for the underestimation of abundance that would be found for some species due to their low representation in the samplers used.

2.3.3. Distribution of fishing effort

The basic input data at the ICES rectangle scale will be the international effort data as described in section 2.1. Effort will be divided into the total hours by beam and by otter trawl gears as encounter mortalities will differ for these gears. ICES rectangles cover an area of approximately 30*30 nautical miles and studies of the Dutch beamtrawl fleet in the southern North Sea suggest that fishing effort is not distributed randomly or evenly at that scale (Rijnsdorp *et al*., 1998; Piet *et al*., 2000; Piet *et al*., *submitted*). In the index of disturbance described in section 2.2 for fish communities it is assumed that effort is spread evenly across the total area. This assumption is acceptable for fish, because their high motility means that any small-scale effects of clumping in fishing activity will be inconsequential to the overall effect per rectangle.

Benthic invertebrate species have much lower motility than fish. Many species will only move on the scale of metres in a day if at all, with the highest motility species, such as swimming crabs, being unlikely to move beyond the scale of a square kilometre. For these communities the microscale distribution of fishing effort within each ICES rectangle will have important consequences for the overall mortality suffered. For example, because animals can only be killed once, if the majority of effort is clumped in a small area of the rectangle and that area is repeatedly fished over a year, the total mortality of invertebrates at the scale of the whole rectangle is likely to be less than if the same amount of effort is spread evenly across the whole rectangle. However, it is also important to consider that animals with high motility may actually suffer higher mortality with a clumped effort distribution if they actively move into areas that are being regularly fished. Studies of recently trawled sites have shown that highly motile scavenging species such as swimming crabs, hermit crabs and starfish do move into disturbed areas and in these cases if trawling is frequent enough these species may actually suffer higher overall mortality (e.g. Kaiser & Spencer, 1996).

In order to account for these factors the modelling framework is based on a grid of cells making up each individual ICES rectangle (See Box A below). Within each cell there will be a community of invertebrates made up of a number of characteristic species types of differing motility (and vulnerability – see section 2.3.4 below). The composition of the community will be determined by the absolute abundance values derived from the survey data as described in section 2.3.2. The model will be dynamic in space and time such that, dependent on the motility of the animals and the proportion of each population killed in each cell, individuals will move by diffusion within and between cells. Given that Rijnsdorp *et al.* (1998) found that fishing effort distribution can be described as random at the scale of 1*1 nautical mile, it is likely that the individual cells will be set at this size, such that the overall ICES rectangle is made up of 900 individual cells. Total fishing effort will then be distributed across the cells within each ICES rectangle based on a particular scenario of fishing behaviour. Scenarios tested should include:

- Random in space and time.
- Even in space and time.
- Clumped in space and even in time.
- Clumped in space and clumped in time.
- Even in space and clumped in time.

Ultimately, fishing distribution scenarios will be validated using existing microscale distribution data. This is already available for the Dutch beamtrawl fleet in the southern North Sea and is likely to be available for the German fleet in this area as well. Further work will be undertaken to try to access microscale distribution data for some of the fleets operating in the central and northern North Sea. These fleets are generally targeting roundfish, whilst the southern North Sea fleets tend to target flatfish and the differences in stock distribution and behaviour may mean that the microscale distribution of the fleets are not comparable.

2.3.4. Calculating encounter mortality

Encounter mortalities (the proportion of a population killed by a single pass of the gear) are available for a number of benthic invertebrate species based on studies undertaken over the last 30 years. Individual studies (e.g. Bergman and van Santbrink, 2000) have been synthesised by Kaiser *et al.* (in prep) and a meta-analysis of the data allows the interpretation of how individual morphological, life history and ecological characteristics affect the encounter mortality of specific species. All species found in the survey data used to calculate absolute abundances of benthic communities will be assigned an encounter mortality (e.g. 5% of the population killed by a single pass of the gear). Where there is no information in the literature for individual species, species will be classified based on the encounter mortality of species with similar morphological and ecological characteristics (e.g. fragility of body type, position in sediment, mobility). Where possible, individual encounter mortalities will be assigned for two standard gear types, otter and beam trawls. Further differentiation of mortality based on variation in gear type is not possible at this stage, but should be investigated in future work. It is also recognised that habitat type affects encounter mortality of individual species due to the effect of the physical characteristics of the habitat (e.g. density, cohesiveness) on the behaviour of the gear. Again this should be considered in future work.

2.3.5. Modelling the total fisheries mortality to the benthic invertebrate community

The modelling framework being developed operates on the theory of *cellular automata*, whereby animals are distributed across a grid of cells making up the overall area (the ICES rectangle), and individuals move within and between cells depending on their motility and the diffusive gradients between cells (See Box A below). For each ICES rectangle the input variables described above (sections 2.3.2. -2.3.4.) will be parameterised. Absolute abundance values will be worked up from the survey data to the scale of the individual cell (e.g. numbers of individuals per species per square nautical mile) and the same distribution of animals assumed across all cells making up the individual rectangle. Having classified each species making up the community for motility (movement rate per day) and vulnerability (proportion killed per encounter with fishing gear), the numbers per characteristic species type (Table A1, Box A) will then be summed. It is necessary to group individual species into a small number of ‘characteristic species’ because it would not be possible to run the model for every species making up the benthic community (likely to be many species including infauna and epifauna).

Initially the model will be parameterised to explore the effect on total mortality per annum of increasing fishing effort, across a number of characteristic community types. A number of different potential microscale distributions of fishing effort will also be applied (eg. even across rectangle but clumped in time, even in time but clumped in space, even in both etc.). Ultimately the model will be run for each ICES rectangle using real effort data from the international effort database, distributed based on information on the microscale distribution of the major fleets fishing in that area, across a benthic community with species composition derived from absolute abundance survey data.

Box A: Benthic Disturbance Modelling Framework

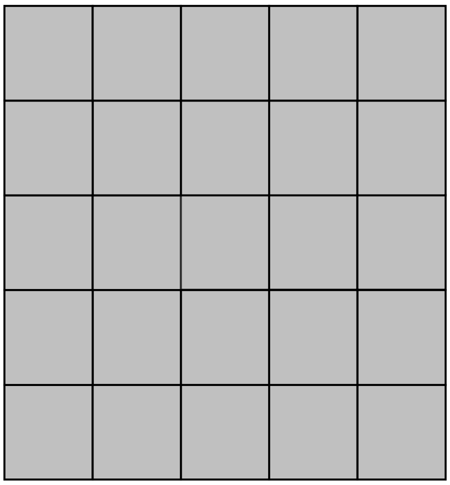


Figure A1: 25 individual cells of the total of 900 1 x 1 nautical mile cells making up each ICES rectangle

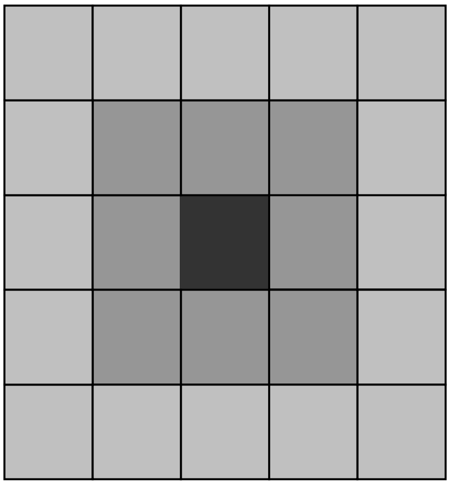


Figure A2: A clump of fishing effort centred around one individual cell.

For every ICES rectangle:

- The total area is divided into 900 individual cells.
- Each cell is 1 x 1 nautical mile in area.
- The whole area consists of homogenous habitat.
- A suite of (n) characteristic benthic species occupies each cell and:
  - all species are evenly distributed,
  - all cells have the same species composition,
  - each cell therefore starts off (at time = T_0) with the same number of individuals of each species.

Characteristic benthic species:

- A minimum of 9 characteristic benthic species will be modelled for each community.
- All real species in the actual survey data are assigned to one of these characteristic species.
- Absolute abundance of each characteristic species is the sum of the total numbers for each real species.
- The number of characteristic species is limited by the running time of the model.

		Vulnerability		
		Low	Medium	High
Motility	Low	Species 1	Species 4	Species 7
	Medium	Species 2	Species 5	Species 8
	High	Species 3	Species 6	Species 9

Distribution of fishing effort:

- Different fishing scenarios will be applied to the ICES rectangle.
- Figure A1 illustrates even distribution in space of effort whilst figure A2 illustrates a clump of fishing effort in space.
- Total effort will be based on real effort data from the international fishing effort database.

3 CONCLUSIONS AND FUTURE WORK

The international effort database has been updated to include the years 1997-2002 and the distribution of total demersal fishing effort across the North Sea has varied little over time. Comparison of the distribution with an earlier compilation of international effort data for 1998 (Callaway *et al.*, 2001) illustrates the importance of accessing Danish effort data, which are currently missing. It will also be important to try to access Belgian and French effort data, which may increase overall effort significantly for some areas of the southern North Sea (Jennings *et al.*, 1999), before finally updating the database to include the years 2003 and 2004.

There is currently a lack of information on the behaviour of the major fleets operating in the northern North Sea. In the southern North Sea information such as the numbers of hours fished in an average day, swept area of the gear and microscale distribution of effort within ICES rectangles are available for the major beam trawl fleets (Rijnsdorp *et al.*, 1998; Piet *et al.*, submitted). It will be important to access this information for the major otter trawl fleets concentrated in the central and northern North Sea, in order that the estimation of total hours fished and overall parameterisation of the effort inputs to the fish and benthic disturbance indices can be improved.

An approach to model the overall disturbance to demersal fish communities has been described and following initial runs and validation of the model (Piet and Star, working paper 2005), the absolute abundance variables are being further refined to try to improve the application. The modelling approach described for the estimation of overall disturbance to benthic invertebrates is still being developed with further work being undertaken on the absolute abundance variables and the microscale distribution of effort. Validation of the benthic invertebrate model will require access to landings and discards data for benthic invertebrates.

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