The Effects of Fishing on Deep-water Fish Species to the West of Britain

Final Report

for

Joint Nature Conservation Committee

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by

Marinelle Basson[1], John D.M. Gordon[2], Philip Large[3],
Pascal Lorance[4], John Pope[5] & Brian Rackham[3].

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1. Commonwealth Scientific & Industrial Research Organisation, Hobart, Tasmania
2. Scottish Association for Marine Science, Oban, UK.
3. Centre for Environment, Fisheries & Aquaculture Science, Lowestoft, UK
4. Institut Francais de Recherche pour l'Exploration de la Mer, Boulogne-sur-Mer, France.
5. NRC Ltd, Burgh St Peter, UK.

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1. Summary

During the last thirty years, dwindling resources for the human consumption fisheries on the continental shelf of the eastern North Atlantic have encouraged the development of fisheries in deeper water. The French trawl fishery for blue ling (*Molva dypterygia*) in deep water to the west of the British Isles commenced in the 1970s and, in the late 1980s, developed to target new species such as the orange roughy (*Hoplostethus atlanticus*), black scabbardfish (*Aphanopus carbo*), roundnose grenadier (*Coryphaenoides rupestris*) and deep-water sharks. During the past ten years, UK fisheries for species such as the anglerfish (*Lophius piscatorius*) and megrim (*Lepidorhombus whiffiagonis*) have extended into deeper waters and new fisheries have developed to target other species such as the roundnose grenadier and deep-water sharks. All of these fisheries have developed very quickly and there is considerable concern that, because most deep-water species are long-lived, have low fecundity and a slow growth rate, stocks can become rapidly depleted and recovery will be slow. Other biological and fishery-related factors also contribute to this concern. A high age/length at maturity combined with the unusual body shape of some species may result in a high fishing mortality on immature fish. Furthermore, the majority of fish caught and subsequently discarded on deck will almost certainly die and, because most species are very vulnerable to injury, it is likely that only a small proportion of fish encountering fishing gears and escaping through meshes will survive.

In this study, data relevant to the effects of fishing on deep-water fish species to the west of Britain are first collated and then used to evaluate these effects using a range of methods. These methods fall into two broad categories. An ecological approach comprising investigations of available trawl survey data, pre- and post-exploitation, and a second approach comprising single species assessments of the main deep-water species found to the west of the British Isles.

For the single-species assessments, most of the area of interest lies within ICES Sub-areas VI and VII, and Division Vb (Faroes). The data used are those reported to the ICES Study Group on the Biology and Assessment of Deep-water Fisheries Resources in February, 2000. The latest year for which total international catches and fleet catch-per-unit-effort (CPUE) data are available is 1998 and, consequently, the conclusions made in this study regarding the state of deep-water stocks refer to the situation at the end of 1998. It is emphasised that very little is known about stock structure and migration of deep-water species. For assessment purposes, what little information is available has been used to define ‘assessment units’ in terms of ICES Sub-areas and Divisions to the west of Britain. The main assessment methods used are the Schaefer dynamic production and DeLury constant recruitment models. The CPUE data used in all analyses are those available for the French trawl fleet. Thus, the assessments carried out rely heavily on the quality of these data. This data series is still quite short (8-9 years), and this may have some effect on results. A full description of the assessment methods used and available CPUE data is given in Section 5.5. It should be noted that some assessment results, for example, of estimates of absolute population size and maximum sustainable yield (MSY), may be sensitive to the assumptions about natural mortality, which is generally difficult to estimate, even for well-studied species. The ratios of current population size to unexploited biomass, or biomass at the start of exploitation, should, however, be robust to assumptions about natural mortality. Estimates for orange roughy, roundnose

grenadier and blue ling in ICES Sub-areas VI and Divisions VIIb,c, of, firstly, minimum virgin biomass (B_0), calculated by raising swept area estimates of relative density from German surveys in the 1970s to total surface area, and, secondly, of MSY, calculated using a procedure developed by Beddington and Cooke, are compared with the results from the Schaefer and Delury analyses. A review of the distribution and general biology, stock structure and fisheries, and a description of available catch-effort and length and age composition data are given for each species.

Trawl survey data are available for the period 1973 to 1999. Several techniques are used to explore whether there have been changes in the assemblage of fish species over this period, including comparisons, pre- and post-exploitation, of size-spectra, species composition of survey catches, biodiversity indices, trends in CPUE from trawl surveys and presence/absence data in survey catches. These analyses would ideally require the collation into one database of all the various deep-water trawl survey data held by different countries. This could not be achieved for all areas to the west of Britain because, on inspection, some of the data are unvalidated and contain a considerable number of inconsistencies and anomalies. It is estimated that to validate all available data and build a comprehensive database would take about one man-year. This is clearly outside the scope of this present study. To allow progress to be made, all available data for an area known as the Hebridean continental slope were collated into a single database. This area was selected because it is where most of the deep-water fishing effort has taken place and, therefore, should facilitate comparison pre and post-exploitation. It should be noted, however, that the distribution of valid trawls stations, by cruise and depth-band, is very unbalanced, with data for the deeper depth-bands only available for cruises after 1982, and that for a number of cruises only a single haul was carried out in each depth-band. These factors must be borne in mind when considering the results from analyses. It is also important to view these results in combination with the results from the single-species assessments. Despite these shortcomings, and given the difficulty and high cost of deep-water sampling, the Rockall Trough, of which the Hebridean continental slope is apart, is probably the most intensively sampled deep-water area in the world.

In 2000, the ICES Advisory Committee on Fishery Management (ACFM) expressed the view that most deep-water species in the ICES area are, at present, harvested outside safe biological limits as embodied in the precautionary approach (Anon., 2000), and the assessments carried out in this study support this view. They indicate that the level of exploitable biomass in 1998 of orange roughy, black scabbardfish, roundnose grenadier, deep-water sharks (principally the leafscale gulper shark *(Centrophorus squamosus)* and the Portuguese dogfish *(Centroscymnus coelolepis))* and blue ling *(Molva dypterygia)* was below the precautionary reference level and, for some species, was close to or possibly below the precautionary limit point. A full description of the precautionary reference points used in the assessments is given in Section 5.2. It is emphasised that the confidence limits around biomass estimates are, for most species, quite wide and, consequently, the assessment results presented in this study should be interpreted with caution. There are also a number of reservations and caveats which relate to individual assessments and these are fully described for each species.

Long-term trends in standardised CPUE from trawl surveys are calculated using general additive, general linear and linear mixed effects models. Exploratory investigations revealed that the unbalanced nature of the data is a serious problem if they are analysed on a species-by-species basis. The only species for which such an analysis could be carried out was roundnose grenadier. This problem is resolved by considering two coarse groupings : ‘exploited’ and ‘unexploited’ species. However, it is emphasised that the results from analyses should be treated with caution because there is still a considerable amount of variation in the data which is not explained by the models. Confidence limits about biomass estimates are also wide. Notwithstanding these concerns, the results strongly suggest that there has been a decline in the biomass of exploited species since the mid to late 1980s. The biomass of exploited species is estimated to be currently at around 0.20 of the pre-exploitation mean (1973-1987). The results for roundnose grenadier also indicate a decline in biomass with time. Current biomass is estimated to be between 0.15 and 0.23 of mean pre-exploitation biomass. These results are similar to the results from single species assessments. It is shown that there also appears to have been a decline in the biomass of unexploited species to around 0.45 of the mean pre-exploitation biomass. This decline is consistent with available information on the mortality of discards and the low survival rate of escapees through trawl meshes.

In the presence/absence analyses, the proportion of SAMS (Scottish Association of Marine Science) survey hauls with zero catches of the main commercial deep-water species are analysed to explore whether there have been changes in the proportions with time. The results suggest that it is very likely that there has been a decrease in the abundance of the Portuguese dogfish since the 1980s. This result is consistent with the results from the assessment of deep-water sharks. A range of other species did not show any trends in the proportion of non-zero hauls.

A comparison of catch composition data from SAMS semi-balloon trawl surveys, carried out in 1985 and 1999, indicates that sharks accounted for a lower proportion of the catch of larger fish in 1999. These results also are consistent with the results from the assessment of deep-water sharks. Furthermore, the results from a detrended correspondence analysis of SAMS semi-balloon trawl data, pre and post-exploitation, suggest that there may have be differences in species composition between catches taken in 1985 and 1999. It is emphasised that, until the results are fully analysed in terms of the biology of the species, it would be inappropriate to attribute this to an effect of exploitation.

Diversity indices calculated using data from SAMS surveys carried out with a range of fishing gears show a consistent decline in diversity and taxonomic distinctness with depth, which stabilises at depths greater than 1375m. Diversity indices calculated using SAMS semi-balloon trawl data, pre and post exploitation, show a decline in species diversity but little change in taxonomic distinctness. Note that the number of hauls completed in the surveys using the semi-balloon trawl was small and differences in catch composition and diversity may reflect sampling variance rather than real differences in the composition of fish assemblages.

Size-spectra are calculated and compared for deep-water trawl catches from thirty-five surveys over the period 1973 to 1999. The slopes of the size-spectra are compared against time, using graphical and analysis of covariance methods. There are some indications of an increase in slope with time, but this result is neither strong nor highly conclusive. The data are very unbalanced and the results depend on the gear grouping used and the way in which the year-effects are incorporated in models.

Very few fisheries exist where it is still practical to make a comparison between pre-exploitation and post-exploitation situations. It is suggested that urgent representations be made to funding agencies to arrange for a charter of RV Cirolana to repeat the trawl surveys as carried out in the 1970s using the Lowestoft Granton trawl. Surveys by the French RV Thalassa, using an Arrow trawl, were carried out in 1996 and 1999, and it would be useful for further analyses of size-spectra and survey indices of biomass and abundance to calibrate this vessel and gear against the Cirolana and the Granton trawl.

As noted above, the commercial CPUE data used in all the assessments carried out in this study are those available for the French trawl fleet. Thus, the assessments rely heavily on the quality of these data. These CPUE series are calculated using a multiplicative model taking into account month and ICES Sub-area effects, weighted by fishing effort. It is suggested that for future assessments it would be useful to have information on the confidence limits about annual estimates of CPUE, so that an informed judgement can be made as to the magnitude of any changes with time in relation to background noise.

In this present study, it was only possible to construct a deep-water survey database for the Hebridean continental slope. A considerable quantity of data exists for other deep-water areas to the west of Britain. It is estimated that about one man-year would be required to validate these data and build a database. It is suggested that this work be expedited so that future investigations of the effects of fishing on fish assemblages to the west of Britain can make full use of available data.

2 Introduction

2.1 Definition and general features of deep-water areas and fisheries to the west of the British Isles

2.1.1 Topography and geology

This study concerns the deep-water areas, defined as depths greater than 400m, lying to the west of the British Isles. Most of the area of interest lies within ICES Sub-areas VI and VII although it is also appropriate to consider the eastern sector of Sub-area XII and the Faroes (ICES Division Vb). The most important and best documented fisheries are within the Rockall Trough (Figure1).

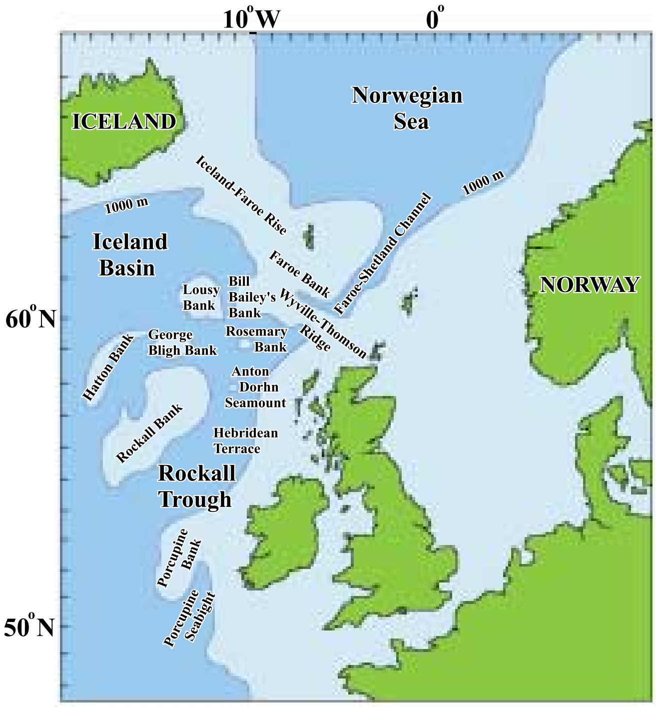

Figure 1. *Deep-water areas of the North-east Atlantic with particular reference to topographical features in the Rockall Trough.*

The northern boundary of the Rockall Trough is formed by the Wyville Ridge at a depth of about 500m. This is a major faunal barrier and there is little similarity between the fish assemblages on either side of the ridge (Bergstad *et al*. 1999; Gordon, 2001). To the west and north-west, the Rockall Trough is separated from the Icelandic basin by the Rockall Plateau and a chain of northern banks. To the south the Rockall Trough gradually increases in depth onto the abyssal plain. To the west of Ireland the slope on the western edge of the Porcupine bank is steep, whilst to the south the Porcupine Seabight, has more gentle slopes.

The underlying geology of the Rockall Trough has been described by Scrutton (1986) and the resulting structure of the continental margin by Jones *et al*. (1986). Most of the area is covered with sediments whose deposition has been modified by volcanic activity, bottom currents and glacial processes.

2.1.2 Hydrography

The hydrography of the area is well documented (Ellett and Martin, 1973; Ellett *et al*. 1986). The water column is derived from several different water masses, some of which, such as Mediterranean outflow and Norwegian Sea overflow, can be intermittent and geographically variable.

There is a gradual decrease in temperature with depth in the Rockall Trough. There is also a well-defined seasonal thermocline to depths of about 500 m, which breaks down during the winter and early spring. The deep winter mixing, sometimes to depths of about 1000 m, is important in redistributing nutrients which are vital to the spring phytoplankton bloom, which is the original source of most of the food energy reaching the deep-sea. Below 500 m the temperature continues to decline gradually but the annual variations are negligible (< 0.5^0C).

It is important to recognise that the hydrographic regimes to the north and east of the Rockall Trough are fundamentally different. As already mentioned, the Rockall Trough is separated from the Norwegian Basin by a number of underwater ridges such as the Wyville-Thomson Ridge between Shetland and the Faroe Islands. At depths down to the top of the ridge the temperature regime is similar on both sides of the Ridge, but to the east the temperature decreases rapidly to less than 0^oC below sill depth. These differing temperature regimes have a profound effect on the composition, abundance and biomass of the fauna, including the fish. In the Rockall Trough, the biomass peak for demersal fish is between 1000 and 1500 m whereas abundance and biomass decrease rapidly below about 500 m in the Norwegian Basin (Bergstad *et al*. 1999).

As with temperature, the annual changes in salinity are small. However longer term changes in salinity associated with the North Atlantic circulation have been documented (see Section 4.1.5).

The currents of the Rockall Trough are well documented. The main feature is a north-flowing current along the Scottish continental slope which is present throughout the year. The mean current speeds are between 3 and 30 cm/sec increasing northwards. There is probably a consistent counter-current going south along the eastern edge of the Rockall Bank. Currents have important implications for the life history of organisms, including fish, which produce pelagic eggs and larvae. If the currents were simple linear flows then many planktonic organisms might be swept out of the area before having a chance to grow and breed. However the flows are not linear and many gyres or eddies are thrown off the main current which have the effect of increasing the residence time of the water and the organisms living in it. The losses of zooplankton from the Rockall Trough into the Norwegian Sea and northern North Sea as a result of the slope current have been estimated. These were considered to be large (21%) for animals living in the epipelagic zone (0-500 m), moderate (8%) for the mesopelagic zone (300 - 1000 m) and only about 1% for the bathypelagic zone (700-1800 m) (Mauchline 1986, 1990).

Very little is known of the biology and distribution of the eggs and larvae of deep-water fish, but clearly those that remain deep in the water column may have a better chance of remaining in an area suitable for subsequent development. Perhaps the reason for our lack of knowledge of the young stages is because they remain close to the bottom, which is an area that is difficult to sample and as a consequence poorly known.

2.1.3 Fish populations

There have been detailed studies on the fish populations of both the Rockall Trough (Gordon and Duncan, 1985a; Gordon, 1986, Gordon and Bergstad, 1992) and the Porcupine Seabight (Merrett *et al.* 1991 a,b). Other studies cover the whole area (Gordon *et al.* 1996 and Ratz, 1984). There are many papers on aspects such as the biology of individual species or families, trophic ecology, reproduction etc., which have resulted from these and more recent studies. A bibliography of the deep-water fish and fisheries of ICES Sub-areas VI and VII and adjacent areas can found in Section 9.

Gordon (1995) has outlined some of the main features of the fish assemblages of the area. At depths between about 400 and 1500 m there may be between 40 and 50 demersal species present in catches from the Rockall Trough at any given depth, depending on gear type. The number of species decreases quite markedly below about 1500 metres. The best estimate, derived from combining data from several trawl types, is that total abundance and biomass of all species is maximal at depths between about 1000 and 1500 metres. Thereafter, the abundance and biomass declines rapidly with depth. These changes are almost certainly related to the energy supply reaching the deep water from the surface layers and also to the diet of the deep-water benthopelagic fishes. The primary source of energy to the deep sea is from surface production of phytoplankton in the euphotic zone that in turn is consumed by higher trophic levels. Some of this energy reaches the deep sea as a continuous rain of dead organisms or their products. Recently, it has been shown that there is a rapid seasonal input of organic material directly associated with the transport of dead phytoplankton to the deep-water sediments. The quantity of these materials reaching the sea bed declines with increasing depth, and the resulting production of benthic organisms such as molluscs, sea urchins and worms, which are very largely dependent on such energy input, could never support the benthopelagic fish populations. The rapid sinking of large, dead organisms to the seabed can provide a valuable food source for some scavenging fish species. However, there is little doubt that the success of the demersal fishes of the slopes results from the transfer of the energy of surface production downwards, via the mesopelagic fauna of both fishes and invertebrates. One possible pathway is via the overlapping food chains of organisms which occupy specific depths. Many mesopelagic organisms also carry out daily vertical migrations, living at depth during the day and migrating upwards at night to feed close to the surface. Over the slope this vertical migration carries the food source directly down to the seabed. There is also evidence that the daytime aggregations of mesopelagic organisms at depth can impinge horizontally onto the slope. Investigations at SAMS have shown that benthopelagic fishes of the slope feed mainly on pelagic and benthopelagic organisms and make very little use of benthic prey. It is therefore reasonable to assume that the success of these fishes, and their maximum biomass at mid-slope depths, is the result of the predation on this abundant food source. It is also worth noting that the mesopelagic fauna are largely unexploited or impinged upon by anthropogenic activities.

Relatively few species make up most of the biomass, and Figure 2 shows how the species composition changes with depth. These data are taken from German surveys (ISH Walther Herwig surveys, 1974-80) of the Rockall Trough using a large commercial bottom trawl fitted with a finer mesh in the codend (Ratz, 1984). At 200 m in the southern Rockall area the dominant species are typical of the outer shelf. This gradually changes with increasing depth and by 600m all the dominant species are typically deep-water. The high proportion of the smoothhead (*Alepocephalus bairdii*), which is of no commercial value, at greater depths is higher than would be found further north in the Rockall Trough.

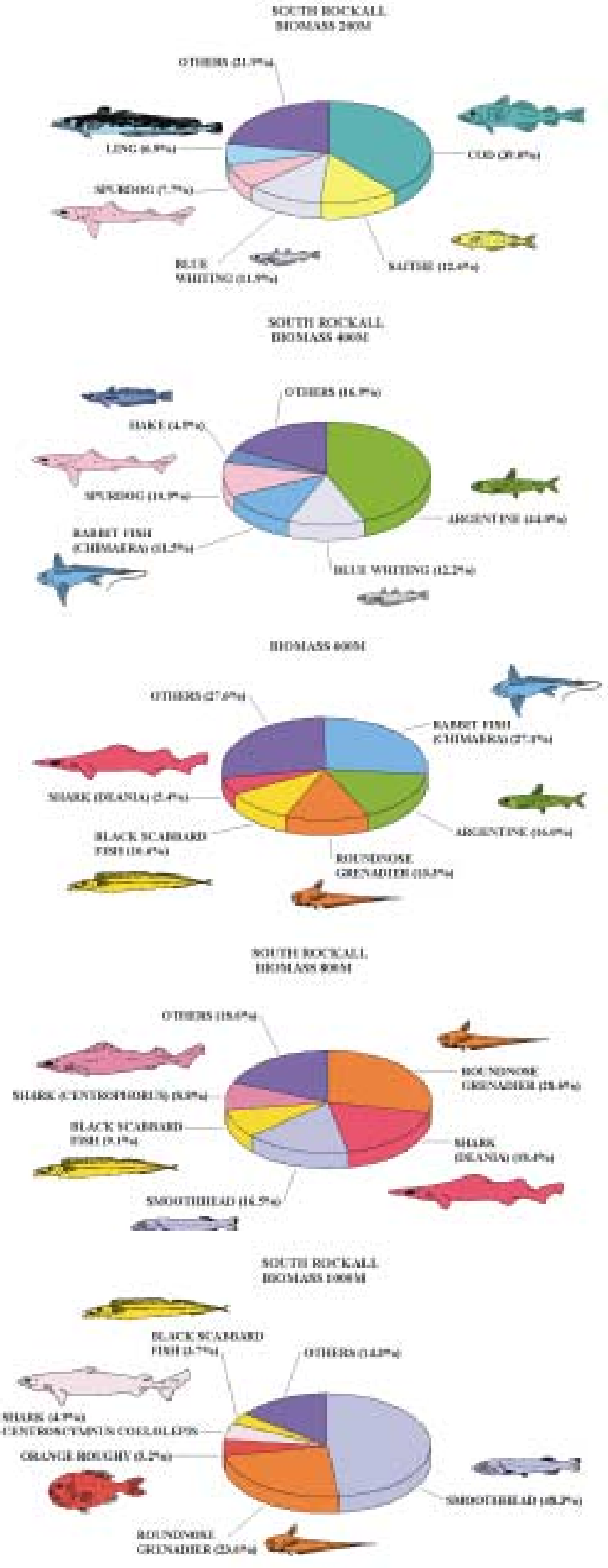

Figure 2. *The percentage by weight of the top five species at 200m intervals down the slope of the Rockall Trough (data from Ratz,,1984).*

2.1.4 Invertebrate fauna

Mauchline (1986) has reviewed the ecology of the pelagic invertebrate fauna of the Rockall Trough. Most of the recent information results from a time series of pelagic sampling carried out by SAMS between 1973 and 1976. These studies have provided a wealth of information on the seasonal and depth distribution of the invertebrate fauna, which in turn has been linked to the diet and distribution of commercially exploited fishes.

The benthic fauna of the Rockall Trough has been studied since before the Challenger Expedition (1873-1876), and since the 1970s has been the subject of one of the longest deep-sea time-series (Gage, 1986 and 2001). These studies have centred on seasonal and annual changes in distribution and biology. There is growing interest in the ecosystem effects of fishing on the benthos, and these long-term studies might help to understand the relative roles of anthropogenic and natural effects.

2.1.5 Description of fisheries

2.1.5.1 Bottom trawl fisheries in ICES Sub-areas VI and VII and Division Vb.

The major features of the fisheries have been described by Allain (1999), Anon (1995, 1996, 1998 and 2000), Gordon (2001), Gordon and Hunter (1994), Koslow *et al*. (2000), Lorance and Dupouy (2001).

The origins of the deep-water bottom trawl fishery can be traced back to the late 1960s, when Soviet and other eastern bloc countries began to exploit roundnose grenadier in international waters to the west of Rockall Plateau and on the Hatton Bank. A by-catch of other deep-water species would have been retained, but the landings of these fish are not well documented. Although the Russian fisheries in this area have ceased or are at a very low level, fishing continues by other nations in these international waters although the landings are often poorly documented (Anon, 1998). In the early 1970s, German trawlers began to exploit spawning aggregations of blue ling (*Molva dypterygia*) in the northern parts of the Rockall Trough. By the mid to late 1970s, French trawlers, which traditionally fished along the shelf edge for species such as saithe (*Pollachius virens*), had began to move into deeper water to exploit blue ling and gradually replaced the German fleet. The French fishery continues to the present time as both a target and a by-catch fishery. There appears to be little doubt that in the early years of the fishery the by-catch of species such as roundnose grenadier (*Coryphaenoides rupestris*), black scabbardfish (*Aphanopus carbo*), deep-water sharks and many other less abundant species was discarded. It was only in 1989 that these species began to be landed as a result of a marketing initiative by the French industry. Blue ling remains a target species, especially in the spring and early summer. Roundnose grenadier is also a target species in its own right. To some extent the species targeted depends on the size of the vessel, with the larger ships fishing deeper and targeting roundnose grenadier.

These multi-species bottom-trawl fisheries should not be confused with the French fishery for orange roughy (*Hoplostethus atlanticus*). Although there is still a degree of secrecy associated with this fishery, there is little doubt that it takes place at greater depths (down to about 1600 m) than the multi-species trawl fishery and in areas of steep-slopes and seamounts. It is quite probable that many of the catches are almost entirely of orange roughy with few discards. Any by-catch is likely to be of species that are of little interest commercially.

The French fleet has been described by Lorance and Dupouy (2001). They divided the fleet into 3 components. One, of vessels of from 49 to 55m, is fairly homogeneous in terms of horsepower, age and equipment, and is specialised in exploitation of deep-water species. All the other vessels of this size form the second component. The third component consists of smaller high-sea trawlers of about 30 to 38 m.

The Scottish fleet first became interested in exploiting the deep water in 1992/93 when the French landings of the high value orange roughy increased. However, it soon became apparent that the Scottish vessels were not large enough to exploit the depths inhabited by this species and instead they began fishing on the upper slope after discovering that the high value anglerfish or monkfish (*Lophius piscatorius*) also occurred in deep water. The by-catch of deep-water fishes consists of species such as roundnose grenadier, blue ling and black scabbardfish. It is difficult to determine the amount of effort devoted to deep-water fishing by the Scottish fleet. According to the final report of the Fisheries Research Services (FRS) Marine Laboratory to a EC FAIR deep-sea fisheries project (Anon., 1999b), at least one Scottish vessel is known to work full-time in deep water. The majority work in a variety of fisheries including the traditional shelf fisheries in the North Sea and west of Scotland, on the Rockall Bank and along the shelf edge fishery for monkfish and megrim, as well as in deep water fisheries in the Rockall Trough and the Faroe-Shetland channel. Vessels move between fisheries according to fishing opportunities, fish prices, quota restrictions and weather. At the end of 1998, 21 vessels in the fleet were known to have fished in deep water in the past or were newly built boats with the capability and intention of doing so in the future. Most of these vessels were modern and in the 25 to 35 metre length range, although two of the most recent additions to the fleet were over 40 metres. Since 1997, most new vessels have been built to work as twin rig trawlers, while many of the existing vessels have converted to this gear type. The majority of these vessels can probably fish to depths of around 1100 metres, but in practice fish down to about 900 metres. It has been reported that the conversion to twin rig gear has restricted the depth to which vessels can fish. Vessels in the 25 to 35 metre length range cannot fish safely in deep water during severe weather, so fishing effort may be restricted during the winter months.

Ireland has carried out exploratory surveys in the 1990s but, with the exception of some commercial trawling in deep water in 1993, no fishery has developed. However, under the fleet-renewal project, new or refitted vessels will carry out exploratory fishing under the auspices of Bord Iscaigh Mhara (BIM) in 2000.

2.1.5.2 Other fisheries

There are also two deep-water pelagic trawl fisheries for semi-pelagic species on the upper Atlantic slope. The major fishery is for blue whiting (*Micromesistius poutassou*). This directed fishery on spawning fish is mainly carried out by Norway, with Russia, the UK and the Netherlands also catching significant amounts. About 40% of this fishery takes place in ICES Division VIa along the continental slope to the west of Hebrides. Norway accounts for in excess of 70 % of the catch and the UK only for about 3 or 4 %. The other pelagic trawl fishery is a seasonal fishery on spawning aggregations of greater silver smelt or argentine (*Argentina silus*) The erratic nature of some of the national fisheries, particularly the Irish, has been commented on by McCormick (1995). Earlier ideas that the stock had been fished down in a few years now appear to be discredited.

There are also important longline and net fisheries on the Atlantic slope. Spanish and UK(E+W) longline fleets (the latter landing mostly in Spain) target hake *(Merluccius merluccius*) with deep-water sharks as a by-catch. Depending on market prices, sharks can sometimes be the target species. A Norwegian longline fleet targets ling (*Molva molva*) and tusk (*Brosme brosme*) over a wide area of the North-eastern Atlantic and is well documented (Bergstad and Hareide, 1996; Magnússon *et al*. 1997). There is also a Spanish and UK gill/tangle net fishery for anglerfish.

2.2 Previous studies of the effects of fishing on deep-water species to the west of Britain.

In recent years some progress has been made towards evaluating the effects of fishing on deep-water fish assemblages to the west of Britain. Survey estimates of the overall size composition of deep-water fish on the European continental slope have been made during periods before and after exploitation. These have been compared both directly (Large *et al*. 1998) and with size spectra data for the North Sea at the turn of the century and in the 1990s (Pope and Large, 1996). These preliminary studies suggest that the overall size composition of deep-water fish on the Hebridean continental slope may have changed since the early 1970s, possibly as a result of increased exploitation in the intervening years. These studies are described in more detail in Section 4.3.2.

In addition, members of the ICES Study Group on the Biology and Assessment of Deep-sea Fisheries Resources have carried out stock single-species stock assessments of a number of deep-water fish species to the west of the British Isles. In 1998, the Group, using the most recent data available (1996), concluded that the biomass of orange roughy was probably below the limit reference point (U_{lim}) in ICES Sub-area VI and below the precautionary reference point (U_{pa}) in Sub-area VII, whereas the biomass of roundnose grenadier in both Sub-areas appeared to be above U_{pa} (Anon., 1998) (a full description of these biological reference points and the precautionary approach in general is given in Section 5.2).

However, it was emphasised that the results from these size spectra investigations and single species assessments should be viewed with caution because the analyses are based on limited data.

2.3 Project aims

It is known that time-series survey data for deep-water areas to the west of Britain are available for specific periods during the last 30 years. These data are in various states of compilation and partial analysis. Also an additional two years’ data are now available to augment the landings and CPUE data series used in the single species assessments carried out at the ICES Deep-water Study Group in 1998. Many of the data series analysed comprised only four or five years' data so the addition of two further years may have a considerable effect on results.

The purpose of this study is to collate available data relevant to studying the effects of fishing on deep-water species to the west of Britain and, where these data allow, to evaluate these effects using methods which fall into two broad categories. An ecological approach comprising comparisons, pre- and post -exploitation, of size-spectra, species composition of survey catches, biodiversity indices, trends in catch-per-unit effort (CPUE) from trawl surveys and presence/absence data in survey catches, and a second approach comprising single species assessments of the main deep-water species found to the west of the British Isles. The species assessed are those under the remit of the ICES Deep-water Study Group and comprise orange roughy, black scabbardfish, deep-water sharks (principally the leafscale gulper shark (*Centrophorus squamosus*) and the Portuguese dogfish (*Centroscymnus coelolepis*), roundnose grenadier, blue ling and the greater forkbeard (*Phycis blennoides*).

2.4 Project overview (including participation)

This two year project is divided into two phases: -

Phase 1, which was completed by 31/3/1999, comprised:-

1. Collation of survey and commercial catch data.
2. Preparation of a data inventory.
3. Exploratory data analysis to identify limitations and problems.
4. Investigation of the feasibility of constructing long time series of CPUE by combining survey data-series using generalised linear models.

Drafting a report of progress and liaising with participants in Phase 2 to identify detailed aims.

Phase 1 included a three-day meeting at the Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Lowestoft for participating scientists (see below). The main output was a preliminary report submitted to the Joint Nature Conservation Committee (JNCC) on the 30th April 1999.

Phase 2, which was completed on 31st March 2000, comprised:-

1. Compilation of a deep-water survey database.
2. Calculation and comparison of size spectra, pre- and post-exploitation, and investigation of inter-annual variation.
3. Investigation of the effect of fishing on the composition of survey catches and the position of species groups in size spectra.
4. Calculation and comparison of diversity indices, pre-and post-exploitation.
5. Construction and evaluation of time-series survey catch per unit effort (CPUE) data using a generalised linear model (GLM) approach.
6. Comparison of time-series CPUE data for commercially exploited and non-exploited species.
7. Collation of available commercial catch, effort and discard data.
8. Single species stock assessments of the species listed in Section 2.3.

Phase 2 also included a three-day meeting at CEFAS, Lowestoft. This document is a preliminary report submitted to JNCC by 31st March 2000.

Participation:

The following scientists have participated in the project:-

Dr Marinelle Basson - CEFAS
Dr John Gordon - SAMS
Philip Large (Contract Leader) - CEFAS
Pascal Lorance - IFREMER
Prof. John Pope - NRC (Europe) Ltd
Brian Rackham - CEFAS
Dr Odd Aksel Bergstad - IMR (Norway)
Dr Daniel Duplisea - CEFAS
Dr Jim Ellis - CEFAS

Please refer to Appendix 9.1 for addresses etc.

3. Compilation of data for deep-water areas to the west of Britain

3.1 Deep-water survey database

In order to carry out the ecological investigations required in this project, it is necessary to bring together the various survey data held by different countries into one database. It is not intended that these data be held in any particular database system, but that they should be organised into relational form so that they could readily be imported into whatever database is preferred by participants, to facilitate subsequent analyses.

The deep-water survey data are those available from [1]CEFAS (UK), [2]SAMS (UK), [3]FRS (UK), [4]IFREMER (France) and [5]ISH (Germany). A preliminary inspection revealed that whilst some of these datasets had been validated and were well structured, others appeared not to have been fully validated and contained a considerable number of inconsistencies and anomalies. It is estimated that about one man-year would be required to validate these data and build a database, a task which would, for some survey-series, almost certainly require going back to the original paper records from each survey. This clearly is beyond the remit of this present study, and it was agreed to confine the database to a single area and to validate the data as far as possible given the time allocated in the contract. The area chosen is the Hebridean continental slope (latitude 54^{o} 30’ to 58^{o} 45’ N west to 12^{o}) (Figure 3).

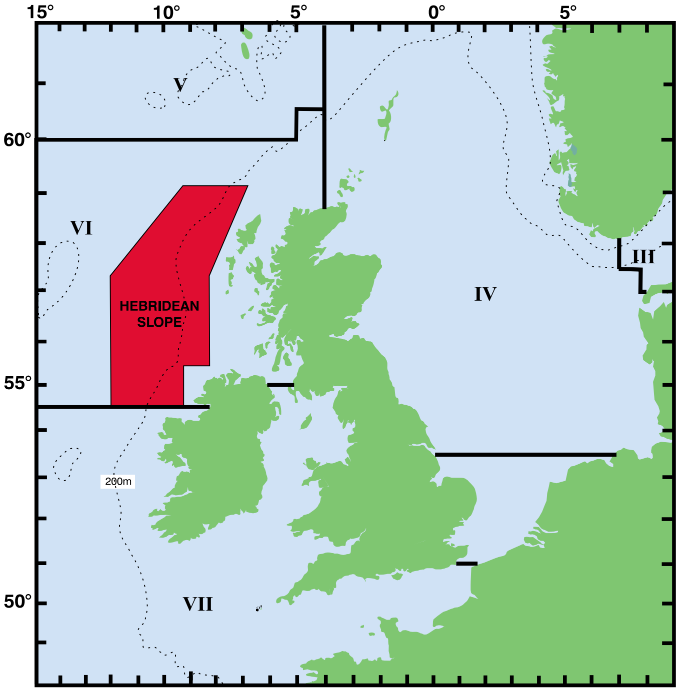

***Figure 3**. Chart showing the Hebridean continental slope in relation to ICES Sub-areas.*

This area was selected because it is where most of the deep-water fishing effort has taken place, and therefore should facilitate comparisons, pre and post exploitation.

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[1] CEFAS - The Centre for Environment, Fisheries & Aquaculture Science.

[2] SAMS – The Scottish Association for Marine Science.

[3] FRS – Fisheries Research Services

[4] IFREMER – The Institut Francais de Recherche pour l’Exploration de la Mer.

[5] ISH – The Institut fur Seefischerei

The data included in the database and subsequently analysed were those for valid tows from surveys carried out by CEFAS (UK), SAMS (UK), IFREMER (France) and ISH (Germany) (Table 1).

Table 1. *Valid trawl stations by year, cruise, gear and depth available for the Hebridean slope, 1973-1999.*

				Depth-band (m)						
Year	Vessel	Cruise	Gear	375-624	625-874	875-1124	1125-1374	1375-1624	1625-1875	>1875
1973	Cirolana	4a/6b	Granton (78')	4	10	8				
1974	Cirolana	1	Granton (78')	1	7	6				
	W.Herwig	14	Trawl (140')	2	2	1				
1975	W.Herwig	17	Trawl (200')	2	1	3				
	Challenger	10b/12b/14b/4b/7b	Granton (S)		5	5				
1976	Challenger	5b/9	Granton (S)	2	2	2	1			
	Challenger	16	Granton (L)	2	1	1	1			
1977	Challenger	7/16	Granton (L)	1	2	1	1			
1978	Cirolana	9	Granton (78')	5	8	7	5			
	Challenger	7	Granton (L)		1	1	1			
1979	Challenger	1	Granton (L)		1	1				
1980	W.Herwig	38	Trawl (200')	9	2	2				
1981	W.Herwig	47	Trawl (200')	4	2	2	2			
1982	W.Herwig	50	Trawl (200')		2	1				
1983	W.Herwig	58	Trawl (200')	5	4	3	2			
	Challenger	13	OTSB (S)	1	1	1	1	1	1	
1984	Challenger	9	OTSB (P)	1	1	5	1	1	1	
1985	Challenger	3	OTSB (S)	1	1	15	1	2	1	1
	Challenger	3	OTSB (P)	1	1	2	1	1		
1987	Challenger	20	OTSB (S)	1	1	1	1	1	2	
	Challenger	20	OTSB (P)	1	1	1	1	1		
1990	Challenger	67/71	OTSB (P)			1	1	1		
1991	Challenger	86	OTSB (S)						1	
1992	Challenger	89	OTSB (S)			1	1			
1996	Thalassa		Arrow		1	3	6	2	4	
1999	Thalassa		Arrow			8	12			4
	Challenger		OTSB (S)			5				
			Total	43	57	82	39	10	10	5

These data have two important characteristics. Firstly, they are very unbalanced, with data for the deeper depth-bands only available for cruises after 1982, and secondly, for a number of cruises only a single haul was carried out in each depth-band. These characteristics should be considered when interpreting the results from ecological studies (Section 4).

The database comprises two tables for each organisation (CEFAS, SAMS etc), one containing station details (Table 2) and the other catch details (Table 3). The tables may be related using the common variables COUNTRY, CRUISE, YEAR and STATION. These tables were constructed both as SAS data sets and comma-separated files. The latter can be readily imported into many standard packages, for example EXCEL and ACCESS, as required.

Table 2*.* *Format of station table*

Variable	*Type*	*Length*	*Label*
COUNTRY	Char	3	Country
CRUISE	Char	8	Cruise
DAY	Num	8	Day
DBAND	Char	9	Depth-band
GEAR	Char	8	Gear type
HALDUR	Num	8	Length of haul (mins)
HALTIM	Num	8	End time of haul
HALLAT	Num	8	Haul latitude (degrees)
HALLON	Num	8	Haul longitude (degrees,negative=W)
MAXDEP	Num	8	Maximum depth (metres)
MINDEP	Num	8	Minimum depth (metres)
MNDEPTH	Num	8	Mean depth (metres)
MONTH	Num	8	Month
SHTLAT	Num	8	Shot latitude (degrees)
SHTLON	Num	8	Shot longitude (degrees,negative=W)
SHTTIM	Num	8	Start time of haul
STATION	Num	8	Station no.
VALID	Char	1	Valid haul
YEAR	Num	8	Year

Table 3. *Format of catch table*

Variable	*Type*	*Length*	*Label*
COUNTRY	Char	3	Country
CRUISE	Char	8	Cruise
LENGTH	Num	8	Measured length (cm)
LENNO	Num	8	Number at length
LTYPE	Char	3	Length type e.g. TL, SL ,PAL etc
NODCODE	Char	11	NODC Code
STATION	Num	8	Station no.
SPECIES	Char	8	SYN code (SAMS)
TLENGTH	Num	8	Total length (cm)
WEIGHT	Num	8	Calculated weight of individual fish(gm)
YEAR	Num	8	Year

Each species is denoted by a SAMS SYN code and by a NODC (National Oceanographic Data Centre) 10 digit code. Length type (LTYPE) refers to the format of the original measured length (total length (TL), standard length (SL) and pre-anal length (PAL) etc). Where total length was not measured, the measured length has been converted to total length (TLENGTH) using conversion factors supplied by SAMS. These total lengths are then converted into individual fish weights (WEIGHT) using SAMS length/weight conversion factors. In some cases where individual fish were caught at a station, the total catch weight has been used if a length/weight conversion factor was not available (a full description of the methodology used is given in Section 4.3.3).

The depth-bands used are those applied in previous studies of deep-water fish assemblages to the west of the British Isles (Coggan *et al*. 1998) (Table 4).

***Table 4**. Depth-bands used in survey database*

Depth-band classification	*Depth-interval (m)*
1	375 –624
2	625-874
3	875-1124
4	1225-1374
5	1375-1624
6	1625-1874
7	1875-2124

3.2 Commercial catch, effort and discard data.

The data used are those collated and tabulated by the ICES Deep-water Study Group in February 2000. A full description of landings, effort, CPUE and available discard information is included in the single species assessments in Section 5).

4 Ecological studies

The trawl survey data contain a wealth of information which can be viewed in various ways. In this section, the data are viewed from an ecological point of view rather than species-by-species. Although not all the surveys were designed with this in mind, they provide data which can used to make simple ecological investigations. Several techniques are used to explore whether there have been changes, and if so, what kind of changes, in the assemblage of fish species over the period covered by the trawl surveys (1973-1999). For example, size spectrum analysis (Section 4.3) focuses on changes in the size distribution of all species combined. Changes in species composition are investigated using detrended correspondence analysis (DCA) (Section 4.4), and changes in the relative biomass and abundance of species in survey catches are explored using diversity indices (Section 4.5). The survey information can also be used to construct indices of relative biomass and abundance for individual species, or groups of species, which are considered in Section 4.6. Since most of the approaches in this section use relatively coarse aggregations of data and because the various gears used in the different surveys were not intercalibrated, the results will not always tell the full story. It is also important to note that some of the measures, or indices, used here may not be sensitive enough to detect changes that have taken place. It is therefore important to view results from the different analyses in this section, in combination with results from Section 5, where analyses are done on a species-by-species basis.

A number of difficulties are encountered when using trawl survey data to investigate the ecological effect of fishing on fish assemblages. These difficulties are relevant to all the analyses and are therefore discussed in the next several sections.

4.1 Factors relevant when using trawl survey data to investigate the ecological effect of fishing on fish assemblages

4.1.1 Gear effects

Relatively few fishing gears have been used in deep-water surveys. For those that have been used, some of the differences in catch composition and species presence or absence are documented. Studies in the Rockall Trough compared several trawl types including Granton and semi-balloon trawls (Gordon and Duncan, 1985a; Gordon, 1986; Gordon and Bergstad, 1992). The smaller trawls, especially those fished on a single warp, were inefficient at catching larger species such as deep-water sharks, black scabbardfish and smoothheads. On the other hand, a small semi-balloon trawl fished on a single warp caught, at certain depths, significant numbers of a small deep-water eel (*Synaphobranchus kaupi*) which was seldom encountered using other types of trawl. Descriptions of the gears used on the various surveys are given in Appendix 9.2.

4.1.2 Area effects

Species composition is known to vary quite considerably with latitude. Bridger (1978) noted a clear north/south divide to the west of the British Isles, with higher proportions of commercially unimportant species such as alepocephalids in the southern area. In re-analysing these data, Gordon and Swan (1997) considered ICES Sub-areas VI and VII separately. Ehrich (1983) divided the German survey data into two areas at 52°N. This corresponds closely to the boundary between ICES Sub-areas VI and VII. There were differences in total biomass, species composition and depth of occurrence of some of the potentially marketable species. All the German survey data has recently been re-analysed (Anon., 1999b). For this purpose, the whole region (VI, VII and XII) was divided into eight areas based on topography and other physical features. Gordon *et al.* (1996) compared catch composition between Rockall Trough and the Porcupine Seabight separately for a Granton trawl and the semi-balloon trawl using detrended correspondence analysis (DCA), and found significant differences between areas and between gears.

4.1.3 Depth effects

Gordon and Bergstad (1992) used multivariate analysis to compare the catch compositions between gears and depths and showed that a high proportion of the variation was attributable to depth. There is little evidence of zonation (i.e. abrupt changes in fauna with depth) in deep-water fishes (Haedrich and Merrett, 1990) and each species has it own characteristic depth range. The depth range of individual species varies considerably from about 2000 m for *Synaphobranchus kaupi* to a few hundred metres for *Bathypterois dubius.* Another common feature is the 'bigger deeper' effect whereby the largest individuals live at the greatest depth. However, this might be better described as the 'smaller shallower' effect to account for the observation that juveniles live at shallower depths and adults have a broader distribution at depth (Merrett *et al.* 1991b). Some species do not conform to this trend, the most noticeable being roundnose grenadier in which fish of intermediate lengths occupy the greatest depths (Gordon, 1979b). This can have important implications because, as a fishery develops and moves into deeper waters, the modal length in catches will decrease and could mask any fishery-related change in length composition.

4.1.4 Seasonal effects

4.1.4.1 On biology

It was a long held belief that the constancy of the deep-sea environment (lack of light and insignificant changes in temperature) would lead to continuous growth and all year round breeding. However, with the advent of SAMS time-series studies in the deep-water to the west of the British Isles, which began in the 1970s, it soon became apparent that this was not the case. There have been many studies on the deep-water benthic invertebrates (see Tyler, 1988) which show that seasonality of growth and reproduction is not uncommon. The annual periodicity is probably related to seasonal changes in physical processes such as eddy kinetic energy or to seasonal variations in the vertical flux of organic matter from surface production.

Difficulty in estimating age in deep-water fishes precludes investigations of seasonal changes of growth. Seasonal cycles of reproduction are, however, quite well documented for many demersal fish of the upper to mid-slopes of the Rockall Trough and Porcupine Seabight (e.g. Gordon, 1979a; Gordon and Duncan, 1985a, 1987; Coggan *et al*. 1998, 1999).

The interesting question is what provides the signal to synchronise the reproductive cycle? There are undoubtedly cycles of eddy kinetic energy in the Rockall Trough, but probably the most likely explanation is seasonal variation in the quantity or quality of the food supply. The dominance of pelagic and benthopelagic organisms in the diet and their links with surface production have already been described (Section 2.1.3).

4.1.4.2 On fish distribution

Although seasonal trends in distribution, associated with spawning, are well documented for the semi-pelagic species, such as blue whiting and the argentine, there is less evidence for the demersal species. The seasonal aggregation of blue ling is an exception and a large part of the fishery targets spawning aggregations. There is a considerable amount of local anecdotal evidence in support of seasonal changes in local abundance of other species on the slope, but on closer examination it is usually found that the level of research vessel sampling is inadequate to support such claims. The use of commercial data for these purposes is risky because so many vessels fish for other species on the shelf where seasonal availability is important. Perceived seasonal changes in the slope fishery may simply reflect changes in effort.

4.1.5 Episodic effects

The North Atlantic Oscillation (NAO) is the dominant recurrent mode of atmospheric behaviour in the North Atlantic (Dickson and Turrell, 1998). The NAO alternates between a “high-index” pattern, characterised by an intense Iceland Low with a strong Azores Ridge to its south, and a “low-index” pattern in which the signs of these anomaly-cells are approximately reversed. The pressure index between these cells is the conventional index of NAO activity, and this index has exhibited considerable long-term variability. Thus the 1960s, i.e. before exploitation of the deep-water areas to the west of Britain, were characterised by the most protracted and extreme negative phase observed, and the gradual change to the high index in the 1990s was the largest low frequency change on record. These changes have a wide range of physical and biological effects in the North Atlantic, including the intensity of deep convection at the main Atlantic sites (Greenland, Labrador and Sargasso Seas) (Dickson *et al*. 1996; Dickson, 1997) and the freshening of the upper 500-800m layer of the northern North Atlantic, a process referred to as the "Great Salinity Anomaly” (Dickson *et al.* 1988).

In addition to the above it is possible to imagine that a particularly strong cold water overflow from the Norwegian basin or a strong influx of Mediterranean water could result in short-lived changes in species composition in deep-water to the west of the British Isles. Although there is a northward flowing slope current in the Rockall Trough, gyres associated with this current are considered to provide a sufficiently long residence time for many pelagic invertebrates (Mauchline 1986, 1990). Most deep-water fish have pelagic eggs and larval stages and will depend on the same gyres for their retention in the area until they settle on the bottom at or after metamorphosis. It is possible that, in some years, the slope current may be particularly strong and this could carry pre-recruit stages into the Norwegian Sea where they will not develop into adults because of the low temperature.

Intermittent spawning in long-lived species should also be taken into account. This has been suggested for orange roughy in Australian waters by Bell *et al.* (1992).

4.1.6 Effects of local topography

All the trawl data are biased towards areas which are suitable for trawling and in some cases, such as the SAMS surveys where light gear was used, to areas with soft mud or sand bottoms. Some species or species assemblages closely associated with habitats such as coral have seldom been sampled. It is probable that data from commercial vessels correspond to fishing on a much wider range of substrate types.

4.2 A way forward

From the above, it follows that any attempt to investigate the ecological effect of fishing on deep-water fish assemblages must take into account as many of these factors as possible so as to compare like with like. Where the data permit, attempts have been made to remove depth, area and gear effects by comparing data collected using the same gear at the same depths in the same location and also by using multivariate modelling methods. Seasonal effects have been largely ignored because, in most instances, available survey data are insufficient to compare like with like.

The effects of episodic events, such as the great salinity anomaly, on deep-water fish assemblages to the west of Britain are extremely difficult to take into account, largely because little is known about them. It is known that the ‘freshening’ of the northern North Atlantic was confined to the upper 500-800m layer, so although some deep-water fish may have been affected, much of the deep-water environment below a depth of 800m may have been quite stable over the period of interest.

It was noted earlier that the available trawl survey data (Table 1) have two important characteristics. Firstly, they are very unbalanced, with data for depth-bands deeper than 1375m only available for cruises after 1982, and secondly, for a number of cruises only a single haul was carried out in each depth-band. These characteristics should be considered when interpreting the results from the analyses we have carried out in this section.

4.3 Investigation and comparison of size-spectra

4.3.1 General background

Studying the size spectra of survey catches of fish is an approach developed from the concept of the particle size spectrum as proposed by Sheldon *et al.* (1972, 1973) and by Platt and Denman (1978). Platt (1985) proposes the particle size spectrum as a unifying principle in marine ecosystems. An initial application of the idea to fishing survey data can be seen in Pope and Knights’ (1982) comparison of size spectra from the North Sea and Faroe Bank. These size spectra were constructed as the logarithm of the total count of all fish of any species, per cm group per tow, plotted against length group. Such fish size distributions have been shown to be regular features of fishing surveys of the North Sea and Georges Bank (Pope *et al.* 1988) and the slope of a size spectrum appears to reflect the intensity of fishing (Bianchi *et al.* 2000). This is indicated by size spectra being steeper in the North Sea (which is fished more heavily) than on Georges Bank. Studies in the North Sea suggest the slope of the size spectra seems to be relatively insensitive to the precise form of fishing gear used for sampling (Anon., 1992), so it may prove a robust measure to compare over systems and through time.

4.3.2 Previous studies of deep-water fish assemblages to the west of Britain

The general significance of deep-water size-spectra in terms of production and structure of the assemblage has been described by Haedrich and Merrett (1992). An attempt to investigate the effect of fishing on deep-water assemblages to the west of Britain was made by Large *et al.* (1998). The size spectrum of the catch taken during a French trawl survey of the Hebridean continental slope in 1996 (i.e. post deep-water exploitation) was compared with similar data from CEFAS deep-water surveys carried out during the early 1970s (i.e. pre-exploitation). Due to the varied morphology of deep-water fishes (some are long and thin whilst others are short and stout), fish length was considered not to be a very informative index of size. The length compositions of each species were, therefore, converted into weight distributions using length-weight conversions. The size spectra, when plotted as log numbers against log weight classes (Figure 4), indicated an increased negative slope after exploitation.

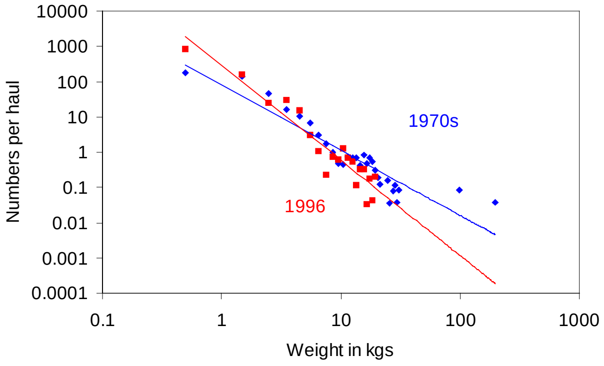


Figure 4. *Comparison of size spectra for the Hebridean slope, pre- and post-exploitation, as estimated from two CEFAS trawl surveys in the early 1970s and a single French trawl survey in 1996, respectively.*

This might suggest that the size spectrum had changed since exploitation of deep-water species intensified in the late 1980s. The slope of the size spectrum of Hebridean fish in the 1970s (-1.88) is broadly similar to that of fish assemblages in the North Sea in 1904 (2.29) (Figure 5).

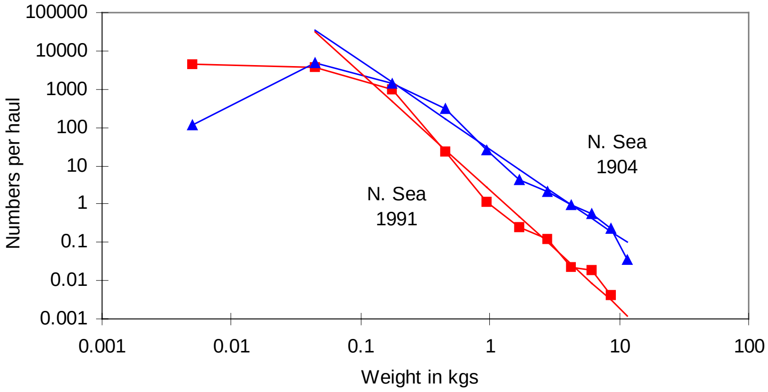


Figure 5. *Comparison of size-spectra for the southern North Sea.*

However, by 1996 the slope of the Hebridean Shelf fish had become much steeper (-2.70) and was comparable with that observed in the North Sea in 1991 (-3.06). It is recognised that the steepening of the slope for size spectra for the Hebridean Shelf may have been confounded with gear and depth effects. The French survey (RV Thalassa) used an Arrow trawl and fished over a depth range of 750-1750m, whilst the MAFF surveys (RV Cirolana) were carried out using a Granton trawl over a depth range of 540-1100m. Concern was also expressed that the estimated slopes may be very sensitive to a few points at the extreme margins of the size spectra. The more extensive data sets now available (see Table 1 in Section 3.1) enable the hypothesis of a steepening slope in the post-exploitation period to be examined in more detail, using a graphical and an analysis of covariance approach. It was noted earlier that these data are very unbalanced.

4.3.3 General protocol for the calculation of size spectra
All analyses were confined to data for the Hebridean continental slope (latitude 54^o 30’ to 58^o 45’, west to 12^o) (Figure 3). Data from this area are available from a wide range of surveys (Table 1) and it is also the primary area of exploitation by commercial vessels.

Due to the varied morphology of deep-water fishes, the length compositions of each species were converted into weight distributions using length-weight conversions from SAMS surveys (see Section 4.3.2). These were not available for some species, and in these instances fish weight was estimated using the length relationship for a species with a similar morphology (often from within the same family). Size-spectra were then calculated for each cruise and gear by averaging the weight composition of catches across stations within depth-bands, and then across depth-bands within cruises. The depth strata used were those applied in previous studies of deep-water fish assemblages to the west of the British Isles (Coggan *et al*. 1998) (Table 4). In some years there was more than one cruise carried out by a given vessel and gear combination (Table 1). In these instances, size-spectra were first calculated within depth-bands for each cruise and then averaged within and then across depth-bands to give an overall size spectrum for the cruises combined.

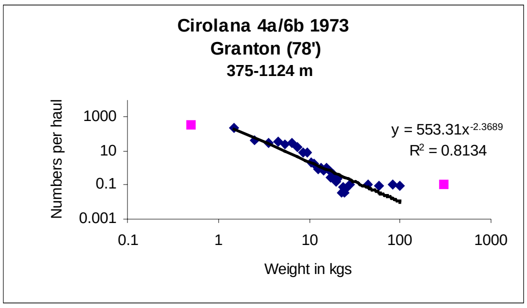
Although the SAMS length/weight relationships used were considered to be the best available, in some instances they may be biased to selected length ranges. However, this should not lead to a bias in any pattern in the slope of size spectra with time because the same length-weight conversions were used to calculate size-spectra, pre- and post-exploitation.

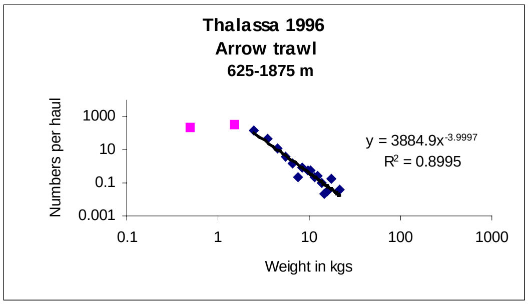
Examination of the catch records revealed that not all of the catch had been measured on some of the Walther Herwig surveys and some of the Cirolana cruises. According to the literature (Ehrich, 1983), only species of commercial interest were measured on some of the early Walther Herwig cruises. The data from these surveys were excluded from further analysis. On Cirolana 5b/1974, 10% of the catch was not measured but weighed and counted. These fish were fairly well distributed across all stations and had a substantially smaller mean weight than the remainder of the total catch. The data from this cruise were also excluded from analysis. Other Cirolana cruises were included in the analyses on the basis that virtually all the catch was measured (Cirolana 4/1973 and Cirolana 6b/1973), or most of the catch was measured (81% on Cirolana 1/1974) and the unmeasured component had a similar mean weight to the measured catch, or anecdotal information from available records and from staff on the cruise indicated that most of the species not measured were rare in catches and often present in small numbers (Cirolana 9/1978)

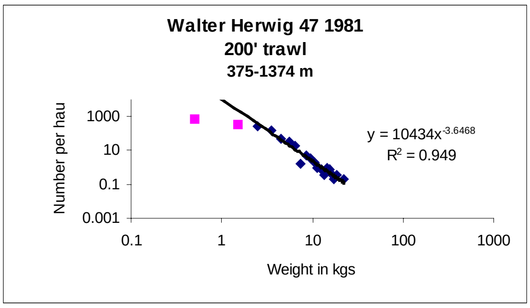
4.3.4 Size spectra results

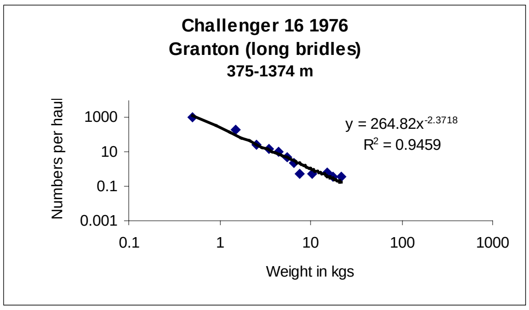
4.3.4.1 Graphical comparisons pre- and post exploitation
Examples of size-spectra for the seven gears used in trawl surveys to the west of the British Isles are shown in Figure 6. Data for the smaller weight groups for some surveys was thought to be influenced by selectivity. The Arrow trawl, the BT200 trawl and the Lowestoft Granton trawl all had substantial foot-ropes fitted with heavy bobbins, and it seems likely that the selectivity of these gears for small fish may have been low in comparison with fish of a greater size.

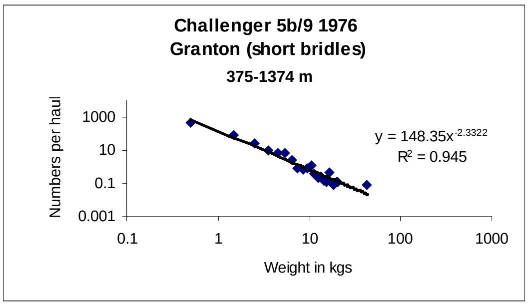
These data-points were treated as outliers and excluded from regressions. Data for occasional catches of large sharks (Figure 6, Cirolana 4a/6b, 1973) and anglerfish were also treated as outliers and excluded from regressions.

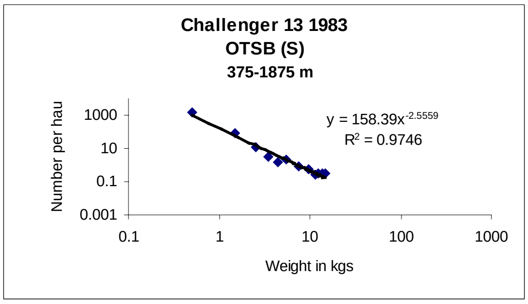












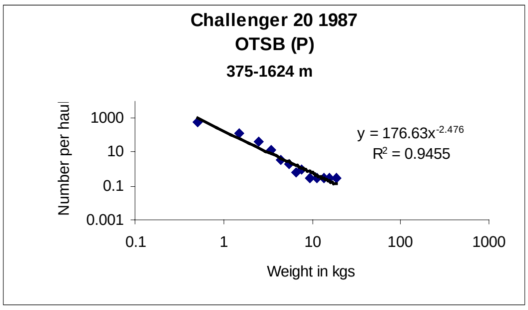


***Figure 6**. Examples of size-spectra for the seven gears used in trawl surveys to the west of the British Isles (points denoted by a red square symbol have not been included in regressions – see text)*

The slopes of the size spectra, calculated for all available trawl surveys since 1973, are plotted against time in Figure 7.

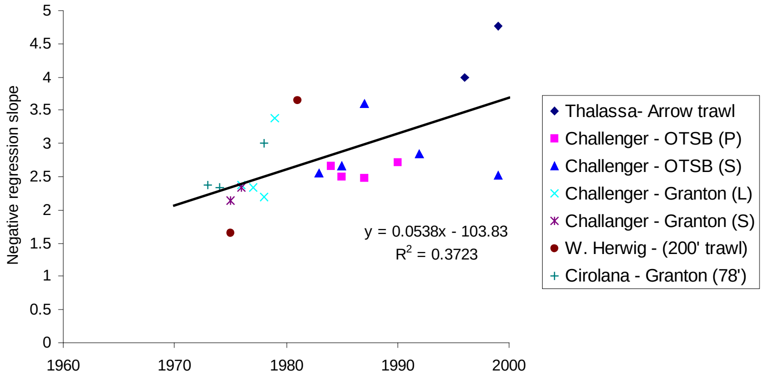


Figure 7. *Slopes of size-spectra, calculated from all available trawl surveys since 1973, plotted against time.*

There is some evidence of a steepening of slope and this is largely driven by the slopes of the size spectra of catches taken on Thalassa surveys in 1996 and 1999. However, trawl depth distribution effects might also explain these changes because data for the deeper depth-bands are only available for cruises after 1982 (Table 1). The slope (2.51) of the size spectrum of the catch taken on a SAMS survey in 1999, using an otter trawl semi-balloon (single warp), is similar to the slope (2.40) observed for catches from corresponding surveys in the mid-1980s using the same gear (Figure 8). However, the size range of the total catch is different with fewer larger fish present in 1999. It should be noted that the number of stations carried out on these surveys is small, 15 stations in 1985 and only 5 stations in 1999. Notwithstanding, it could be argued that these surveys may provide a more reliable insight into changes in the slope of size–spectra because they were carried out using the same vessel and fishing gear at exactly the same location and depth.

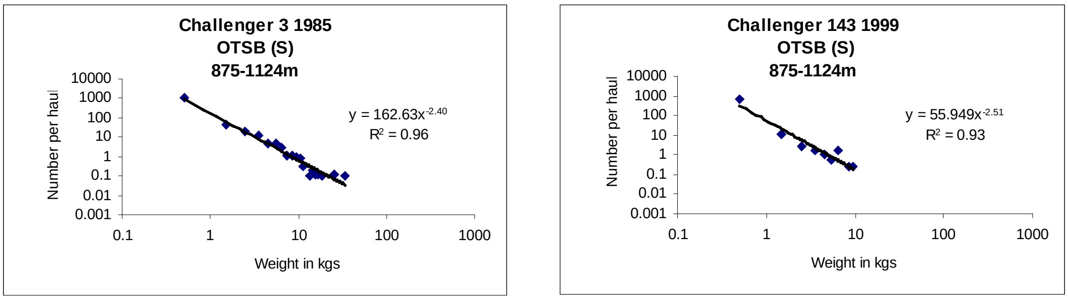


Figure 8. *Comparison of size spectra for SAMS surveys (semi-balloon otter trawl with single warp) carried out in 1985 and 1999.*

An attempt to remove the possible effects of depth was made by examining the slopes of the size spectra, calculated for all available trawl surveys since 1973, by depth-band (Figure 9). The fitted regressions show some evidence of a steepening slope with time in all depth-bands, however, only the regression for the 1125-1374m depth-band is statistically significant. It should be noted that the regressions for the deeper depth-bands are based on few observations.

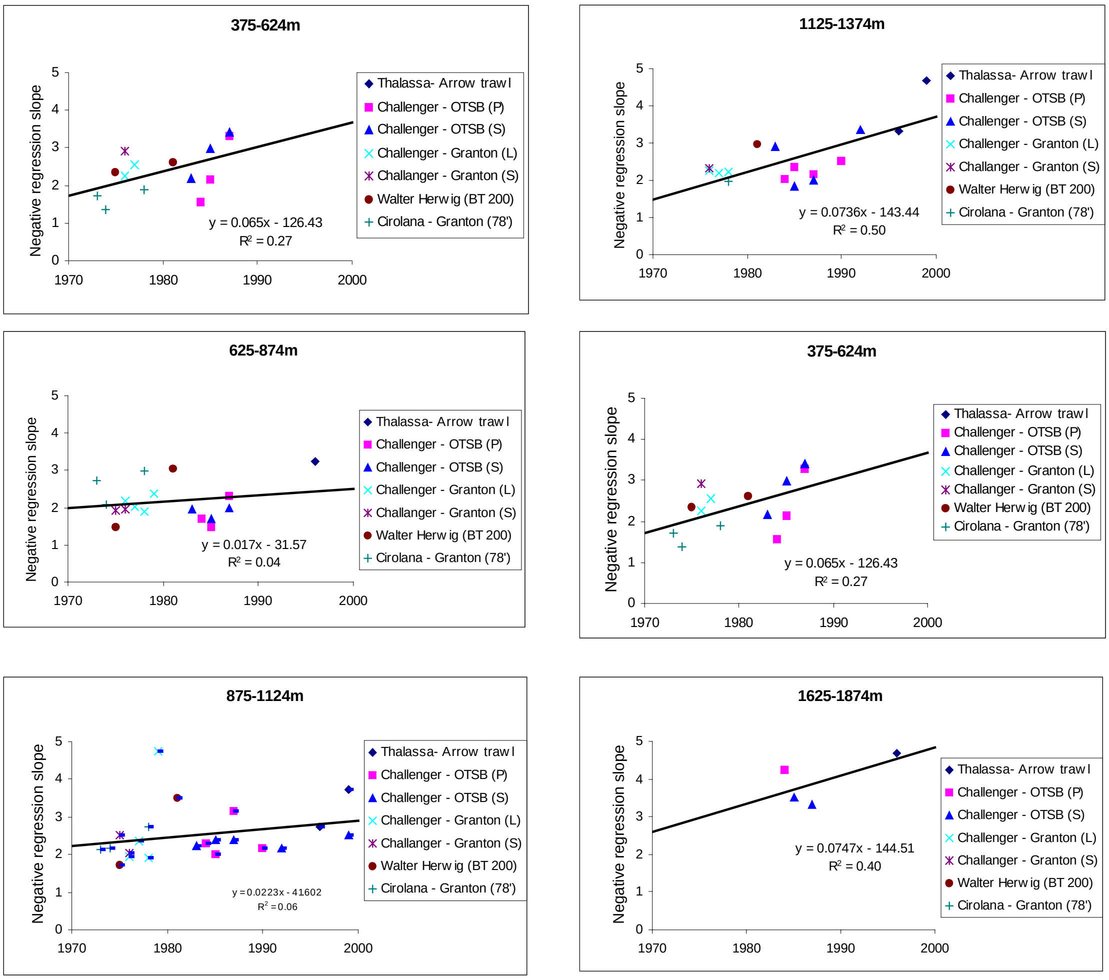


Figure 9. *Slopes of size-spectra, calculated from all available trawl surveys since 1973, plotted against time by depth-band.*

4.3.4.2 Analysis of covariance of size spectra

The graphical approach highlighted the possible gear and depth-band effects on estimates of size-spectra slopes. An analysis of covariance approach, which essentially involves fitting linear models to the data, allows for the depth-band and gear effects to be estimated explicitly. This approach also provides a more formal framework for exploring whether there have been changes in size spectra slopes over time.

The next four sections (4.3.4.2.1 to 4) are rather technical, and those readers not interested in technical details are advised to move on to Section 4.3.5 where the results are summarised.

4.3.4.2.1 Choice of factors in the analysis of covariance.

Table 1 (Section 3.1) shows the research vessel cruise, gear, depth and year classifications in the raw data. Clearly, it would be impossible to make comparisons based on each gear, depth and year. To reduce the multiplicity of gear types two forms of gear grouping were explored. In the first instance, the gears were reduced to 5 gear-groups (Table 5) as follows:

Grouping A

Gear Group	Description
1	Challenger OTSB used on a single warp,
2	Challenger OTSB used on paired warps,
3	Various Granton trawls used in the earlier period until 1979,
4	The Walther Herwig BT200 used in 1975 and 1981,
5	The Thalassa Arrow trawl.

Table 5. *Classification of cruises and gears into broad gear types (Grouping A) used in the analysis of covariance of size spectra.*

Cruise	Gear	Year	Gear Classification				
			1	2	3	4	5
Ciro4A	Granton (78')	1973			*		
Ciro6B	Granton (78')	1973			*		
Ciro1	Granton (78')	1974			*		
Chall10B	Granton (S)	1975			*		
Chall12B	Granton (S)	1975			*		
Chall14B	Granton (S)	1975			*		
Chall4B	Granton (S)	1975			*		
Chall7B	Granton (S)	1975			*		
WH17	BT200	1975				*	
Chall16A	Granton (L)	1976			*		
Chall5B	Granton (S)	1976			*		
Chall9A	Granton (S)	1976			*		
Chall16B	Granton (L)	1977			*		
Chall7C	Granton (L)	1977			*		
Chall7D	Granton (L)	1978			*		
Ciro9	Granton(78')/GOV	1978			*		
Chall1	Granton (L)	1979			*		
WH47	BT200	1981				*	
Chall13	OTSB (S)	1983	*				
Chall9B	OTSB (P)	1984		*			
Chall3	OTSB (P)	1985		*			
	OTSB (S)	1985	*				
Chall20	OTSB (P)	1987		*			
	OTSB (S)	1987	*				
Chall67	OTSB (P)	1990		*			
Chall71	OTSB (P)	1990		*			
Chall86	OTSB (S)	1991	*				
Chall89	OTSB (S)	1992	*				
Thalassa1	Arrow	1996					*
Chall143	OTSB (S)	1999	*				
Thalassa99	Arrow	1999					*

In this grouping, the Challenger and Cirolana surveys with Granton trawls are grouped together. If there is a strong vessel effect, this grouping may not be ideal. Since the Granton and OTSB(P) gears are expected to be similar, it is not unreasonable to group the Challenger Granton and Challenger OTSB(P) cruises together, but keep the Cirolana Granton trawl surveys separate. This is the same gear-grouping that is used in the CPUE analyses (Section 4.6), and this grouping provides better overlap between years and gears (see Table 6 below) than gear group A. Thus, gear group B was as follows:-

Grouping B

Gear Group	Code: Description
1	SAS: Challenger OTSB used on a single warp,
2b	SAM: Challenger OTSB used on paired warps, and Granton trawls,
3b	ENG: Cirolana Granton trawls,
4	GFR: Walther Herwig BT200 used in 1975 and 1981,
5	IFR: Thalassa Arrow trawl.

Table 6. *Summary of Gear Grouping B and year coverage.*

Year	Gear Classification				
	1=SAS	2b=SAM	3b=ENG	4=GFR	5=IFR
1973			*		
1974			*		
1975		*		*	
1976		*			
1977		*			
1978		*	*		
1979		*			
1981				*	
1983	*				
1984		*			
1985	*	*			
1987	*	*			
1990		*			
1991	*				
1992	*				
1996					*
1999	*				*

In Table 5, only a few within year comparisons exist. It was therefore decided to split the time period into just two periods for analysis with this gear grouping:-

Year Group	Description
1	1973-1987 ‘pre exploitation’
2	1988-1999 ‘post exploitation’

In theory, the decision to use two year groups (rather than individual years) should increase the number of inter-gear comparisons available in the data. This can be achieved by making an assumption that size spectra would have been similar for the same gear fishing the same depth strata within a given time period. However, despite this, in gear grouping A no within period comparisons exist between gear type 3 and 5, or gear type 4 and 5. Hence, the burden of inter-period comparisons are carried solely by gear classifications 1 and 2. It should be noted that neither gear classifications 1 or 2 were used in the same years as classifications 3 or 4, and that temporal overlap only exists between gear classifications 1 and 5 in 1999. It is therefore clear that the design is unbalanced and inferences drawn from it should be treated with extreme caution.

With regard to gear grouping B, the gear/year coverage is somewhat improved (Table 6). There is now an additional year (1978) linking gear groups 2 and 3, and therefore indirectly linking gear group 5 to the other gear groups. Because of this improvement, analyses with gear grouping B were performed with two time-classifications: (a) the two year-groups as defined above (1973-1987, and 1988-1999) and (b) year as a continuous variable.

Since depth bands fished also varied between cruises, these were also taken as factors. Depth class factor codes used in the analyses for both gear groupings are those shown earlier in Table 4 (Section 3.1).

4.3.4.2.2 The analysis of covariance model chosen

Size spectra in terms of the logarithm of numbers against the logarithm of weights are used, as in the graphical analyses. The basic size spectrum model is calculated as the simple regression model:-

Ln (numbers per weight group)= a + bLn (weight) + ε

where ε is a normal error, a is the intercept and b is the slope.

More complex models are then considered by progressively introducing variables such as the depth, gear and time period effects. Firstly, these were introduced as main effects (affecting estimates of intercepts), and then as interactions with Ln (weight) (affecting estimates of slope). As each additional variable was introduced, the reduction in the sum of squares (SSq) and degrees of freedom (DF) was noted. This information was used to evaluate whether the inclusion of the variable leads to a significant improvement in the fit of the model to the data.

The full model fitted was:-

Ln (numbers per weight group)= a + d(Depth) + g(Gear) + t(Time) + (a + ad(Depth) + ag(Gear) + at(Time))* Ln (weight) + ε

where d(Depth), g(Gear), and t(Time) represent the main effects due to the 7 depth classification, the 5 gear classification, and the 2 time period classification variables and ad(Depth), ag(Gear) and at(Time) indicate equivalent effects on the slope.

Size groupings with zero counts were omitted from the analysis because of the logarithmic transformation. In theory, zero counts could have been included by assuming a Poisson model based on the untransformed data, but exploratory analyses showed that the Poisson assumption of variance proportional to mean was violated.

Data for the smaller weight groups for some surveys thought to be influenced by selectivity, and for occasional catches of large sharks and anglerfish, were excluded from analysis (referred to for the remainder of this section as ‘standard exclusions’). These exclusions were the same as those used in the graphical presentation in Section 3.3.4.1. Examination of the size-spectrum for each cruise suggested that for all surveys there may be a case for excluding data for fish under 1kg and over 20kg from analysis. Hence, as well as a run of the model with the standard exclusions, further model runs were made progressively excluding these two groups of data. Model runs were thus:-

1. Standard exclusions (as per described in Section 4.3.4.1)
2. Additionally excluding data in all weight groups under 1kg
3. Additionally excluding data in all weight groups over 20 kg.

Analyses for gear grouping B was conducted in a similar way, but runs were only done for the standard exclusions.

4.3.4.2.3 Results of the analysis of covariance: gear grouping A.

Tables 7,8 and 9 show the ANCOVA results for the three runs. In each run the basic model (including only ‘Ln Weight’) accounts for the greater part of the variance. The depth and gear factors remove some further variance both as main effects and as modifications of slope. Given the large numbers of residual degrees of freedom in the data sets, all of these effects are highly significant. By contrast, the effect of year grouping is less important as a main effect (though still significant at the 3% level in all models; see column ‘P’ for the row marked ‘Year Group’ in Tables 7,8,9). The effect of year grouping is, however, small and not statistically significant as a modifier of the slope (as the interaction with Ln weight).

Table 7. *Analysis of covariance of size-spectra: gear grouping A – standard exclusions.*

Cause	DF	SSq	MSq	F	P
Ln Weight	1	3697.0	3697.0	4058.3	<0.00001
Depth Class	6	59.1	9.8	10.8	<0.00001
Gear Class	4	162.1	40.5	44.5	<0.00001
Year Group	1	4.6	4.6	5.0	0.0255
Ln Weight.Depth Class	6	49.2	8.2	9.0	<0.00001
Ln Weight.Gear Class	4	51.8	13.0	14.2	<0.00001
Ln Weight.Year Group	1	2.3	2.3	2.5	0.1161
Residuals	926	843.6	0.9	1.0	<0.5000
Total	949	4869.6	5.1	5.6	

Table 8. *Analysis of covariance of size-spectra: gear grouping A – standard exclusions plus data in all weight groups <1kg excluded*

Cause	DF	SSq	MSq	F	P
Ln Weight	1	1979.0	1979.0	2162.5	<0.00001
Depth Class	6	63.7	10.6	11.6	<0.00001
Gear Class	4	205.6	51.4	56.2	<0.00001
Year Group	1	5.9	5.9	6.4	0.0114
Ln Weight.Depth Class	6	39.4	6.6	7.2	<0.00001
Ln Weight.Gear Class	4	42.0	10.5	11.5	<0.00001
Ln Weight.Year Group	1	0.2	0.2	0.3	0.6024
Residuals	841	769.6	0.9	1.0	0.5000
Total	864	3105.4	3.6	3.9	

Table 9. *Analysis of covariance of size-spectra: gear grouping A - standard exclusions plus data in all weight groups <1kg and >20kg excluded*

Cause	DF	SSq	MSq	F	P
Ln Weight	1	1750.0	1750.0	1957.9	<0.00001
Depth Class	6	69.0	11.5	12.9	<0.00001
Gear Class	4	196.1	49.0	54.8	<0.00001
Year Group	1	5.3	5.3	6.0	0.0149
Ln Weight.Depth Class	6	33.8	5.6	6.3	0.0000
Ln Weight.Gear Class	4	40.5	10.1	11.3	<0.00001
Ln Weight.Year Group	1	0.0	0.0	0.0	0.9342
Residuals	796	711.5	0.9	1.0	0.5000
Total	819	2806.2	3.4	3.8	

Attempting to reduce the variance by excluding small and large weight groupings has little effect on overall residual variation and appears to make the year slope effect even less important than in the models with just the standard exclusions. It is possible that the low year effect on the slope is due to it being confounded with gear and depth effects and also to it being the last factor fitted. However, a superficial interpretation would be that there is little evidence of a year effect between the pre- and post-1988 periods.

Figure 10 shows bar charts of the size of the parameter estimates for each of the main effects (contributing to the intercept, left figure) and interactions with Ln weight (contributing to the slope, right figure) from each of the three runs. Results from the three runs are broadly similar. Only the slope factors for gears 2, 3 and 4 (parameters marked G(2), G(3) and G(4)) show different signs between the initial run and the two runs made with the data from the extremities omitted. Other features worth noting are the differences in parameter estimates by depth-band, and the fact that gear 5 (Thalassa Arrow trawl) has a higher intercept and a steeper slope than other gears. The effects of the year factor are small on both slope (parameter LW.YG(2)) and intercept (parameter YG(2)).

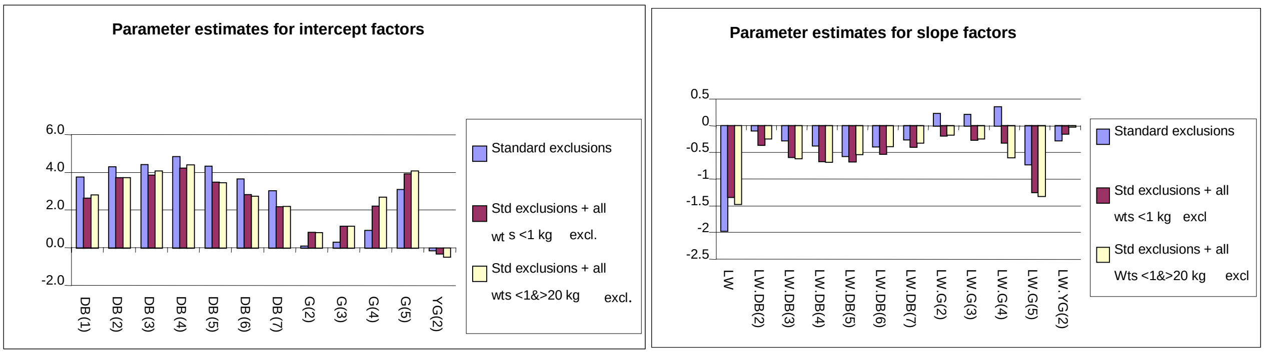


Figure 10. *Parameter estimates for intercept and slope factors included in the analysis of covariance of size spectra : gear grouping A.*

Since the dataset is unbalanced, with some gear types used in only one of the two year groups, it is possible that the observed data could be explained either by gear effects or by year effects. If so, it would become very difficult to establish whether gear or year is genuinely responsible. To examine whether this theoretical possibility is a real problem for this dataset, one can examine the correlation between parameter estimates. Figure 11 shows a substantial negative correlation between the parameter estimates of the year group 2 slope and the gear group 5 slope. There is a corresponding positive correlation between the year group 2 slope and the gear group 5 intercept. This may indicate that the steeper slope associated with gear 5 might alternatively be due to an undetected year effect. It was noted earlier that the detection of the year effect rests mostly on gears 1 and 2, which are the only gears used in both time periods. (Note that the correlation between the year group 2 slope and intercept parameters is expected on statistical grounds, and does not indicate a problem.).

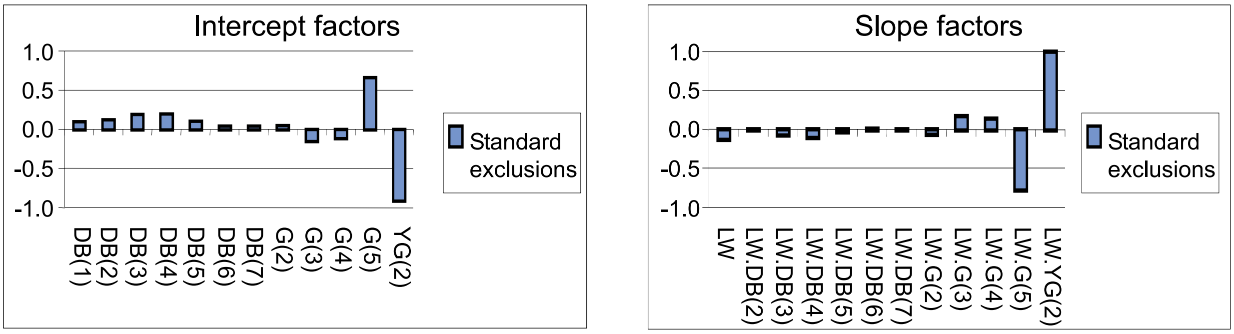


Figure 11 Correlation of the year group 2 slope parameter estimate with parameter estimates for intercept and slope factors included.

An exploratory analysis of gear groups 1 and 2 alone (results not presented) does not indicate a significant year group factor. However, the single warp semi-balloon trawl gear (gear group 1) is not ideal for estimating size spectra due to the possibility of the central warp herding larger fish away from the net.

4.3.4.2.4 Results of the analysis of covariance: gear grouping B.

The ANCOVA results for gear grouping B are shown in Tables 12 and 13. If two periods are fitted to the data, the year interaction term is significant if it is fitted before the gear-interaction term, but not the other way around (Table 12). This again highlights the potential confounding between gear and year effects, particularly when two year groups are used. The result is also not entirely surprising given that the Thalassa survey has very steep slopes with Ln Weight (Figure 7), and only occurs in the second period. Although in this gear grouping (B), the Thalassa survey is linked to other gear types via the SAMS data (with OTSB(S) gear) in 1999, this link is relatively weak because of the small number of hauls.

Table 12. *Analysis of covariance of size-spectra models: gear grouping B for the 2-period year grouping (1=(years <1988), 2=(years > or = 1988))*

Terms	Residual Df	RSS	Df	SS	F	Pr(F)
1.LnWt+Depth+Gear	845	818.8				
2. + yrgrp	844	810.9	1	7.907	9.12	0.0026
3. +lnwt * dband	838	783.0	6	27.91	5.36	<0.0001
4. +lnwt * yrgrp	837	760.3	1	22.66	26.1	<0.0001
5. +lnwt * cygear	833	722.2	4	38.11	11.0	<0.0001
If Gear is fitted before Year group (after model 3 above)						
4. +lnwt * cygear	834	722.5	4	60.49	17.4	<0.0001
5. +lnwt * yrgrp	833	722.2	1	0.284	0.33	0.5666

At a given depth band, differences between gear groupings are greater than differences between time periods for the same gear group. This is illustrated in Figure 12 for a subset of the gear groups, where the symbols for gear-group are further apart than the year-group symbols for an individual gear group.

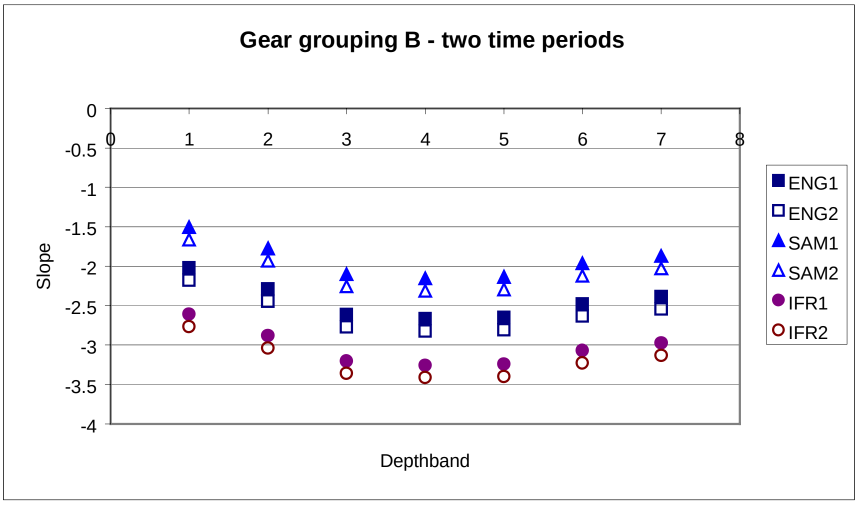


Figure 12. *Predicted slopes for the model with 2 time-periods (solid symbols for pre-1988, and open symbols for post-1988). The legends are the gear grouping name (e.g. 'ENG'), plus a '1' for the first period, and a '2' for the second period. For clarity, only a subset of gear groups are plotted.*

If year is treated as a continuous variable, the results are somewhat different (Table 13). First, the year-interaction term is now significant irrespective of whether it is included before or after the gear-interaction term.

Table 13. *Analysis of covariance of size spectra models: gear grouping B, with the year treated as a continuous variable*

Terms	Residual Df	RSS	Df	SS	F	Pr(F)
1.lnwt+dband+cygear	845	818.8				
2. + year	844	809.8	1	8.976	10.4	0.0013
3. +lnwt * dband	838	784.4	6	25.46	4.92	<0.0001
4. +lnwt * year	837	776.5	1	7.863	9.12	0.0026
5. +lnwt * cygear	833	718.2	4	58.36	16.9	<0.0001
If cygear is fitted before year (after model 3 above)						
4. +lnwt * cygear	834	724.1	4	60.33	17.5	<0.0001
5. +lnwt * year	833	718.2	1	5.89	6.83	0.0091

Figure 13 also shows that the estimated change in slope between pre- and post-exploitation periods is now greater. The figure shows the AVERAGE slope over each of the two periods, so comparisons of predicted slopes in 1973 compared to 1999 would be even further apart. Secondly, the model also estimates the slopes for the Cirolana and Thalassa surveys as being more similar than in the 2-period model (Figure 12). It was noted earlier, however, that this is based entirely on indirect comparisons via the other gear types, SAMS data in particular. The depth-band effects are similar in the two models, and this is encouraging.

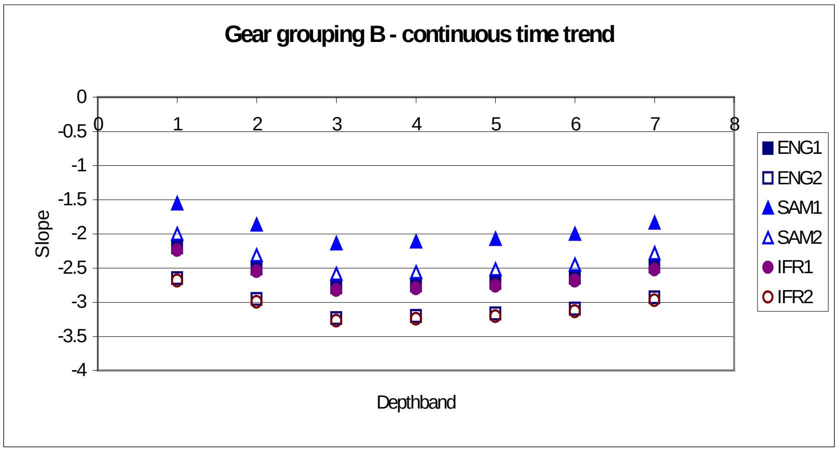


Figure 13. *Predicted slopes for the model with a continuous time-interaction, presented as the average slope for 1973-1987 (solid symbols), and the average for 1988-1999 (open symbols). The legends are the gear grouping name (e.g. 'ENG'), plus a '1' for the average over the first period, and a '2' for the average over the second period. For clarity, only a subset of gear groups are plotted.*

With regard to the analysis with gear grouping B, the answer to the question (whether there has been a substantial change over time in the slope of the size spectra) depends on the treatment of 'year', i.e. whether 2 periods are considered or whether year is treated as a continuous variable. Unfortunately, there is no easy way to choose between the two models. The models cannot be compared through the standard ANOVA, because they are not nested. The model diagnostics are very similar, and neither model shows strong residual patterns, so that neither can be rejected on these grounds. Since the two models estimate the same number of parameters, the residual sums of squares can be compared, and it is worth noting that the 2-period model has a higher residual sum of squares than the model which treats 'year' as a continuous variable.

4.3.5 Discussion

Results from the size spectra analyses with generalised linear models depend somewhat on the gear grouping used, and the way in which the year-effects are incorporated in the models. When years are grouped together into two periods ,(pre- and post-exploitation), it is not possible to determine whether the estimated change in slope between the two periods is due to a change over time, or due to the different gears used in the two periods. When year is treated as a continuous variable, this problem appears to be less severe, and results suggest that there have been changes in the slope over time (with steeper slopes in recent years).

Although it is fair to say that there are some indications of an increase in the slope of the size spectrum, this result is neither very strong nor highly conclusive. There are two ways of interpreting this: (i) either there has been very little change in the size spectrum slope as suggested by the SAMS surveys carried out in 1985 and 1999, or (ii) there has been a relatively big change, but the data are incapable of detecting the change. Regarding (i), this is possible but one may expect to see a change in the slope based on experience in other harvested ecosystems (e.g. the North Sea) where such changes have been detected over a long time period (more than 90 years). The deep-water fishery has been operating for a far shorter period, and may also operate in such a way that there is less change in slope for a similar level of exploitation. Such a situation could arise if the discards and incidental by-catches cover a relatively wide size range of fish rather than mainly smaller specimens. Since discards or any returned fish are highly unlikely to survive, the effect would be one of additional mortality on a much wider size range than that targeted by the fishery. This could lead to a reduction in the intercept (essentially catch rate), but no, or very little, change in the slope of the size spectrum.

Regarding (ii), the only way to resolve whether the size spectra has or has not reacted to the increased exploitation of the area in the post 1988 period would properly require that some within year gear comparisons be made between gear group 3 and particularly gear group 5. Ideally this would involve a comparison of RV Cirolana using the 78' Granton trawl as used in 1973 and R.V. Thalassa using the Arrow trawl as used in 1996 and 1999. Very few fisheries exist where it is still practical to make a comparison between pre exploitation and post exploitation situations. This possibility is also fast vanishing for the deep-water fisheries. Thus, the possibility of RV Cirolana being chartered, while she is still in service, to make a final cruise alongside of R.V. Thalassa in this area should be urgently presented to funding bodies.

4.4 Effect of fishing on the species composition of fish assemblages.

4.4.1 Introduction and general background

Our knowledge of the fish assemblages of areas such as the North Sea is based on extensive sampling by a large number of gear types and is, therefore, unlikely to be biased by the catch of a particular gear. However, the amount of sampling in the deep-sea has been very limited both in terms of number of samples and of gears used. An experienced observer could probably look at a catch on deck and place it within about a 200 m depth band and make a fairly informed guess about the type of gear used. Similarly, subtle differences in species composition and abundance can usually separate a catch from the Hebridean slope from one taken in the Porcupine Seabight.

In this section, we attempt to evaluate the effect of fishing on the species composition of fish assemblages, as reflected by the composition of catches taken on SAMS surveys carried out using a single warp semi-balloon otter trawl. These surveys were carried out in 1983, 1985, 1987, 1992 and 1999, and provide a useful comparison pre and post-exploitation, since the same gear was used at the same location, in the same depth-band (875-1124m) and, for the surveys in 1985 and 1999, at the same time of year.

4.4.2 Graphical comparisons pre-and post exploitation

A comparison of the size distribution in catches for the cruises in 1985 and 1999 is given in Figure 14. Catch is used as a proxy for biomass and numbers have been grouped on a log 2 scale i.e. weight-class 7 comprises fish within a weight range of 2^7 and 2^8 grams (128-256g) (Sheldon *et al*. 1972).

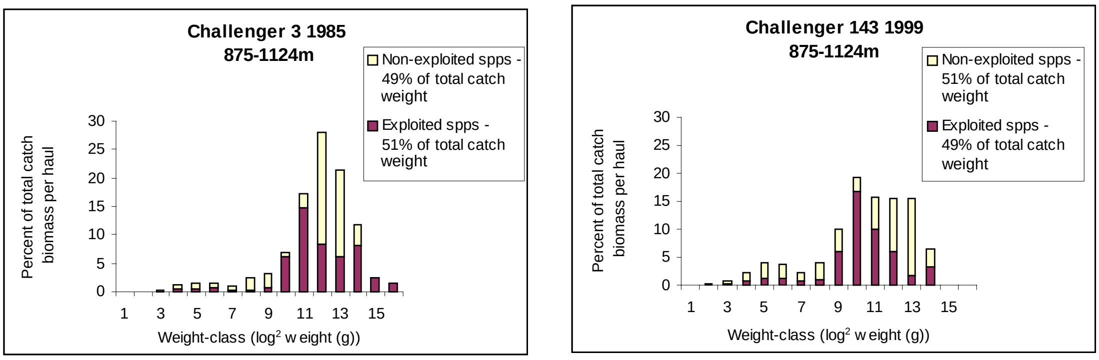


Figure 14. *Comparison of size distribution in catches taken on SAMS trawl surveys (semi-balloon gear - single warp) carried out in 1985 and 1999.*

The proportion of exploited and non-exploited species in each weight class is also shown. This comparison indicates that the proportion by weight of larger fish (>2^{11}g , around 2kg) in the catches taken during the 1999 survey (38%) was lower than in 1985 (65%), and also that the proportion of smaller fish (<2^{9}g, around 0.5kg) was higher (8% in 1985, 17% in 1999). The proportion of exploited and non-exploited species in catches was the same in both surveys, roughly half and half. The percentage composition by species family of individual weight-classes is described in Figure 15.

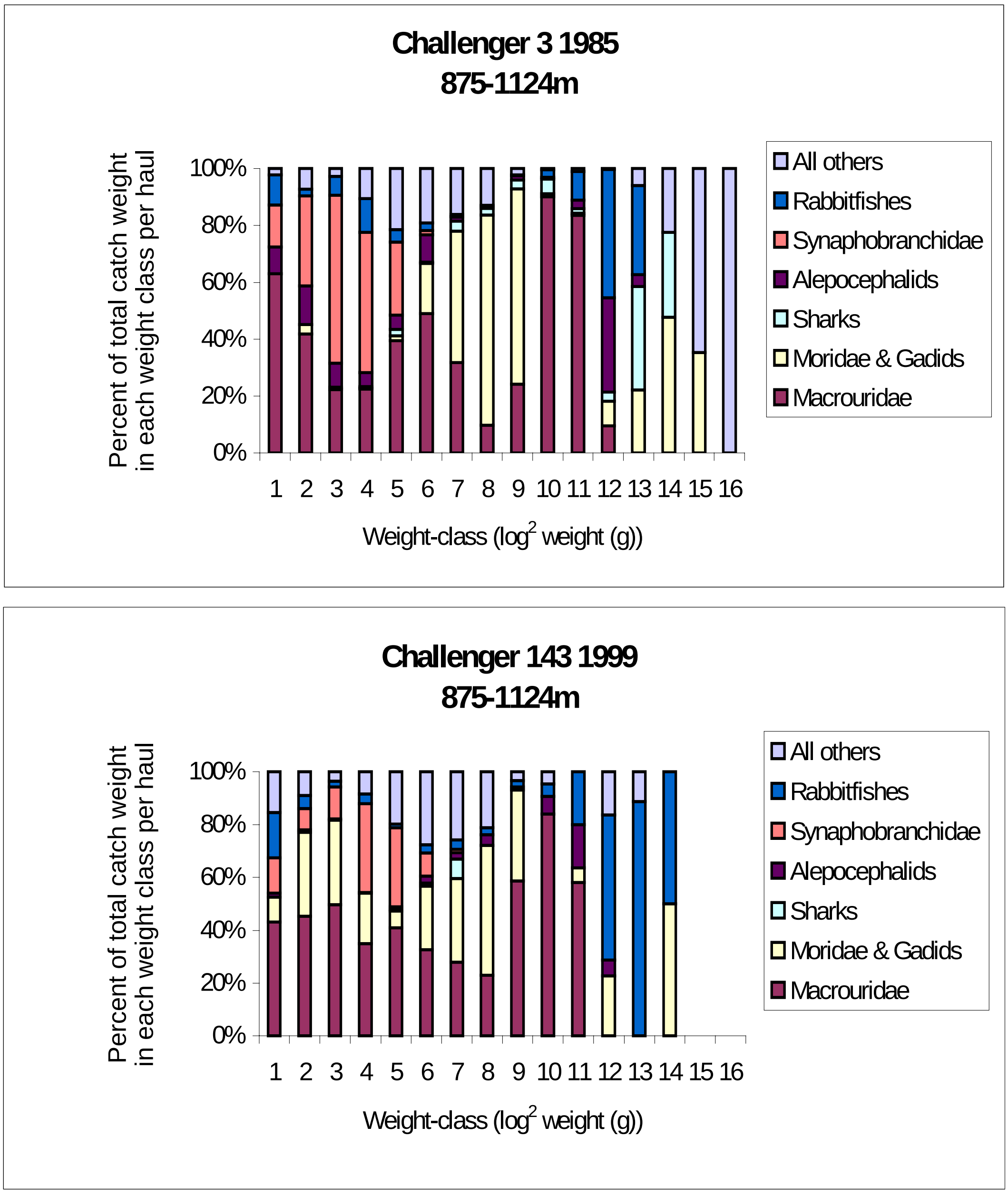


Figure 15. *Percentage composition by species family of individual weight classes in the size distribution in catches taken on SAMS trawl (semi-balloon gear - single warp) carried out in 1985 and 1999.*

Fewer deep-water sharks were present in catches in 1999 and rabbitfish accounted for an increased proportion of larger fish. However, graphical methods clearly have limitations as far as detecting smaller, more subtle changes in the species composition of catches is concerned.

4.4.3 Detrended correspondence analysis

Multivariate ordination techniques have frequently been used to explore differences in catch composition. Detrended correspondence analysis (DCA) was used by Gordon and Bergstad (1992) to compare the catches of three different trawls over a wide depth range in the Rockall Trough. In a further study DCA was also used to compare the catches of different gears in the Rockall Trough and the Porcupine Seabight (Gordon *et al.* 1996).

DCA uses catch data to reveal information on the distribution of species among stations. The data analysed are in the form of a rectangular matrix of catches by species and stations, and the results generated are scores of individual species and stations along underlying gradients (axes) revealed by the analysis. Usually, only the first two axes are useful in analyses of ecological data, and the conventional way of illustrating the results is in the form of a scatter plot of species or stations.

For this present study, a DCA analysis was carried out using catch data from the SAMS surveys in 1985 and 1999 described earlier and also from occasional tows using the same trawl at the same location at similar depths carried out in 1983, 1987 and 1992.

Figure 16 shows the distribution of species in the co-ordinate system formed by the two first ordination axes (axes 1 and 2), which explain most of the variance in the data. For presentational reasons, each species has been allocated a simple numerical code (see Appendix 9.3 for key to species). The dominant species that are present in all hauls are grouped close to the origin, whereas species occurring far apart in the diagram tend not to occur in the same hauls. Based on this species ordination, an ordination of stations can then be calculated (Figure 16).

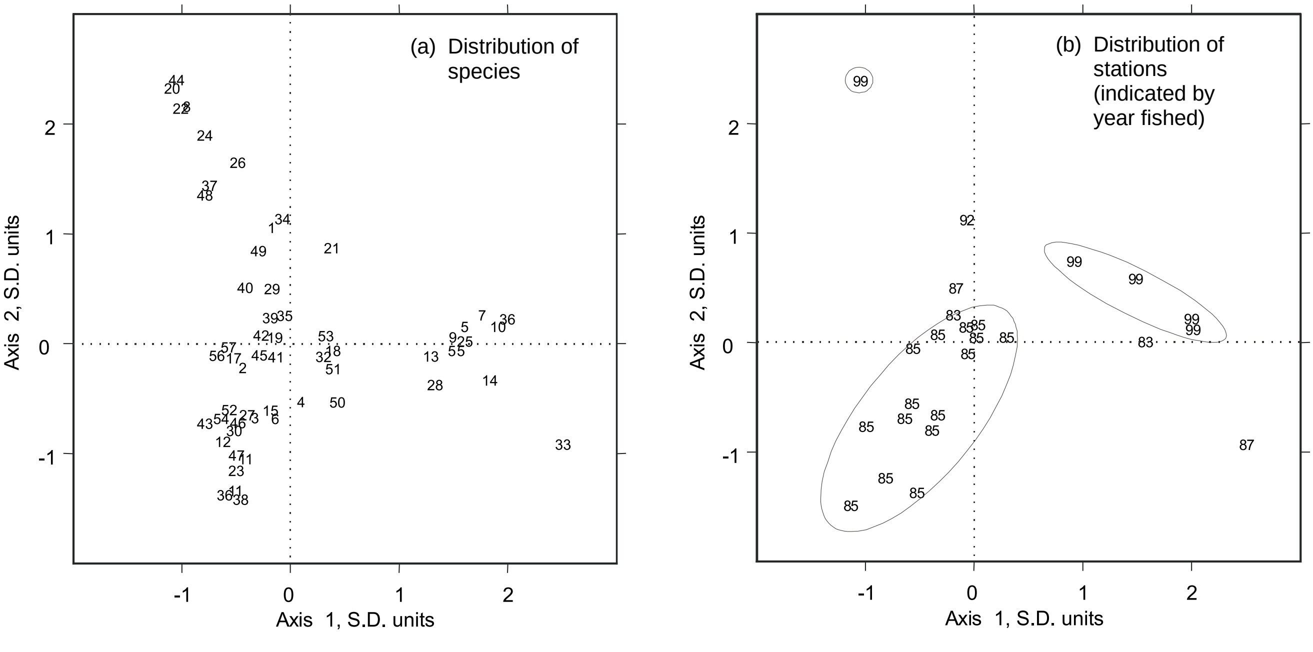


Figure 16 *Results of detrended correspondence analysis (DCA) of single warp OTSB trawl catches at about 1000 m depth on the Hebridean Terrace, 1983-1999. The distribution of a) species, and b) stations. Stations from 1985 and 1999 are encircled.*

The results show that stations in 1985 and 1999 appear to form coherent clusters suggesting some inter-annual differences in catch composition despite there also being considerable intra-year variation. One station in 1999 is very different from all the others and was characterised by a very large catch of juvenile roundnose grenadier. In a DCA, stations occurring about 4 standard deviation units apart will generally have entirely different species compositions. Thus in this analysis no stations are totally different but there are still suggestions of a marked and consistent difference in the composition of catches between the 1985 and 1999 surveys.

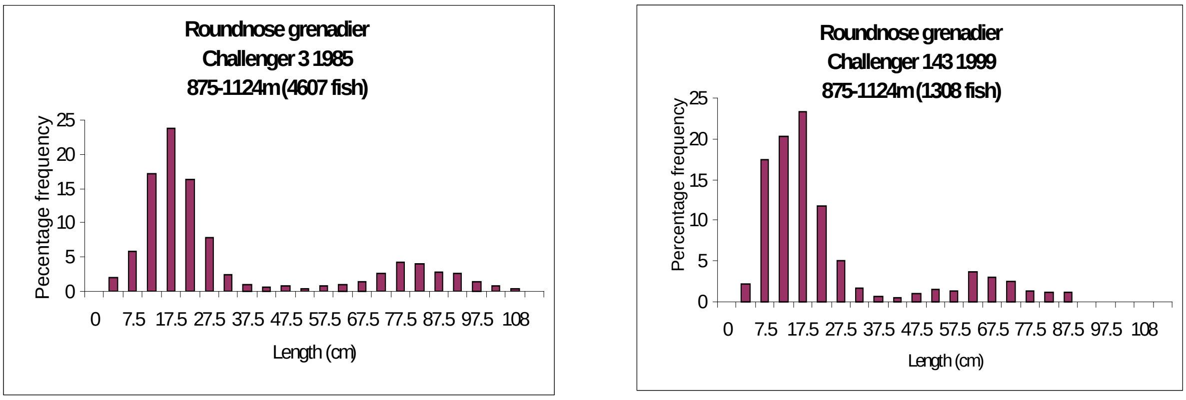
Table 14 shows the top ten species by number for the pooled data for the 1985 and the 1999 cruises expressed as a percentage of the total catch of that cruise.

Table 14. *The top ten species by number for each cruise expressed as a percentage of the total catch.*

Cruise	3/85			143/99	%
No. Hauls	15			5	
	Species	%		Species	%
	Synaphobranchus kaupi	26.3		*Synaphobranchus kaupi*	65.9
	Coryphaenoides rupestris	25.1		*Coryphaenoides rupestris*	14.5
	Nezumia aequalis	15.8		*Lepidion eques*	5.7
	Lepidion eques	6.5		*Nezumia aequalis*	2.7
	Chimaera monstrosa	5.5		*Antimora rostrata*	2.6
	Alepocephalus bairdii	5.4		*Coelorhinchus occa*	1.9
	Notacanthus bonaparti	4.0		*Hydrolagus mirabilis*	1.7
	Coelorhinchus occa	3.1		*Trachyrhincus murrayi*	1.6
	Hydrolagus mirabilis	2.1		*Coryphaenoides guentheri*	0.7
	Xenodermichthys copei	1.1		*Alepocephalus bairdii*	0.5

This shows the dominance of relatively few species and particularly of the cut-throat eel (*Synaphobranchus kaupi*) and *Coryphaenoides rupestris.*

A preliminary examination of the size distributions of the dominant species suggest that in most cases they are remarkably similar between cruises with a bias towards juveniles as is to be expected with this trawl. *Synaphobranchus kaupi* exhibits a well marked bigger-deeper phenomenon and the size of the juveniles in this study agree with previously published data for this depth (Gordon and Mauchline 1996). The reproductive biology is still the subject of debate, but, even if spawning occurs in the Rockall Trough, it will be a depths much greater than are presently exploited. The length distribution of *Coryphaenoides rupestris* at 1000 m is markedly bimodal (Gordon, 1979b). The modal length of the peak of juvenile fish is similar between the cruises but there appears to be a shift to a smaller modal size of the adult fish in 1999 (Figure 17).


Roundnose grenadier
Challenger 3 1985
875-1124m (4607 fish)

Roundnose grenadier
Challenger 143 1999
875-1124m (1308 fish)

Figure 17. *Comparison of length composition, of roundnose grenadier, 1985 and 1999* ***(Note;*** *for this species head length was measured at sea and total length data have been calculated using a conversion factor.supplied by SAMS)*

4.4.4. Discussion

The results from a DCA analysis suggest that there may have been temporal changes in species composition between catches taken in 1985 and 1999 in the Rockall Trough. However, until the results are fully analysed in terms of the biology of the species, it would be inappropriate to attribute this to an effect of exploitation. The nature of the sampling gear, with its bias towards sampling juveniles and against sampling large active species, is an important factor. Adults of some of the species are under-represented and these are probably the most impacted by the fishery. Finally, it is important to note that the surveys carried out in 1985 and 1999 comprised only 15 and 5 hauls, respectively, and differences in catch composition may reflect sampling variance rather than real differences in the composition of fish assemblages. A detailed study of these results is in progress and will be published in due course.

4.5 Investigation and comparison of diversity indices, pre and post-exploitation.

4.5.1 Introduction and general background

A range of diversity indices has been applied to species abundance data and these have been reviewed in several texts (Pielou, 1975; Washington, 1984; Magurran, 1991). Species diversity comprises three components: species richness (the number of species present), the relative abundance of species (species evenness) and taxonomic distinctness (how closely related the species are). The numerous diversity indices used in the literature vary in their sensitivity to these components. Consequently, no single index can convey all important changes in community structure that can occur with time. A range of indices, each selected for its sensitivity to a particular type of variation in assemblage structure, has been used in this present study. The principal aim is to detect any changes in the structure of the deep-water fish assemblage to the west of British Isles that may have occurred as exploitation has increased. Other comparisons of diversity indices, by depth-band for example, are also made.

4.5.2 Data

The survey data available for analysis are described in Table 1 in Section 3.1. The data used for investigation of diversity indices in the pre-exploitation phase were as follows:-

SAMS semi-balloon otter trawl – single warp (OTSB(S) – 1983-87
SAMS semi-balloon otter trawl – paired warps (OTSB(P) – 1984-87
SAMS Granton trawl - short bridles (GTS) – 1975-76
SAMS Granton trawl – long bridles (GTL) – 1976-79

The data used for investigation of diversity indices in the post-exploitation phase comprised:-

IFREMER Arrow trawl (ARO) – 1996 & 1999
SAMS semi-balloon otter trawl – single warp (OTSB(S)) – 1999

A summary of the number of trawl hauls available by survey series and depth-band is given in Tables 15 and 16. Only data for benthopelagic species were analysed. Data for blue whiting (*Micromesistius poutassou*) and the silvery pout (*Gadiculus argenteus*), and mesopelagic species were excluded. In the analyses, only blue whiting occurs in sufficient numbers to influence diversity indices.

Table 15. *Number of stations per strata for calculation of diversity indices, pre-exploitation.*

	Survey series			
Depth-band (m)	GTL	GTS	OTSB(S)	OTSB(P)
375-624	3	2	3	3
635-874	5	7	3	3
875-1124	4	7	17	8
1125-1374	3	1	3	3
1375-1624			4	3
1625-1875			4	1
>1875			1	
Total	15	17	40	24

Table 16. *Number of stations per strata for calculation of diversity indices, post-exploitation.*

	Survey series	
Depth-band (m)	OTSB(S) 1999	ARO 1996-99
375-624		
625-874		1
875-1124	5	11
1125-1374		18
1375-1624		4
1625-1875		2
>1875		4
Total	5	40

4.5.3 Methods

The following diversity indices were calculated using catch data for each survey-series, expressed both in terms of abundance and biomass:- Shannon species diversity (H'), Hill's N1, Hill's N2, Delta (Δ) and Delta star (Δ*).

It is beyond the scope of this present analysis to describe in detail how these indices are calculated. In brief, Hills'N1 index is the exponential of a Shannon species diversity index (Hill, 1973; Shannon and Weaver, 1963). Both of these indices take species evenness and richness into account. Hill's N2 index is the reciprocal of a Simpson index which is more a measure of species dominance and is rather less sensitive to species richness (Simpson, 1949),. The Δ and Δ* indices were first proposed by Warwick and Clarke (1995). The Δ index describes taxonomic diversity and is empirically related to Shannon's diversity index but with an added component of taxonomic distinctness. The Δ* index is considered to be a measure of taxonomic distinctness rather than species diversity. Hall and Greenstreet (1998) suggested that the Δ and Δ* indices include a component of taxonomic distinctness and should be more sensitive than conventional measures at detecting the early stages of community change.

Having calculated the diversity indices, the results for each survey series, plotted by depth-band, are then compared pre-and post exploitation. In addition, a further comparison of diversity indices is made using SAMS survey data collected in 1985 and 1999, using the same gear (OTSB(S)) in the same location at the same time of year.

4.5.4 Comparison of diversity indices and discussion

The diversity indices for catches from the six gear and year classifications described in Tables 15 and 16, expressed in numerical abundance (Figure 18) and biomass (Figure 19), show a general trend of declining diversity and taxonomic distinctness with depth over the depth range 375-1374m, which then stabilises at depths greater than 1374m.

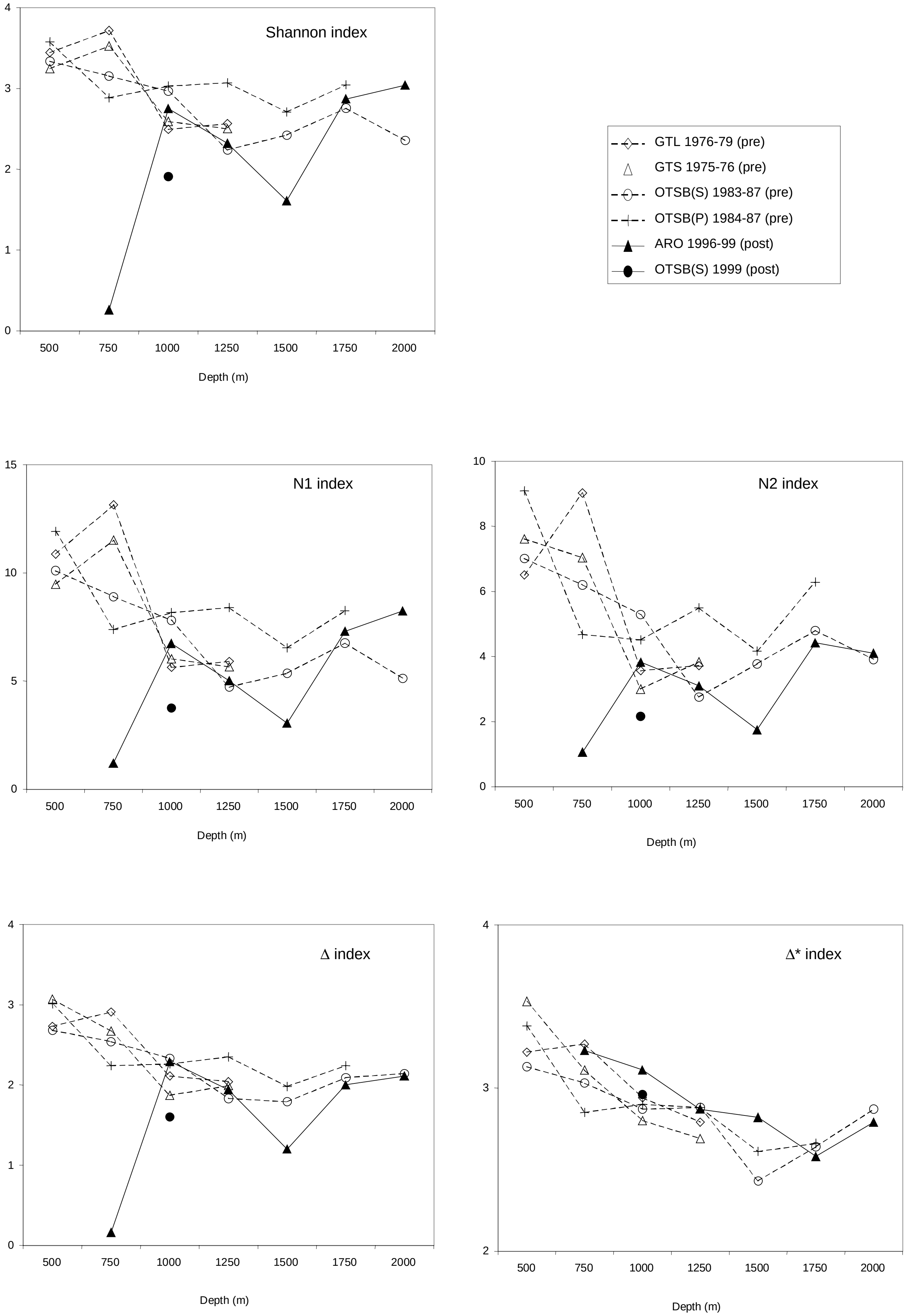


***Figure 18**. Diversity indices calculated from catch abundance data by gear and depth band.*

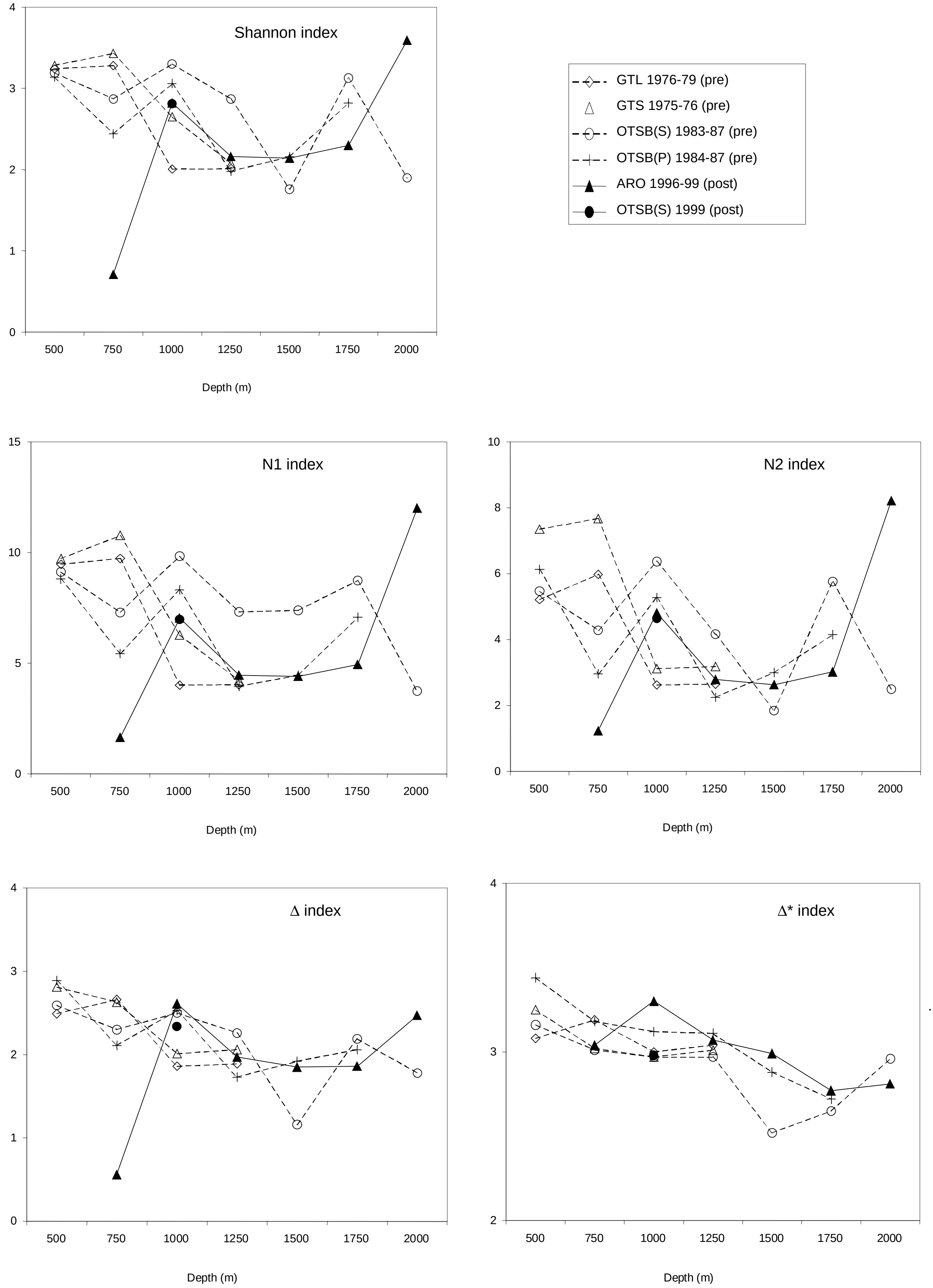


Figure 19. *Diversity indices calculated from catch biomass data by gear and depth band.*

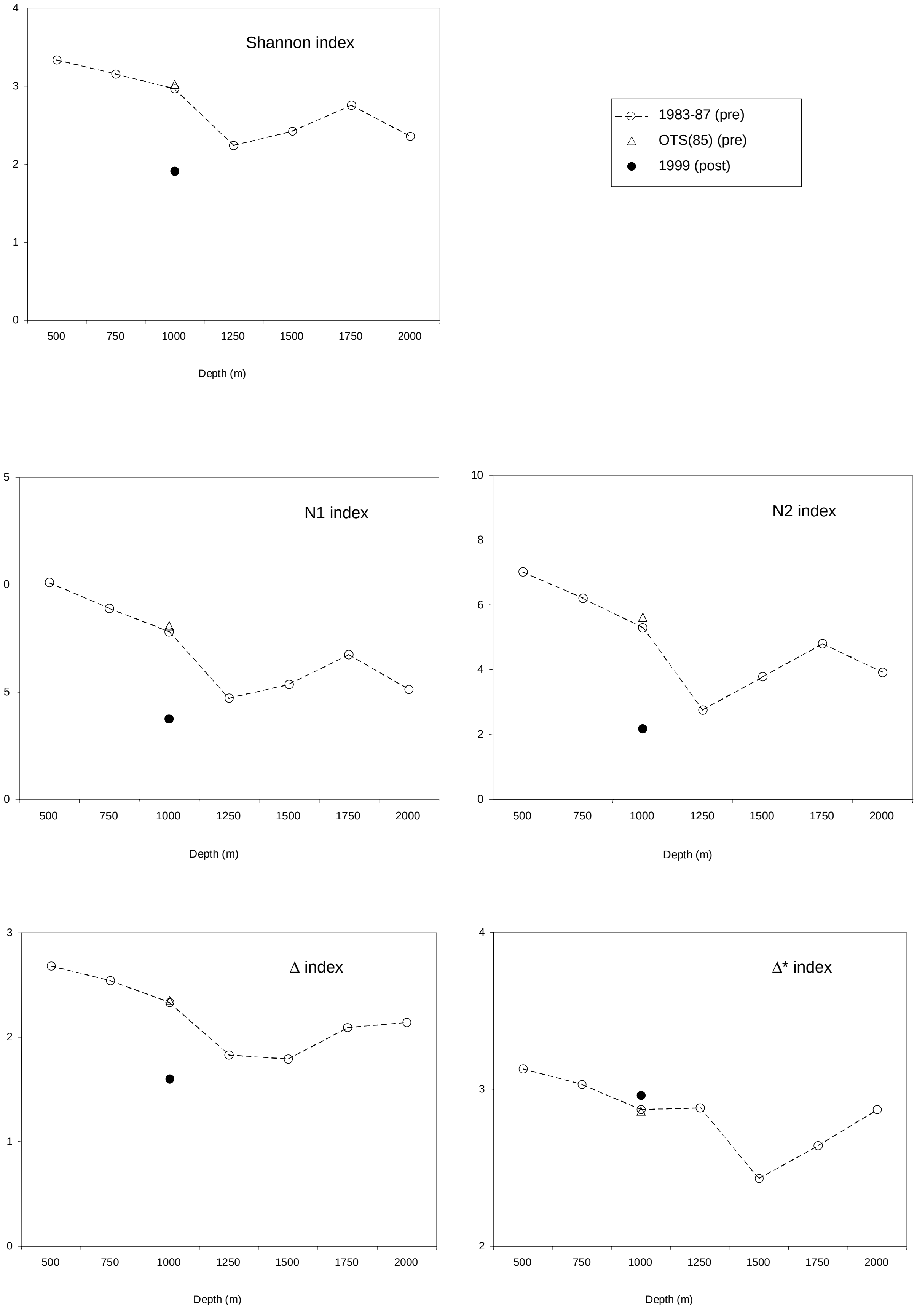


***Figure 20**. Diversity indices calculated from catch abundance data from the OTSB(S) surveys, 1985 and 1999.*

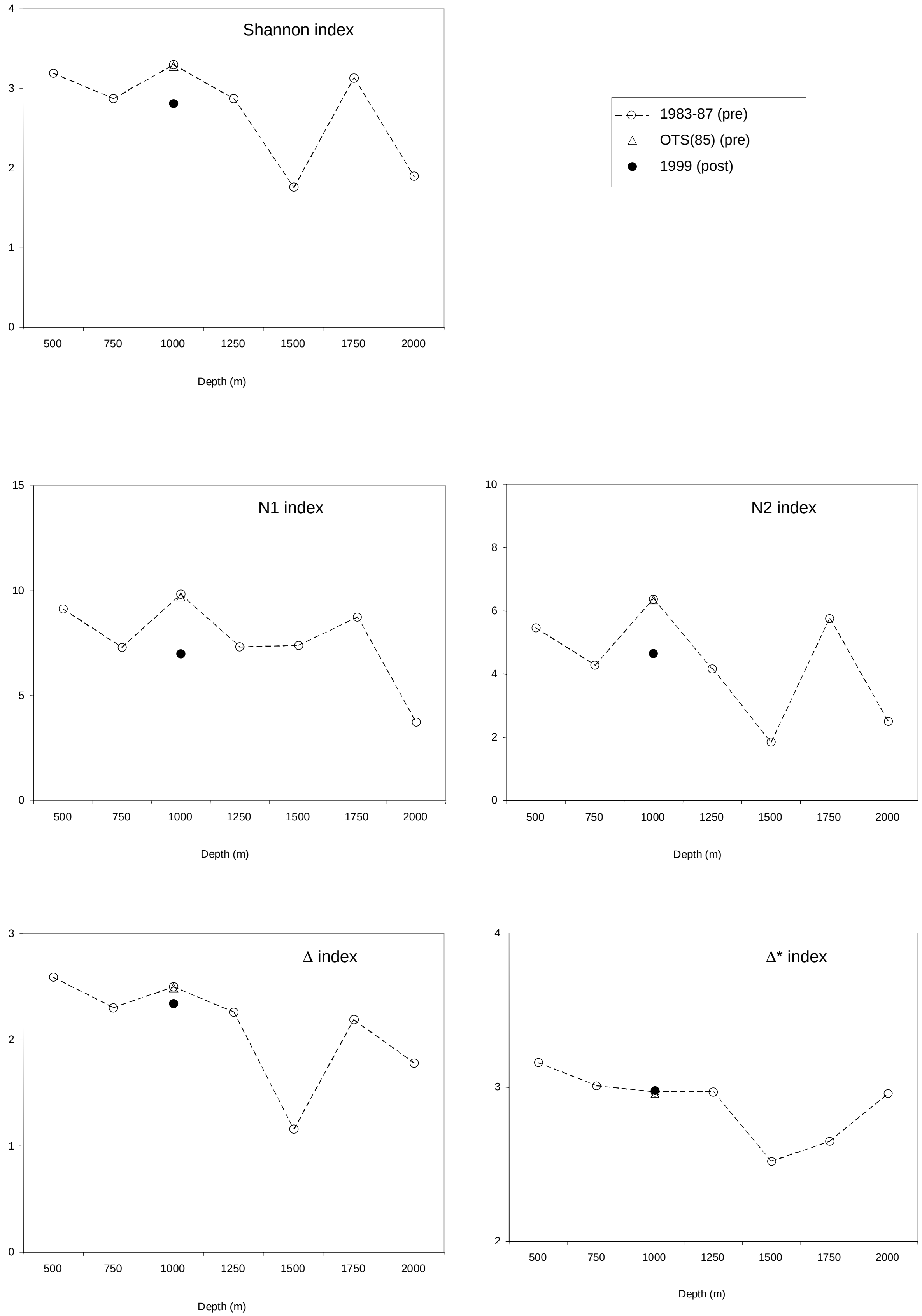


__Figure 21.__ Diversity indices calculated from catch biomass data from the OTSB(S) surveys, 1985 and 1999.

The indices for the IFREMER surveys using the Arrow trawl (post-exploitation) are quite variable and should be interpreted with caution. The very low values in the 625-874m depth-band, for example, are based on a single haul where the catch comprised a high proportion of roundnose grenadier. The only other data available post-exploitation, from the SAMS OTSB(S) survey in 1999, suggest that diversity in terms of numbers may be lower in the 874-1124m depth-band (where most of the exploitation has taken place) than in any of the surveys carried out pre-exploitation, although some of these differences may be confounded by gear effects. This difference is more reliably shown when the diversity indices for the SAMS OTSB(S) surveys in 1985 (pre-exploitation) and 1999 (post-exploitation) are compared in isolation (Figures 20 and 21).

The fact that there is little change in the Δ^* index and a smaller change in Δ index, pre and post-exploitation, suggests that any changes in species diversity are probably due to changes in species dominance and not taxonomic distinctness. It should be noted, however, that these SAMS surveys comprised only 15 and 5 hauls, respectively, and differences in catch composition may reflect sampling variance rather than real changes in species diversity. A detailed study of these results is in progress and will be published in due course.

4.6 Long term time trends inferred from survey indices of relative biomass and abundance.

4.6.1 Introduction and general background

The survey data series contains invaluable long-term information on the relative biomass and abundance of deep-water fish, as measured by the catch per unit effort (CPUE) in weight and numbers, respectively. The earliest surveys took place prior to exploitation, and the most recent surveys were conducted in 1999. In theory, this should allow us to construct a long time series of survey indices of relative biomass and abundance. There are, however, serious problems when analysing the combined data from all surveys. The main issue relates to the fact that different vessels, gear types and depth bands were sampled by the different surveys. These factors affect catchability and hence survey CPUE (as an index of overall species relative biomass and abundance), so they need to be taken into account when considering the combined dataset. There are well-established statistical techniques for dealing with such problems, and generating ‘standardised’ indices of relative biomass and abundance. The main requirement is, however, that there should be sufficient data and, in particular, sufficient ‘overlap’ of data across and between the important factors to enable parameter estimation. Unfortunately, the survey dataset is highly unbalanced (see Section 3.1). This limits the levels of detail that can be included, and the types of analyses that can be performed.

4.6.2 Data

The survey data used are those described in Table 1 (Section 3.1). Note that only cruises 17 and 47 of the Walther Herwig were included, for the reasons described in Section 5.3.3. Also, exploratory analyses revealed several clear outliers, and subsequent analyses excluded stations which had catches of less than 10kg. It is important to note that not all cruises were designed to sample deep-water species, but some were gear trials from which data were collected on an opportunistic basis. The exclusion of the few stations with low catches has only a minor effect on parameter estimates, and does not change the overall results.

Initially, the plan was to analyse the survey data by species, and to model the catch rates, in terms of numbers per hour, as a Poisson process. The advantage of this approach is that zero-hauls (i.e. hauls which did not catch any of the species under consideration) can be included in the analysis. Hauls with a zero catch of a given species contain some implicit information. For example, if the proportion of hauls with zero catches (in depth bands and locations where animals would be expected) changes over time, this may indicate that the population numbers have changed. Unfortunately, two major problems were encountered with this type of analysis.

The first problem relates to treating the data on a species-by-species basis. Survey CPUE were compiled for those species with a reasonable number of observations, and exploratory analyses performed. There are three species with a reasonable number of non-zero catches: roundnose grenadier (215 stations), black scabbardfish (171 stations) and rabbit fish *(Chimaera monstrosa)* (167 stations). The exploratory analyses confirmed that the unbalanced nature of the data is a serious problem when viewed on a species-by-species basis. The spread in the data values is also extremely wide which means that parameter estimates have very high standard errors. The only species for which an analysis of catch rates can meaningfully be performed is roundnose grenadier. In theory, the model fit could have been improved if more factors could be included, but the data are such that the parameters are not estimable. Instead, the problem was resolved by considering two coarse groupings: exploited and unexploited species groups. The definitions of these two groups are given in Appendix 9.4.1. The aggregated, data are better behaved since each data point is the sum of catches for a group of species. This reduces the spread of the data to some extent, and gives better coverage (or balance) of data across and between the relevant factors.

The second problem relates to the inclusion of zero hauls. The exploratory analyses showed that the Poisson error model cannot adequately describe the error distribution, mainly because the assumption of variance proportional to mean is violated. Although other relationships (e.g. variance equal to some power of the mean) were tried, the model fits remained extremely poor, and patterns in residuals persisted. We therefore consider two separate types of analysis below. First, the non-zero hauls (i.e. CPUE > 0) are analysed with multiplicative models which are easily translated into generalised linear models in terms of the logarithm of CPUE. Second, catch information from all hauls (including zero-hauls) are converted to ‘presence/absence’ data and modelled as binomial processes. In theory, results from these two approaches can be combined at the end. In practice, however, this proved unnecessary, since none of the species or groups of species allowed both types of analyses to be successfully performed.

Section 4.6.3 presents data, methods and results for the CPUE analyses of exploited and unexploited species groups, and for roundnose grenadier. Section 4.6.4 presents details and result of the presence/absence analyses for a subset of species. An overall discussion is given in 4.6.5.

4.6.3 Standardised time series of survey CPUE

4.6 3.1 Data

The main aim of this analysis is to generate a standardised time-series of indices of relative biomass for the exploited and unexploited species groups. This is done by fitting models which attempt to explain the observed CPUE (called the response variable) as a function of other quantities (called explanatory variables, such as gear type and depth).

The observed CPUE at each station is simply the catch in weight divided by the duration of the tow. The data were aggregated by first summing the catches of all the exploited (or unexploited) species by station, and then dividing by the duration of the tow. The analysis is based on the natural logarithm of CPUE (referred to as lncpue). It is convenient to consider station-by-station data rather than aggregating further, for example, by combining information from stations in the same depth band on the same cruise. The station-by-station data allow the actual mean depth of the tow rather than an arbitrary depth band definition to be used as an explanatory variable.

Exploratory analysis indicated that apart from changes over time, differences in depth of haul and differences between gear types should be taken into account. Given the unbalanced ‘design’ of the data, a compromise ‘gear’ definition has been used here. If all the actual gear types are included, there are essentially too many parameters to estimate reliably. A very coarse grouping which considers all gears except the SAMS semi-balloon otter trawl on a single warp (OTSB(P)) as a so-called ‘commercial-type’ gear group and OTSB(S) as a so-called ‘scientific-type’ gear was considered. Although this appears to work for the SAMS data series, it is too coarse for the full dataset. The following alternative was found to explain significantly more of the variation than the 2-gear grouping:

Code: Description
GFR -German gears : 200 bottom trawl (200BT) and 140BT
ENG -CEFAS gears’ : Lowestoft Granton trawl (LWGT)
SAM -SAMS commercial gears’ : Granton trawl–long bridles GT(L), Granton trawl –short bridles (GTS) and the semi-balloon otter trawl–paired warp OTSB(P)
SAS -SAMS scientific gears : OTSB(S)
IFR -French gear : Arrow trawl (ARROW)

Please refer to Appendix 9.4.2 for details of each gear.

Note that this is a 5-level definition compared to 8-levels which would be required for gear type.

4.6.3.2 Methods

The nature of the data does not allow for an optimal model to be selected, or for a large number of explanatory factors to be included. The approach taken here was to consider three different types of models to help determine an appropriate set of explanatory variables to include. Results from the three models were compared to determine whether results are robust to the model definition, given the chosen set of factors. The implications of this approach are discussed below.

Exploratory analysis revealed three important points. First, the relationship between lncpue and mean depth is dome shaped, with highest lncpue values in depths between 625 and 1374m. Second, the effect of gear type is highly significant. Third, the relationship between lncpue and time is not linear over the whole time period. Given this, three models were fitted with the chosen explanatory variables (year, mean depth and gear-grouping):

- a general additive model (GAM) which estimates a smooth time-trend (and mean depth relationship) and gear-grouping as a factor;
- a general linear model with 2nd (GLM2) or 3rd (GLM3) order polynomials for time, 2nd order polynomial for mean depth, and gear-grouping as a factor;
- a linear mixed effects model (LME), with 2nd order polynomials for the time and mean depth relationships, and a random effect for gear-grouping.

Although more details are given in the technical appendix (Appendix.9.4.3), it is worth highlighting some of the differences between the three types of models here. The main difference between the GLM and the GAM is that the GLM restricts the relationships between the (continuous) variables to a pre-specified parameterisation (e.g. 2nd order polynomial), whereas the GAM model fits a nonparametric function through the data. The GAM model is therefore more flexible, and is very useful in identifying the shape of an underlying relationship between two variables. The LME, treats the continuous variables in the same way as the GLM, but assumes that the differences between the lncpue for the gear-groupings are essentially due to random effects. In this particular case, we assume that the random effect only applies to the intercept, and not to the other parameters. The LME approach is particularly useful when there are limited data to estimate many factor-parameters.

The formulation of all three models are such that they estimate a common time trend in lncpue for all gear-groupings and at all depths, but with different levels of lncpue depending on depth and gear. A simplified analogy of this would be a set of regressions with the same slope (relationship with time) but different intercepts (for depth and gear). The implications of this assumption are further explored and discussed below.

4.6.3.3 Results

4.6.3.3.1 Exploited species

Results of the three models are, on the whole, very similar, and this is encouraging. For example, the relative catchabilities of the different gear groups are almost identical (Appendix 9.4.4.1). The estimated mean depth effects are also very similar (Figure 22).

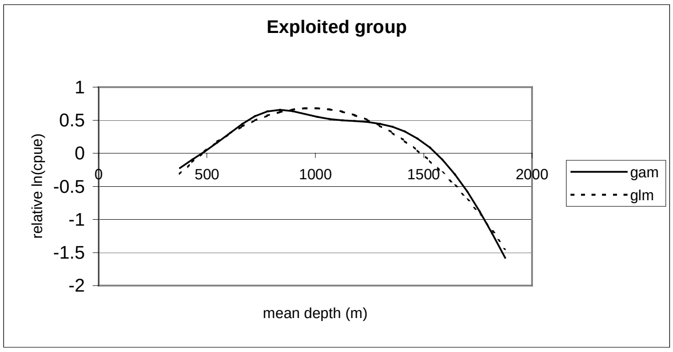


***Figure 22**. Estimates of mean depth effects for the GAM and GLM2 models applied to the exploited group. Estimates for the LME model are almost identical to those for the GLM and are therefore not shown.*

The estimated time trends (Figures 24, 25 and 26) all suggest that the relative biomass of exploited species is now well below levels in the mid-1970's. The GAM model suggests a 3rd order polynomial for the time-trend. Care has to be taken not to over-parameterise the models, so a 2nd and 3rd order polynomial were tried in GLM models. The third order term in year was significant at the 10% level (Appendix 9.4.4.1). Results for both versions are presented below. It is important to note that the inclusion of gear type has a dramatic effect on the estimated time-trend. This strongly suggests that most of the gear-effect has been separated from the time-trend, so that the resulting time-trend is not merely a reflection of the gear-types used.

The relative biomass appears to have declined somewhat even before the main fisheries started in 1988, though there was, almost certainly, some fishing prior to 1988. For example, the French blue ling fishery started in 1972 (Moguedet, 1988).

Since the time trends are not linear, it is informative to consider the ratio of current to pre-exploitation relative biomass indices. Such a ratio can be referred to as a ‘depletion’ ratio. The details of the time trends between 1973 and 1985 are slightly different for the 3 models, so that the depletion ratio could be sensitive to the chosen reference year. Table 17 gives the ratio of current relative biomass to levels in 1973, 1988, as well as relative to the average between 1973 and 1988. The latter is probably the most sensible measure given that some fishing probably took place prior to 1988.

Table 17. *Ratios of relative biomass indices of exploited species in 1999 compared to pre-exploitation for three models.*

Model:	GAM	GLM2	GLM3	LME
1999 vs 1973	0.18	0.18	0.17	0.19
1999 vs 1988	0.28	0.28	0.24	0.30
1999 vs mean 1973-1987	0.22	0.20	0.20	0.21

The similarity in results for the different models (based on identical data) suggests that the uncertainty around the ratio of 1999 to earlier CPUE should also be similar for the three models. It is simplest to estimate the coefficient of variation (CV) of the ratios for the GLM2 model. For the comparison between 1999 and the mean pre-exploitation levels, the CV is 32% implying an approximate 95% confidence interval (CI) of [0.10, 0.37].

As noted before, the deeper depth bands have only really been sampled since 1981, and then there have been far fewer hauls than in the shallower depths. Although the inclusion of mean depth as an explanatory variable should, in theory, remove the effect of depth from the time-trend, the unbalanced nature of the data may mean that this is not entirely achieved. A brief exploration of the data for depths up to 1374m was therefore conducted. The depletion ratio for the depth subset (depths 375-1374m), with a GLM2 model, is 0.25 (1999 versus the mean pre-exploitation level) with a CV of 33%, and approximate 95% CI=[0.13, 0.48]. Also, a GAM model fitted to data from depth band 3 only, leads to very similar estimates of relative gear-effect, and the depletion ratio (1999 versus the mean pre-exploitation level) is estimated at around 23%. These are not major changes over results for the full dataset.

It is also informative to fit a GAM model with depth, gear and year effects to just those species for which commercial CPUE are available (see Section 5). Even without fitting any models to the commercial CPUE and catch data to estimate absolute biomass, the CPUE time series in ICES division VIa, suggest decreases in relative biomass for all these species. Ratios of CPUE in VIa in 1998 to the maximum CPUE (usually at the start of the series) suggests current relative biomass of between 10 and 50% of the pre-exploitation levels, depending on the species.

The estimated depth and gear effects were similar to those estimated for the full set of exploited species. The estimated year-effect for this subset of exploited species shows a stronger decline over time than estimates for the larger set of exploited species. The ratio of estimated indices in 1999 compared to 1973 is 9% (the ratio is 17% for the full set; Table 17), and compared to 1988 it is 23% (28% for the full set, Table 17).

Irrespective of any factors which cannot be incorporated into the models because of the unbalanced and sparse nature of the data, the decline in relative biomass of exploited species, estimated from survey data in Division VIa, is entirely consistent with the commercial CPUE data. The extent of the decline has some uncertainty associated with it, but it would, in fact, have been surprising and somewhat inconsistent if the surveys had not shown any decrease, or had shown an increase in relative biomass.

4.6.3.3.2 Unexploited species

In the case of the unexploited species, the mean depth effects are again similar for the three models (Figure 23), though the pattern differs from that for the exploited group shown above (Figure 22). This is not surprising, since the species composition of the two groups are different. The gear effects are also similar for the three models, and results are even similar for the exploited and unexploited species (Appendix 9.4.4.2). It is difficult to know a-priori whether one would or would not expect to see differences in the relative catchabilities of gears between these two species groups. The wide spread of the residuals around the point-estimates do, however, suggest if any such differences did exist, they would be too subtle to estimate from this dataset.

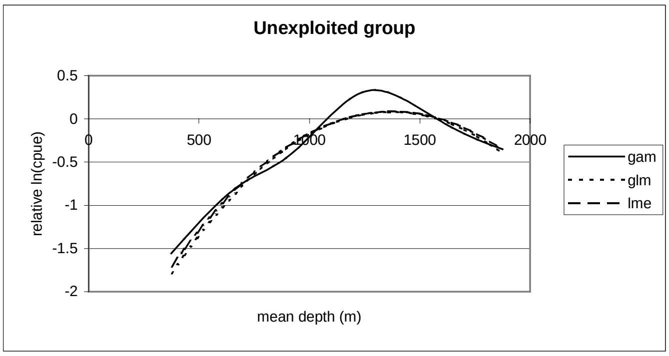


Figure 23. *Estimates of mean depth effects from the 3 models applied to the unexploited group.*

The time trend is reasonably well fitted by a linear trend (a 2nd order term does not significantly improve the model fit, so only a linear GLM was fitted (Appendix 9.4.4.2), but the GAM model suggests small increases and decreases over the period. This result should not, however, be over-interpreted. The overall picture is one of much less decline than for the exploited species (Table 18). The GLM model, for example, estimates the 1999 relative biomass level to be 0.42 (CV=35%) of the average pre-exploitation level. The CV implies an approximate 95% CI of [0.21, 0.83].

Table 18. *Ratios of relative biomass indices of unexploited species in 1999 compared to pre-exploitation for three models.*

Model:	GAM	GLM	LME
1999 vs 1973	0.28	0.30	0.34
1999 vs 1988	0.71	0.60	0.63
1999 vs mean 1973-1987	0.43	0.42	0.46

There are signs of decreased variance in residuals at deeper depths, and this may again be due to the small number of stations at those depths. A GLM analysis of the data from depths<1375m estimate the ratio of 1999 to mean pre-exploitation relative biomass at 0.38 (CV=37%), with an approximate 95% CI=[0.18, 0.80].

4.6.3.3.3 Comparison of results

Figures 24 and 25 show comparisons of the estimated time trends of exploited and unexploited species groups for the GAM and GLM models. Relative CPUE over time for the LME models are similar to the GLM estimates, and are therefore not shown. The time trends are given in relative CPUE in terms of weight, predicted for a fixed depth and gear type. Note that this relative CPUE should not be interpreted as an absolute estimate of density.

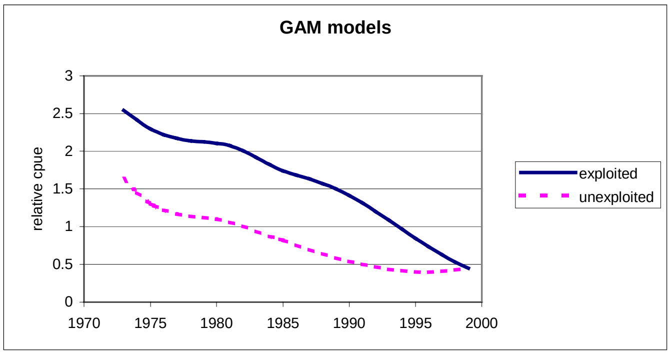


Figure 24. *Estimated relative CPUE over time for the GAM models applied to exploited and unexploited species groups.*

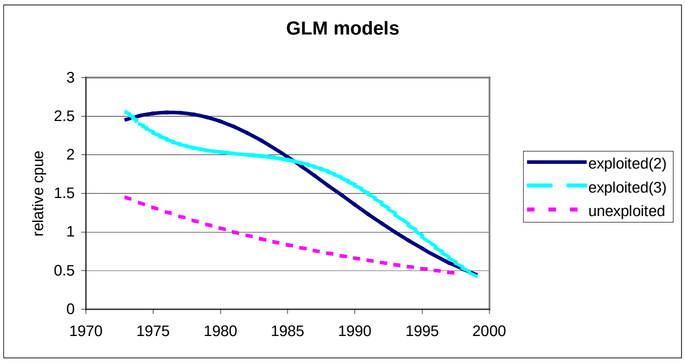


Figure 25. *Estimated relative CPUE over time for the GLM models applied to exploited and unexploited species groups. exploited(2) refers to version with 2nd order polynomial for year, and exploited(3) to the version with 3rd order polynomial for year.*

It is also useful to compare the estimates from the different models directly (Figures 26 and 27).

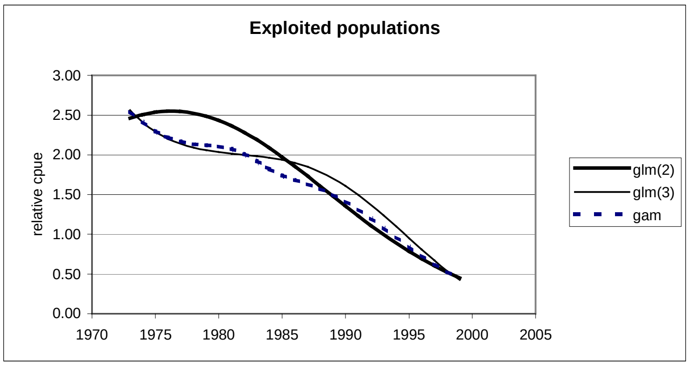


Figure 26. *Estimated time trends of relative CPUE for the two GLM models GLM2: 2nd order polynomial for year; GLM3: 3rd order polynomial for year) and the GAM model applied to the exploited species group.*

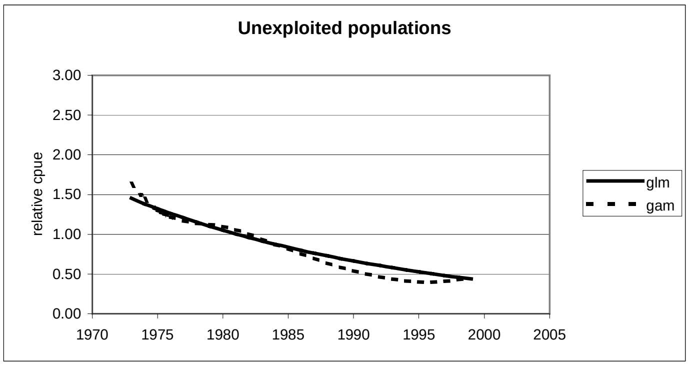


Figure 27. Estimated time trends of relative CPUE for the GLM and GAM models applied to the unexploited species group.

All models indicate a greater change (reduction) in the relative biomass of the exploited species than the unexploited species group. Although the diagnostics suggest that there are no obvious or serious patterns in the residuals, there is still a large amount of unexplained variability, particularly for the unexploited species (Appendices 9.4.4.2 and 3).

There are several factors which have not been considered in the above analysis. One of these is the timing of surveys (i.e. month) within the year. Timing of survey could affect the indices of relative biomass, particularly of migratory species. Nothing can be done about this because of the paucity of data. The relatively coarse gear grouping may also be incapable of fully explaining differences between the cruises, but a more detailed grouping is impractical from an estimation point of view. A factor which can, however, indirectly be taken into account, is the spatial coverage of the various surveys. Figure 28 shows that the SAMS surveys (gear types SAM and SAS) are concentrated in a relatively small area compared to most of the other surveys. This could add to the wide spread of the data, and the large amount of unexplained variability. It is also, of course possible that some locations or local areas within the Hebridean slope, could exhibit different time trends than others. An analysis just based on the SAMS data was therefore also done for comparison.

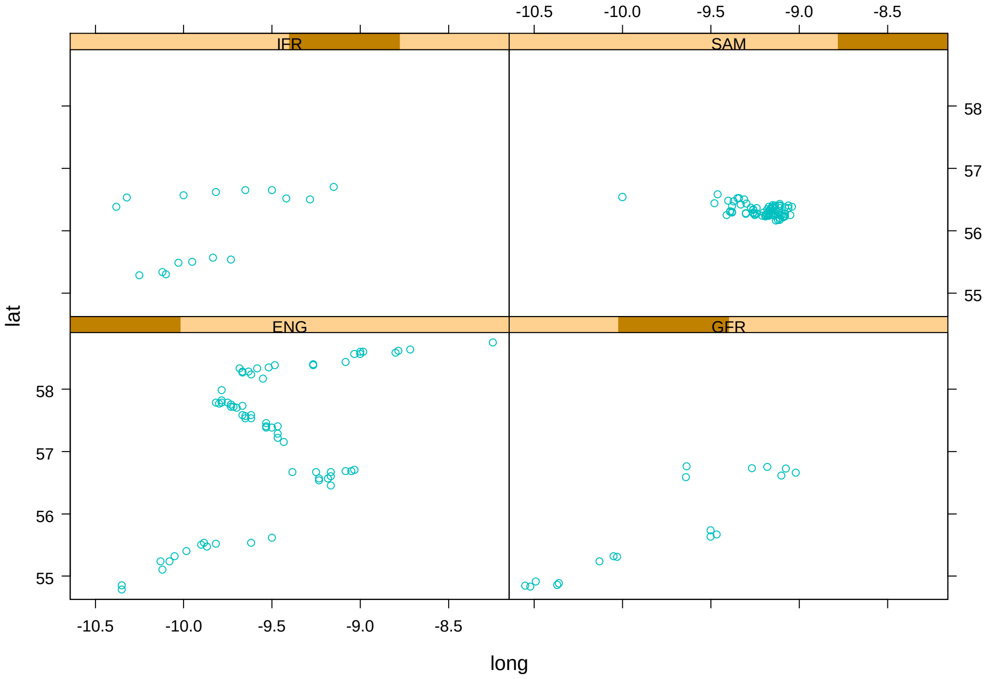


Figure 28. *Station positions by country for all surveys (years are not identified).* ***The quadrant labelled 'SAM' includes the SAM and SAS gear types.*** *Note: minutes are given as fractions e.g. 30 minutes given as 0.5.*

4.6.3.3.4. Results based on SAMS data only

There are two gear groupings for the SAMS surveys, so that a gear effect is retained in the models based only on SAMS data. The models are identical to those fitted to the full data series, except that the earliest year in the analysis is 1975 rather than 1973.

Estimated time trends from GAM models for exploited and unexploited species groups are shown in Figure 29. The estimated trends based on the SAMS data only, are quite different at the start of the series, compared to trends based on the full dataset (compare with Figure 24). Possible reasons for this are discussed below. The decline in the exploited group from around 1985 to 1999, as well as the depletion ratios (Table 19) are, however, similar to estimates based on the full dataset.

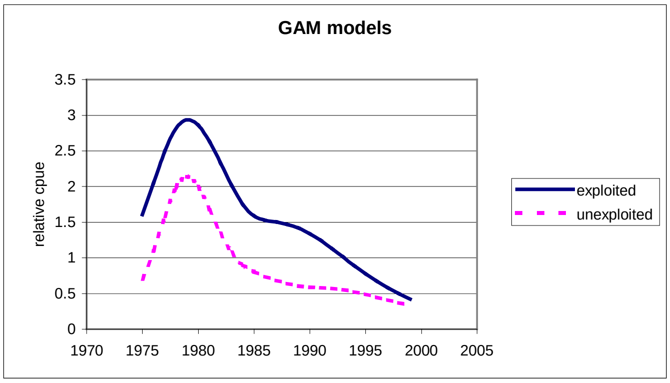


Figure 29. *Relative CPUE over time for the GAM models applied to exploited and unexploited species groups from SAMS data only.*

The picture for the unexploited species group is also different at the start of the series, with the sharp increase and decrease between the mid-70's and mid-80's which is not evident in the full dataset.

Table 19. *Ratios of relative biomass indices of exploited and unexploited species groups in 1999 compared to pre-exploitation, from GAM models applied to the SAMS survey data only. (Ratios relative to 1973 are not given because the data starts in 1975.)*

GAM models	Exploited	Unexploited
1999 vs 1988	0.29	0.52
1999 vs mean 1975-1987	0.20	0.28

A GLM model (with 2nd order polynomial for year) also fits the exploited series reasonably well, and gives a ratio of 1999 to the pre-exploitation mean (1975-1987 of 0.22 (CV=34%). The time-trend for the unexploited species group cannot easily be approximated by a low order polynomial. This is confirmed by the very poor fit of a GLM model, and the sensitivity of results to whether a linear or 2nd order polynomial term with regard to time is fitted. It is possible to fit a GLM to the unexploited group data for the period 1983 onward, and depletion ratios are then similar to those estimated by the GAM. On the whole, the model fits for the SAMS data used on their own are not as good as for the full dataset.

The increase in the time-trends at the start, for both exploited and unexploited species groups, may be real, or may reflect some other factor, such as an increase in gear efficiency caused by a change from using short to long bridles on the Granton trawl gear. Given the available data, the only way to overcome any problem with increased efficiency for the Granton gear types, is to exclude these gears from the analysis. This implies the use of data from 1983 onward. Such an analysis (GAM models) leads to estimated depletion ratios (1999 verus the pre-exploitation average, 1983-1987) of 23% for exploited and 37% for unexploited species groups.

4.6.3.3.5 Results: Roundnose Grenadier (*Coryphaenoides rupestris*)

As noted earlier, roundnose grenadier was the only species for which reasonable model fits could be obtained based on data from all surveys. Even so, there remains a wide spread in the residuals (Appendix 9.4.4.3). The estimated mean depth effect is not very different from that estimated for the exploited species group (Figure 30). This is not entirely surprising, since the survey catches of exploited species are often dominated by roundnose grenadier. The relative gear catchabilities are also very similar (Appendix 9.4.4.3).

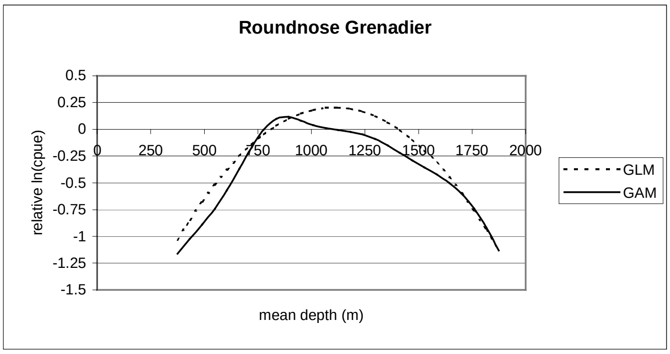


Figure 30. *Estimates of mean depth effects for the GAM and GLM models applied to the roundnose grenadier data. Estimates for the LME are almost identical to those for the GLM, and are not shown.*

The estimated time trends for the GAM and GLM models are shown in Figure 31. Estimates for the LME model are again almost identical to those for the GLM. The main differences between the models lie in the early part of the series where the GAM estimates much more of an initial increase that the GLM is capable of doing with a 2nd order polynomial. Nonetheless, the decline over the latter part of the series is clear.

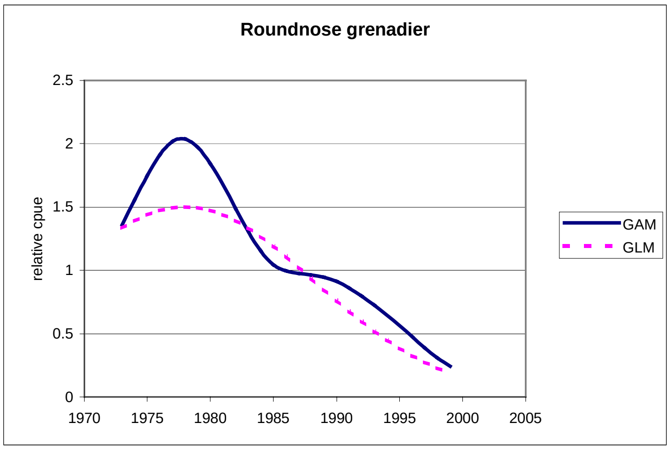


Figure 31. *Relative CPUE over time for the GAM and GLM models applied to roundnose grenadier data from all surveys.*

Depletion ratios for roundnose grenadier are shown in Table 20. The GLM-based ratio of 0.14 has a CV of 54%, reflecting the relatively high standard errors of the parameter estimates. This implies an approximate 95% confidence interval of [0.05, 0.41].

Table 20*. Ratios of relative biomass indices of roundnose grenadier in 1999 compared to pre-exploitation for three models.*

Model:	GAM	GLM	LME
1999 vs 1973	0.18	0.14	0.17
1999 vs 1988	0.25	0.20	0.24
1999 vs mean pre-exploitation	0.16	0.14	0.17

There is some evidence of more positive residuals at deeper depths (>1375m) with the exception of a few large negative residuals for the deepest hauls. It is not possible to say whether there are real differences in time-trends at different depth ranges, or whether this is an artefact of the data. The deeper depths have been relatively poorly sampled, and this may affect results. A GLM analysis of the data restricted to depths <1375m, gives a slightly more optimistic estimate of current biomass relative to average pre-exploitation levels: ratio of 0.23, CV=51%, 95%CI=[0.08, 0.62].

4.6.4 Presence/absence analyses of survey data

In this section, the proportions of hauls with zero catches are analysed, to explore whether there have been changes in the proportions over time.

4.6.4.1 Data

The data for this analysis are considered either by species or species group (call it species X). The number of hauls that contained at least one animal of species X are counted, as are the total number of hauls. This is done by the appropriate categories, for example year, depth band and gear group. From these two quantities it is straightforward to calculate the number of zero-hauls (i.e. hauls that had none of species X), and the proportions of zero-hauls and non-zero hauls.

Since there are only a limited number of hauls per year, and since the data have to be aggregated on a haul by haul basis, this analysis could not successfully incorporate depth band effects or gear effects. We therefore only consider the SAMS surveys, and only include hauls in depths between 375 and 1374m (i.e. depth bands 1 to 4 in Table 4 in Section 3.1). Within the SAMS cruises, the two gear types used in the CPUE analyses have been retained. Gear effects should be less serious in the case of presence/absence data than in the case of actual catch per unit effort. Sensitivity of results to the inclusion of a gear effect are nonetheless explored.

Note that it is not informative to do this type of analysis on species which always (or almost always) occur in hauls, or for coarse groupings of species which lead to all hauls being non-zero hauls.

4.6.4.2 Methods

In this type of analysis the data are treated as a binomial process. One can think of hauls with species X present as ‘successes’, and hauls with species X absent as ‘failures’. We consider whether fitting a linear trend over time with regard to the proportion of non-zero hauls significantly improves the fit compared to a model which fits a common mean proportion to data from all years. The fitting procedure takes the total number of hauls into consideration (for weighting), so that a proportion based on a large number of hauls contribute more to the fit than proportions based on small numbers of hauls. Further technical details are given in Appendix 9.4.5.

Presence/absence analyses were carried out for 7 species or species groups which had some zero-hauls. The species are: Portuguese dogfish (*Centroscymnus coelolepis*), leafscale gulper shark (*Centrophorus squamosus*), blue ling, greater forkbeard and black scabbard fish. The two groupings are the squalid sharks and the scyliorhinid sharks. A few other species, for example, roundnose grenadier and *Lepidion eques*, were considered, but were not appropriate for this type of analysis since they had none or hardly any zero-hauls.

4.6.4.3 Results

The results are shown in Table 21. Only the two deepwater shark species, and the group of squalid sharks (which includes both the Portuguese dogfish and the leafscale gulper shark) have significant time trends in the proportion of non-zero hauls from surveys. There is some indication of a slight trend for greater forkbeard, but the year-effect is not significant at the 10% level (p=0.14).

Table 21 *Estimated slopes (over the period 1975 to 1999) and P-values indicating whether a model with time-effect fits significantly better than a without a time effect.*

Species	Slope	P-value (* = significant)
Portuguese dogfish	-0.12	0.001 *
Leafscale gulper shark	-0.19	0.004 *
Squalid sharks (see Appendix 9.4.1 Table 38)	-0.12	0.011 *
Scyliorhinid sharks (see Appendix 9.4.1 Table 37)	+0.02	0.62
Blue Ling	-0.02	0.66
Greater Forkbeard	-0.05	0.14
Black Scabbard	-0.03	0.37

The implications of the model fitted to the data for Portuguese dogfish are that in 1975, about 70% of hauls contained one or more of these dogfish, whereas in the 1990s this is below 30% (Table 22). The occurrence of leafscale gulper sharks in hauls was only around 30% at the start of the period, either indicating lower abundance, lower catchability or different distribution compared to the Portuguese dogfish. Nonetheless, this proportion is also estimated to have declined, to below 3% in the 1990's (Table 22).

Table 22. Estimated proportions of non-zero hauls from SAMS data in depths 375-1374m, based on presence/absence data.

	Estimated proportion of non-zero hauls	
Year	C. coelolepis	C. squamosus
1975	0.72	0.30
1976	0.69	0.26
1977	0.66	0.23
1978	0.64	0.20
1979	0.61	0.17
1983	0.48	0.08
1984	0.45	0.07
1985	0.42	0.06
1987	0.36	0.04
1990	0.28	0.02
1992	0.24	0.016
1999	0.12	0.004

There are, however, two concerns with regard to this analysis for the deep-water sharks. First, depth effect is not accounted for, and second, according to Gordon *et al.* (1996) the Granton gear type is more likely to catch mobile, supposedly fast-swimming sharks than a semi-balloon trawl. The depth distribution of the Portuguese dogfish is mainly between 665 and 1750m, with a peak at around 1000m. The depth distribution of the leafscale gulper shark is mainly between 875 and 1124m. It is therefore reasonable to consider depth bands 3 and 4 (875-1374m). Due to the lack of samples from the OTSB(P) gear in the 1990's, the second concern can only be addressed by focusing on the OTSB(S) gear. Note, however, that it is not feasible to do exactly the same analysis as above, but it is possible to a similar but simpler analysis, to explore how likely it is that the probability of obtaining a non-zero haul has remained the same over the whole period.

First consider Portuguese dogfish. Even if this gear is not considered to be very efficient at catching deep-water sharks (Gordon *et.al*, 1996), there was a large proportion of non-zero hauls in 1985 (12 out of 16 hauls contained Portuguese dogfish). During the pre-exploitation period, the probability of a non-zero haul in depth bands 3 and 4 is estimated at 0.65 (data from 1983 to 1987, 13 non-zero hauls out of a total of 20). Seven hauls taken in 1992 and 1999 were all zero-hauls. If we assume that there has been no change over time in the probability of a non-zero haul for this gear in depth bands 3 and 4 (i.e. it has remained at 0.65), we can calculate the probability of observing 7 zero-hauls. This probability is extremely low, only 0.0006. In other words, it is very unlikely to see 7 zero-hauls under the assumption of no change. For example, only if the probability of a non-zero haul is at around 0.28, does the chance of observing 7 zero-hauls increase to 10%.

A further concern is that the use of artificial lights on some trawls during the 1985 cruise may have affected (increased) the catchability of some species, including *C. coelolepis* (see Section 9.2). If the analysis is repeated without the data from 1985, results suggest a more severe decrease in the expected proportion of non-zero hauls than the analysis which includes the 1985 data.

Since there are so few non-zero hauls for leafscale gulper shark, it is not sensible to do the same analysis as for the Portuguese dogfish. It is, however, worth noting that a similar analysis for depth bands 3 and 4, but including the Granton trawl gear (i.e. SAM and SAS gear types) shows that there is no strong indication of a change in probability of non-zero hauls over time. The apparent low catchability, or low presence of this species in catches means that much larger sample sizes (more hauls) would be required to detect any changes over time.

The assessment of deep-water sharks (Section 5.6.3) estimates current biomass at around 40% of virgin biomass. Care has to be taken when comparing this type of estimate to estimates obtained from the presence/absence analyses. This is because non-zero hauls include ‘1 or more’ fish, and the analysis provides no information on whether the average number of fish in non-zero hauls has remained the same or has changed. Unfortunately, the survey CPUE data do not provide much more information, and certainly no clear indication of an increase or decrease. If we assume that there has been no change in the mean number of sharks per (non-zero) haul, then a change in the probability of non-zero hauls from 0.7 to 0.3 is compatible with a reduction in density to about 40% of pre-exploitation levels.

4.6.5 Discussion and conclusions - CPUE and presence/absence analyses

Although this has proved to be a difficult dataset to analyse, and although optimal model selection is therefore not an option, results strongly suggest that there has been a decline in the relative biomass of the exploited species group since the mid to late 1980’s. The estimated decline in the exploited species group appears to be robust to the choice of model given the set of explanatory variables that could be included. Results suggest that the exploited species are currently at around a 0.20 of the pre-exploitation mean (1973-1987). The approximate 95% confidence interval for this estimate is from 0.10 to 0.37. It is informative to consider this in the context of the biomass limit and precautionary reference points proposed for these stocks (see Section 5.2). There is less than a 1% probability that current biomass is above the precautionary reference point (U_{pa}). There is a 50% probability that the biomass of the exploited group of stocks is above the limit reference point (U_{lim}). This, of course, means that there is also a 50% probability that current biomass is below U_{lim}. These probabilities are based on a comparison between relative biomass in 1999 and the mean pre-exploitation (1973-1987) relative biomass. The picture would be more pessimistic if based on a comparison between 1999 and 1973.

The above results are compatible with the results from the single-species assessments (see Section 5). It must be remembered, however, that the CPUE analysis is based on a composite group of exploited species, and does not reflect any changes in the species composition within the group. Some exploited species, orange roughy for example, are not well sampled by the surveys, and would therefore not be well represented in the analysis.

There also appears to have been a slight decline in the relative biomass of the unexploited species group to around 0.45 of the pre-exploitation mean (1973-1987).

This result is, however, less conclusive, since the approximate 95% confidence interval is wide: from 0.18 to 0.80. A decline is nonetheless consistent with available information on the mortality of discards and the low survival rate of escapees through trawl meshes. Although biomass reference points are not generally considered for unexploited species, it is not inappropriate to do so if a fishery implies additional mortality (through by-catches) on those species. For the unexploited group of species, there is a 30% probability that current biomass is above the precautionary reference point (U_{pa}). There is a 99% probability that the biomass is above the limit reference point (U_{lim}). These probabilities are again based on a comparison between relative biomass in 1999 and the mean pre-exploitation (1973-1987) relative biomass. The picture would be more pessimistic if based on a comparison between 1999 and 1973.

With regard to specific species, long-term standardised indices of survey CPUE could only be constructed for roundnose grenadier. This species also shows a clear decline over time. Current relative biomass is estimated at around 0.15 or 0.23 of mean pre-exploitation relative biomass, depending on which depth bands are included in the analyses. The confidence interval for the more optimistic estimate (depths between 375 and 1374m) is from 0.08 to 0.62, reflecting the high standard errors of the parameter-estimates. The more optimistic results imply that there is a 6% probability that current biomass is above the precautionary reference point, and a 60% probability that it is above the limit reference point. This result is comparable with the results from the assessment of roundnose grenadier, which estimated current biomass at around 30% of virgin biomass (Section 5.6.4).

Presence/absence analyses based on the SAMS trawl survey data for the depth range 875-1374m and the OTSB(S) gear only, suggests that the probability of catching Portuguese dogfish (*Centroscymnus coelolepis*) in a given haul is likely to have decreased since the mid-1980s. This result is consistent with the results from the assessment of deep-water sharks (Section 5.6.3). A range of other species did not show any trends in the proportions of non-zero hauls with time.

Many reservations and caveats about this dataset have been mentioned (see Sections 4.1 and 4.2), and should be borne in mind. Results from the analyses in this Section should not be over-interpreted. There are many factors which have been impossible to take into account, and there may well be details which are obscured because of this. There is still a great deal of variability in the data that has not been explained by the models. This is partly reflected in the relatively large standard errors of parameters, and wide confidence intervals of depletion ratios. Nonetheless, there appears to be strong indication of a decline in the biomass of exploited deepwater species. These results should be considered in combination with results from other sections in this report.

5 Assessment studies

5.1 Background and general history of previous assessments

Assessment of deep-water stocks to the west of the British Isles comes under the remit of the ICES Study Group on the Biology and Assessment of Deep-Sea Fisheries Resources. The Group meets biennially and by correspondence in intervening years. The Group reports directly to the ICES Advisory Committee on Fishery Management (ACFM). The Terms of Reference for each meeting are set to provide ACFM with the information required to respond to requests for advice/information from the North-East Atlantic Fisheries Commission (NEAFC) and Directorate General (DG) Fisheries in the European Commission. ACFM also supplies advice on the state of stocks to national governments and the EU Council of Fisheries Ministers.

The first meeting of the Study Group was in 1994. At this meeting, and the meeting in 1996, the Group concentrated on collating the background information on what was known about deep-water fisheries within the ICES area and compiling landings data from both official statistics, where available, and from those provided by individual members of the Study Group.

The terms of reference for the 1998 meeting of the Study Group included the additional request to consider the possibility of carrying out assessments of deep-water fish stocks and developing advice consistent with the precautionary approach (Anon., 1998). Although the possibilities for age structured assessments were still limited, there was sufficient expertise amongst those attending the Study Group to begin examining alternative assessment methodologies. Several provisional assessments were carried out using DeLury constant recruitment and Schaefer production models and advice was given on the state of a number of stocks in relation to agreed precautionary reference points. The assessment models used require time-series data of total international landings and CPUE of a component fleet, and the Group suggested that time series of CPUE may be particularly valuable for the assessment of deep-water species

The ICES Study Group met again in February 2000 and the results from assessments carried out as part of this present study were made available to the meeting. The Study Group modified and fine-tuned these assessments in line with the latest information available. The results presented in this report comprise expanded and annotated versions of the latest assessments from the ICES Study Group, and several additional analyses carried out specifically as part of this study. The assessments presented use information recently collected as part of other projects, a summary of which is given in appendix 9.5.

5.2 Precautionary Approach

Deep-water fishes continue to receive attention from national and international management authorities, conventions and non-governmental organisations. Increasing fishing effort on species many of which are considered to be long-lived, slow growing, with low reproductive potential for replacement is a potentially serious threat to deep-water fish stocks in many parts of the world. Moreover, for most stocks the effect of increased levels of fishing is difficult to determine because of a lack of scientific data. However, this is now no longer justification for not introducing management measures. Article 7.5 of the FAO Code of Conduct states that:-

"*States should apply the precautionary approach widely to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment. The absence of adequate scientific information should not be used as a reason for postponing or failing to take conservation or management measures. In implementing the precautionary approach, States should take into account, inter alia, uncertainties relating to the size and productivity of the stocks, reference points, stock condition in relation to such reference points, levels and distribution of fishing mortality and the impact of fishing activities, including discards on non-target and associated and dependent species as well as environmental and socio-economic conditions. States and sub-regional or regional fisheries management organisations and arrangements should, on the basis of the best scientific evidence available, inter alia, determine stock specific limit reference points and, at the same time, the action to be taken if they are exceeded.*"

The urgent need to implement the precautionary approach to manage deep-water fish stocks is exacerbated by the low survival rate of discarded species and escapees. Thus, increasing fishing effort will affect deep-water fish assemblages in general and not just species of commercial importance.

With regard to suitable biological reference points for deep-water stocks, given that the basic data available for these stocks are still comparatively sparse the measures of limit and precautionary reference points suggested for data-poor situations by the ICES Study Group on the Precautionary Approach to Fishery Management (Anon., 1997) are appropriate:-

Fishing mortality (F) reference points
$F_{lim} = F_{35\ \%SPR}$
$F_{pa} = M$

Biomass reference points
$B_{lim} = 0.2 * B_{max}$ (may be a smoothed abundance index)
$B_{pa} = 0.5 * B_{max}$

Where B is exploitable biomass, M is natural mortality rate and $F_{35\%SPR}$ is the F corresponding to a spawning stock biomass per recruit which is 35% of the virgin spawning stock biomass per recruit i.e. when F = 0.

For many stocks there are no absolute biomass estimates available, and instead ICES uses indices of abundance e.g. CPUE index from a research vessel survey or from commercial fishing vessels. These indices are denoted by U, so that U_{lim} is an index for B_{lim}. Thus the reference points become:-

$U_{lim} = 0.2 * U_{max}$
$U_{pa} = 0.5 * U_{max}$

In recent years, ICES has used this notation for all deep-water stocks. Following the practice of the ICES Deep-water Study Group, in this present study we have attempted to comment on the state of stocks in relation to these reference points whenever possible.

Given the paucity of information on deep-water stocks, it is convenient to consider estimates of maximum sustainable yield (MSY). We give estimates of the ratio of MSY to total unexploited biomass, (MSY/B_0), and estimates of MSY in weight where possible, in the sections below. It is, however, important to note that any such estimates should be used and interpreted with great caution. There are two main uses for estimates of MSY in this study. First, ratios of MSY/B_0 highlight the potential differences between the levels of yield that can be expected from slow-growing, long-lived species, compared to the more familiar commercial species, such as gadoids or flatfish. For example, Beddington-Cooke ratios of MSY/B_0 (Beddington and Cooke, 1983) for a typical gadoid, with natural mortality of 0.2, and growth rate of around 0.3, could be around 0.07 to 0.08, or even higher, depending on the age recruitment to the fishery. Whereas ratios for the deep-water stocks may be as low as to 0.02 or 0.03 (see Section 5.3.1.3). Second, estimates of MSY can be useful indicators of the likely order of magnitude of sustainable catches. For example, are sustainable catches likely to be of the order of 100s of tonnes, or 1000s of tonnes?

It is important to note that, particularly in the context of the precautionary approach, MSY should not, by default, be used as an objective, or target to aim for. The fishing mortality at MSY (F_{msy}) should, in fact, be viewed as a limit rather than a target reference point (Anon. 1997) There are many reasons for this in the general case, i.e. any fish stock, not just deep-water species (also see Hilborn and Walters, 1992). The most important reason in the case of the deep-water species, is the fact that the yield-curves tend to be very flat-topped, because of the high age at recruitment to the fishery, so that MSY is not well-defined. This means that effort in the fishery could easily become too high before it is noticed, because there will be no warning signals in the form of declining catches. In addition, estimates of MSY are likely to have large variance because of short data series and/or poorly estimated input parameters. A second reason relates to the fact that harvesting at MSY could imply a stock level below the proposed limit biomass reference point.

5.3 Assessment methodology and software

This section summarises the methods and software used for this present study.

5.3.1 Methods

5.3.1.1 Depletion models

A catch and effort data analysis package (CEDA) was used to apply modified DeLury constant recruitment models when sufficient data were available. It was recognised that, in common with most assessment models, depletion models in general assume that data are from a single stock (i.e. there is no immigration or emigration) and that this approach should not be applied to components of stocks. Notwithstanding these assumptions, and the lack of knowledge regarding the stock structure of deep-water species, it was felt that this method was worth trying as an investigative tool. The DeLury model uses time series of catches in numbers and an index of population abundance (CPUE) to estimate the catchability coefficient (q) of the CPUE index, and the unexploited population size in numbers (K). The software further requires estimates of natural mortality (M), and the ratio of the population size at the start of the time series to the unexploited population size as inputs. The general procedure adopted was to use sensitivity analysis to evaluate the effect on results (goodness of fit, residual plots, model parameter and population estimates) of a range of error models and assumptions for stock size in the first year as a proportion of virgin biomass. Confidence limits about model parameters and population estimates were calculated by bootstrapping. Indexed recruitment depletion models could not be attempted because of a lack of recruit data.

5.3.1.2 Production models

CEDA was also used to fit dynamic (i.e. non-equilibrium) Schaefer production models. Production models are based on the assumption that there is a relationship between biomass in the current year, and biomass in the following year (or several years from now), because of growth and recruitment. The model uses time series of catches in weight and an index of population biomass to estimate the catchability coefficient of the CPUE index (q), the population production rate (r) and unexploited biomass, or carrying capacity (K). Again sensitivity analysis of outputs was used to evaluate the effect of error models and ratio of initial to carrying capacity (defined as the unfished equilibrium stock size). A time-lag of zero was used for all analyses because available time-series of catch and CPUE were too short (frequently 8-10 years) to explore the effect of time-lag over a range of years commensurate to age of recruitment. It was assumed, therefore, that growth rather than recruitment was the main contributor to biomass production. For some of the stocks assessed, available time-series data of CPUE comprise a gradual decline across the time period studied. It should be noted that the results from production models in these circumstances (the so called ‘one way trip’) can be unreliable. As for DeLury, confidence limits about model parameters and population estimates were calculated by bootstrapping.

It should be noted that the concepts of virgin biomass in DeLury and carrying capacity in production models have been treated as being analogous i.e. the level of stock biomass if there was no fishing.

5.3.1.3 Virgin biomass estimation from fish densities calculated using the swept area method and subsequent calculations of estimates of maximum sustainable yield (MSY).

Virgin stock biomass was estimated from fish densities calculated using the swept area method on catches taken during a series of German trawl surveys from 1974 to 1980 (Dupouy and Lorance, 2001). These surveys were carried out pre-exploitation and provide data on the virgin stocks of roundnose grenadier, blue ling and orange roughy in ICES Sub-area VI and adjacent Divisions VIIb,c over a depth range of 400 to 1400m. The horizontal surface of this area was estimated by 200m depth strata, using charts showing known depth contours and a program called ‘PODISU’ written at IFREMER, France. For each depth stratum and species, the observed fish density (kg/nm^2) was raised to the total surface area, and the sum of these estimates provided an estimate of virgin biomass (B_0). Information on the catchability of the trawl used on the German surveys is not available and for this study has been assumed to be unity for each of the three species analysed. Values of B_0 are therefore minimum estimates. There are a number of other reasons why values of B_0 should be treated as minimum estimates. Benthopelagic species can have a variable distribution in the water column which may lead to under-estimation of stock using swept area methods. Similarly, the horizontal surface may underestimate the surface of the seabed down the continental slope.

Estimates of MSY were derived using the Beddington and Cooke procedure (Beddington and Cooke, 1983), where the ratio MSY/B_0 is calculated taking into account natural mortality (M), the growth rate (k, in the von Bertalanffy growth equation) and size (or age) at recruitment to the fishery. It is important to note that this procedure is based on equilibrium calculations under an assumption of constant recruitment. This means that potential effects of variable recruitment and reduced recruitment at low spawning biomass are not taken into account.

MSY/B_0 ratios can only be calculated where estimates of input parameters are available. Furthermore, MSY can only be calculated, in the way outlined above, for stocks with some estimate of pre-exploitation biomass, or directly from the Schaefer production model. For these reasons, MSY-estimates are only given for a subset of the stocks considered below.

5.3.1.4 Estimation of natural mortality (M).

An estimate of M is required for the DeLury constant recruitment model and for estimating MSY using the Beddington and Cooke procedure. For some deep-water species M has been estimated from catch curves using trawl survey data collected pre-exploitation (i.e. total instantaneous mortality (Z)=M) or by using Pauly's empiric formula relating M with growth parameters and mean ambient temperatures. For the species analysed in this present study, where such estimates are not available M has been estimated using a relationship developed by Annala and Sullivan (1996):-

$$M = \frac{\mathrm{Ln}(100)}{\text{maximum age}}$$

where the maximum age is the age at which 1% of a cohort survives and ln is the natural logarithm.

5.3.2 Software

The main assessment software used was CEDA: Catch Effort data analysis, produced by MRAG Ltd, 27 Campden Street, London W8 7EP, UK.

5.4 Landings and discard data

5.4.1 Landings data

The landings data reported to the ICES Deep-water Study Group in February 2000 have been used as the principal source of landings data for assessments and these are presented graphically for each species for which assessments have been carried out (Section 5.6). These include data for 1999 where available.

5.4.2 Discard data

There have been few studies of discarding in the deep-water fisheries to the west of the British Isles.

5.4.2.1 Irish discard studies

Beginning in 1993, Ireland has carried out exploratory deep-water trawling and long-line surveys to the west of Scotland and Ireland using commercial vessels.

In terms of weight, roundnose grenadier and unmarketable sharks were the most important discards in trawl catches. The highest discards in term of numbers were the bluemouth (*Helicolenus dactylopterus),* roundnose grenadier and *Lepidion eques* (no common name – a member of the Moridae) (Connolly and Kelly, 1996). An Irish trawl survey in 1997 carried out repeat tows with a commercial 105mm mesh deepwater rock hopper trawl, with and without a small mesh cod-end liner. The length frequencies of catches showed two distinct modes - landings (marketable size fish 12-25 cm) and discards (6-16 cm) of roundnose grenadier. The results show that the commercial trawl retains very small roundnose grenadier and that a mesh size of 105mm may not be a viable technical conservation measure in deepwater fisheries (Kelly *et al*. 1998; Anon., 1999b)

Discarding from long-line gears was investigated by the Irish Marine Institute in 1997 and 1999, during surveys using chartered Norwegian vessels. The survey vessels used commercial Mustad auto-line systems and commercial size hooks. Discarding of teleosts from long-lines was shown to be very low with the lines selecting for only marketable sized fish. However discards of non-marketable chondrichthyan fish were very high (Clarke *et al*. in prep). In the 1999 survey on the slopes of the Porcupine Bank and in the depth range 500 – 700 m, birdbeak dogfish (*Deania calcea)* dominated the catch. Though the livers of this species are retained by some vessels, the carcasses are discarded. Furthermore, small specimens of chondrichthyans are also caught. While the gear used on this survey is different to the long-lines normally used by fleets in Sub-area VII, it does give rise to concerns about the total mortality on these species (Clarke, 1999).

5.4.2.2. French discard studies

As part of their contribution to the EC FAIR deep-water fisheries project (Anon., 1999b), France was contracted to investigate the discards of roundnose grenadier in the French trawl fishery. The discards were sampled by sending observers on commercial trawlers. A total of 55 tows were sampled between December 1995 and August 1997 (Dupouy *et al*. 1998). About 25% by weight of roundnose grenadier, amounting to about 2000 t were discarded. The pre-anal fin length of the discards ranged from 4 – 16 cm while that of the landings was 15 – 26 cm. Two other species, the birdbeak dogfish and the smoothhead (*Alepocephalus bairdii)*, were also prominent in the discards. The higher discard rates of *A. bairdii* are probably an indication of the fact that the French fleet fishes deeper than other fleets involved in the fishery. Connolly and Kelly (1996) also comment on the fact that their discards of this species were low because they did not encounter large spawning aggregations. Further information on the discards estimated from a research survey in 1996 and from the observations on commercial vessels is given by Allain and Kergoat (1997).

5.4.2.3. Scottish discard studies

As part of their contribution to the EC FAIR deep-water fisheries project (Anon., 1999b), Scotland also investigated the discards from deep-water trawling by both French and Scottish vessels (Blasdale and Newton, 1998) There were clear differences in the two fleets. Most of the effort of the Scottish fleet was between 600 and 900 m while the effort of the French fleet was between about 500 and 1400m. In the shallower depths both fleets target blue ling, anglerfish, black scabbardfish and sharks. At the greater depths the French fleet targets roundnose grenadier and the Portuguese dogfish (*Centroscymnus coelolepis).* Both fleets had a wide range of discards with smoothheads (*Alepocephalus bairdii)* being prominent in the French discards.

5.4.2.4 Mortality of escapees

The effect of changes in pressure as deep-water fish are brought to the sea-surface almost guarantee that fish landed on deck and subsequently discarded will not survive. Also, many deep-water species are susceptible to damage by trawls because their skin is not covered in mucus. Thus, it is also highly probable that a high proportion of fish entering trawls and subsequently escaping through meshes will die (Connolly and Kelly, 1996, Koslow *et al.* 1999). Using data from the SAMS surveys using fine meshed trawls, Gordon, (1997) showed that the percentage of the total catch that might be escapees from commercial trawls could range from about 30 to 85 % in terms of numbers depending on gear type and depth. Because the fish are small the percentage by weight would be lower at between about 3 and 45 %.

5.5 General description of the methodology used to construct French effort and CPUE indices

The DeLury and Schaefer analyses described in this report are based on CPUE data from French trawlers. According to French regulations, the larger offshore trawlers are called *chalutiers de peche industrielle.* These vessels, which fish only for human consumption, have an overall length of between 49 and 55 metres. Two fleets are defined in this size category. Fleet A is a homogeneous fleet in terms of engine power, age and equipment and comprises vessels specialising in fishing for deep-water species since 1988. With the possible exception of the first one or two years of the French deep-water fishery, when skipper ability was improving, the fishing power of those vessels is considered to have been reasonably stable with time. Fleet B comprises all other vessels between 49 and 55 metres in length. There is also a third fleet of high seas trawlers called *chalutiers semi-industriels* comprising vessels between 30 and 38 metres in length. It is the catch and effort data from fleet A which is used to construct time-series CPUE data of deep-water species. For each deep-water species, individual trips are filtered to exclude trips where the landings of the species is less than 10% of the total landings. A second filter is then applied at the annual level to exclude trawlers were the total annual landings of the species is less than 20% of the total annual landings of all species. This second filter excludes occasional landings from trawlers usually practising other *metiers*. The filtered catch and effort data are then analysed using a multiplicative model taking into account month and ICES Sub-area effects, weighted by fishing effort. The annual standardised CPUE index derived from this model, for individual or combinations of ICES Sub-areas/Divisions, is then used as input data for the DeLury and Schaefer models. Thus, the assessments rely heavily on the quality of these data. The data series is quite short (8-9 years), and this may have some effects on results.

5.6 Stock assessments

5.6.1 Orange roughy (*Hoplostethus atlanticus)*

5.6.1.1 Distribution and general biology

Orange roughy has a wide, apparently anti-tropical, distribution (Figure 32).

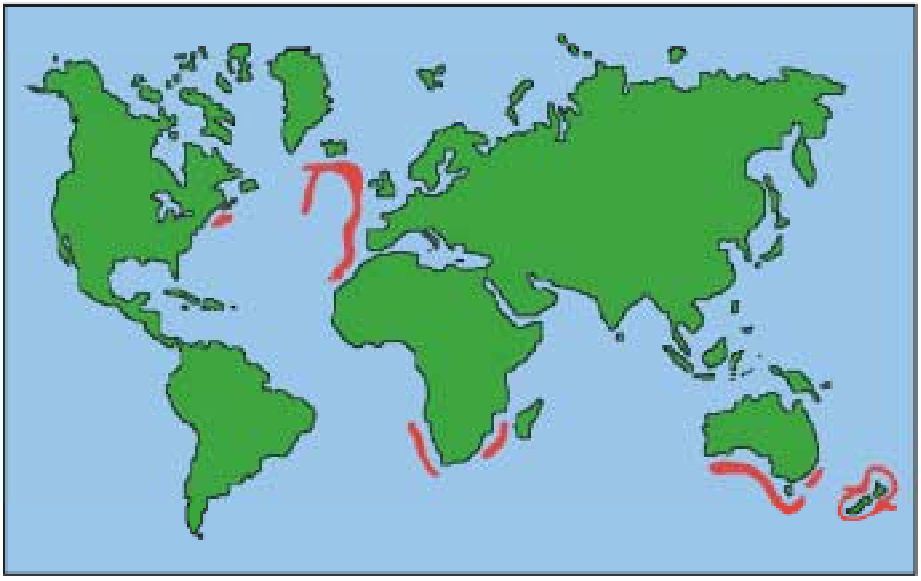


Figure 32. *Distribution of orange roughy*

On the slopes of the north-eastern Atlantic it extends from Iceland to west Africa (20°N). Orange roughy also occurs on the Mid-Atlantic Ridge and has been reported from the continental slope of the western North Atlantic. In the southern hemisphere it is widely reported from around southern Africa, from the southern Indian Ocean, in Australian waters and around New Zealand.

In ICES Sub-areas VI and VII orange roughy is a deep-living species. The maximum depth of occurrence is about 2000 m, but it is probably most abundant at about 1200 m. Catch rates are generally low in research vessel surveys which tend to avoid trawling in areas of steep slopes and pinnacles where orange roughy aggregate.

In the North Atlantic orange roughy reach a maximum size of about 70 cm which is considerably larger than those commercially fished off New Zealand, Australia and Namibia.

Mean length of maturity is around 49cm for males and 52cm for females. Spawning occurs during a relatively short period in January to February and, by March, all the females are spent. Fecundity has been estimated to be 48,500 eggs/kg of body weight equating to an average of around 168,000 eggs per female (Anon., 1998). These values appear to be higher than those observed in stocks in the south-western Pacific.

The diet of orange roughy is dominated by benthopelagic crustaceans (especially decapods), cephalopods and small fishes.

5.6.1.2 Stock structure

Nothing is known of the stock structure in the Atlantic. The fishing grounds so far discovered have appeared to support relatively small aggregations of fish, usually associated with seamounts and other topographical features. Whether or not these are independent populations is not known. However, with time, the probability of finding stocks comparable in size to the stocks exploited in the south Pacific is decreasing. Comparison of enzyme polymorphisms between orange roughy off New Zealand and in the north-eastern Atlantic confirm that they are the same species.

Following the practice of the ICES Deep-water Study Group, for assessment purposes Sub-areas VI and VII have been assessed separately on the assumption that separate aggregations occur in each area.

5.6.1.3 Description of fisheries

None of the trawl surveys to the west of the British Isles in the 1970s or 1980s gave any indication of aggregations of orange roughy. Occasional large hauls of up to 20 tonnes were recorded in the 1970s by German trawlers fishing for blue ling on some of the northern banks of the Rockall Trough (ICES Sub-area VI), but a fishery never developed. In 1989 and 1990 small landings of less than 20 tonnes were made by French trawlers and then in 1991 the landings increased to almost 5000 t. There are currently three fisheries for orange roughy in the North East Atlantic. The main fishery is by French trawlers in ICES Sub-areas VI & VII. There is also a Faroese fishery which has now extended to international waters in Sub-areas X (Mid-Atlantic Ridge) and XII (Hatton Bank) and a small Icelandic fishery which has now almost ceased.

5.6.1.4 Landings and discard data

Figure 33 shows the trends in total international landings of orange roughy by ICES Sub-area. The fishery in Sub-area VI started in 1991, and after an initial peak (3500 t) landings quickly declined to less than 200 t per annum. Landings from Sub-area VII peaked in 1992 at 3100 t and in recent years have stabilised at around 1000 t per annum.

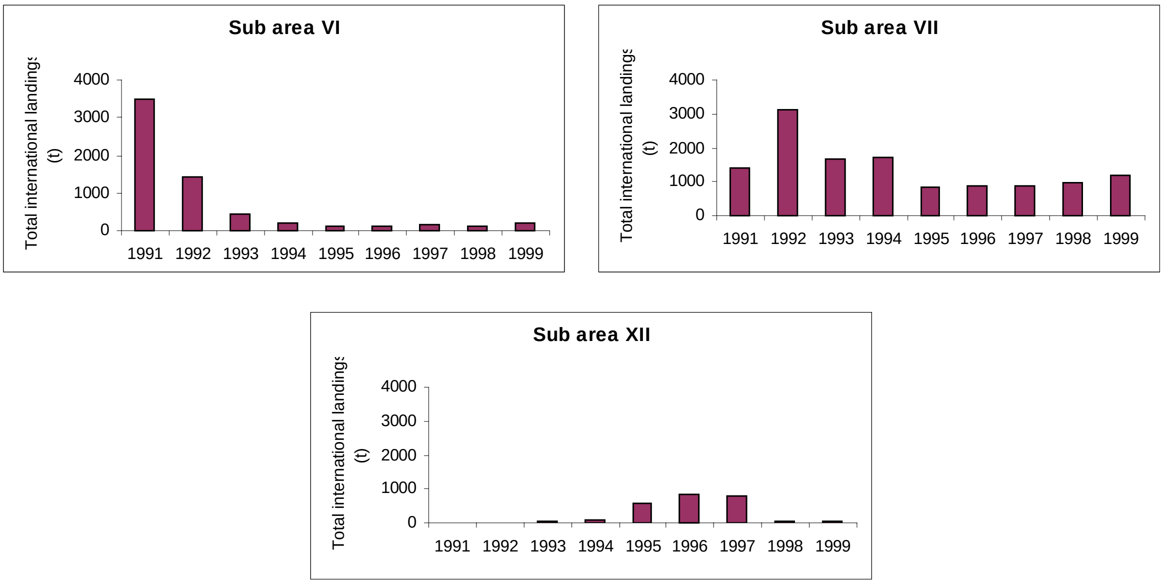


***Figure 33**. Total international landings of orange roughy by ICES Sub-area*

Discard data for orange roughy are sparse, however all available information suggests that the quantities discarded are small.

5.6.1.5 Commercial catch-effort data

Effort data are only available for French trawlers fishing in ICES Sub-areas VI and VII (Figure 34). Fishing effort has declined from initial high values and has now stabilised at a comparatively low level, particularly in Sub-area VI.

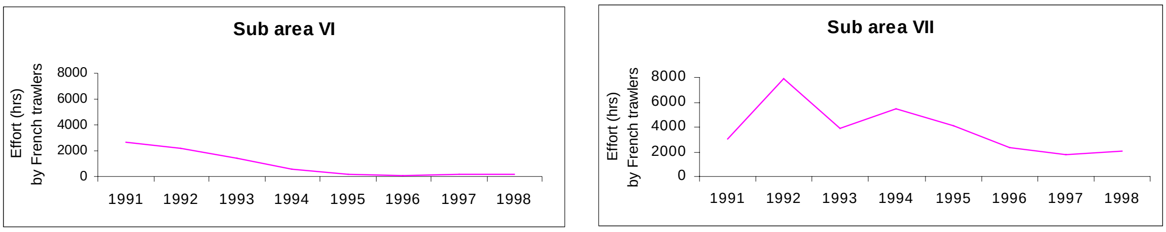


Figure 34. *Effort data from French trawlers - orange roughy*

French trawl CPUE data are available for the period 1992–1998 (Figure 17). In Sub-area VI CPUE declined quite quickly after the fishery commenced and by 1994 was 25% of initial catch-rates. In recent years CPUE has increased slightly and stabilised. CPUE in Sub-area VII shows a similar trend but with a stronger recovery in recent years. This recovery may simply reflect the discovery and subsequent fishing of previously unexploited aggregations.

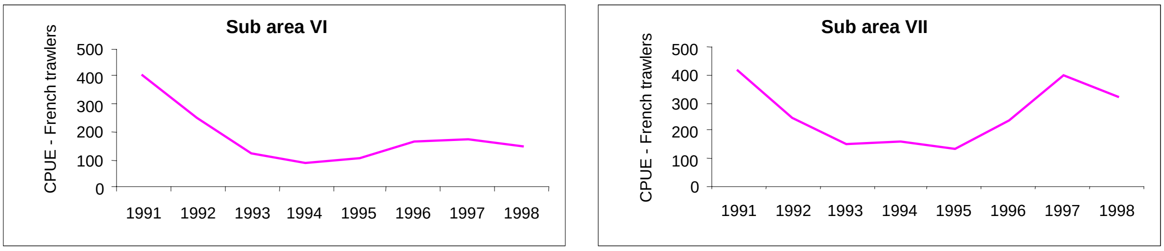


Figure 35. *Catch per unit effort (CPUE) data from French trawlers - orange roughy*

5.6.1.6 Length and age compositions

The length compositions of the French landings from Sub-areas VI and VII in 1994, 1996 and 1998 are shown in Figure 36. Differences in length composition between years, the presence of juvenile fish in 1994 for example, are considered to be due to changes in the geographical distribution of fishing rather than recruitment or changes in stock structure. Quarterly length-frequency distributions of orange roughy landed by French vessels in Scottish ports (Figure 37) have been reasonably similar in recent years with a modal length of around 60cm (Anon., 1999b).

Age composition data are not available for this species as a complete age-length key (ALK) has not yet been completed. Otoliths of small fish (up to 25cm) can be read whole. For large fish, thin slice methods are used. Ages from thin slices suggest that orange roughy can live up to 100 years old. However, these ages are as yet unvalidated. For the large stocks exploited in the south west Pacific, only the ages of juvenile fish have been validated. According to the size at age of these juveniles and the numbers of rings see on larger fish, ages of up to 125 years are considered likely. Age validation is currently under investigation in France.

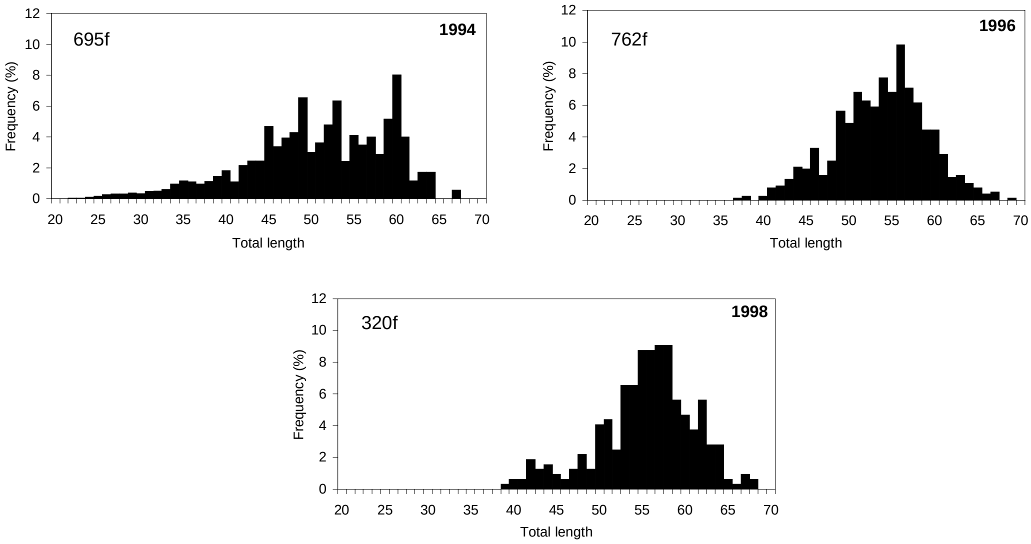


Figure 36. Length distribution of French landings of orange roughy from Sub-areas VI and VII from 1994 to 1998

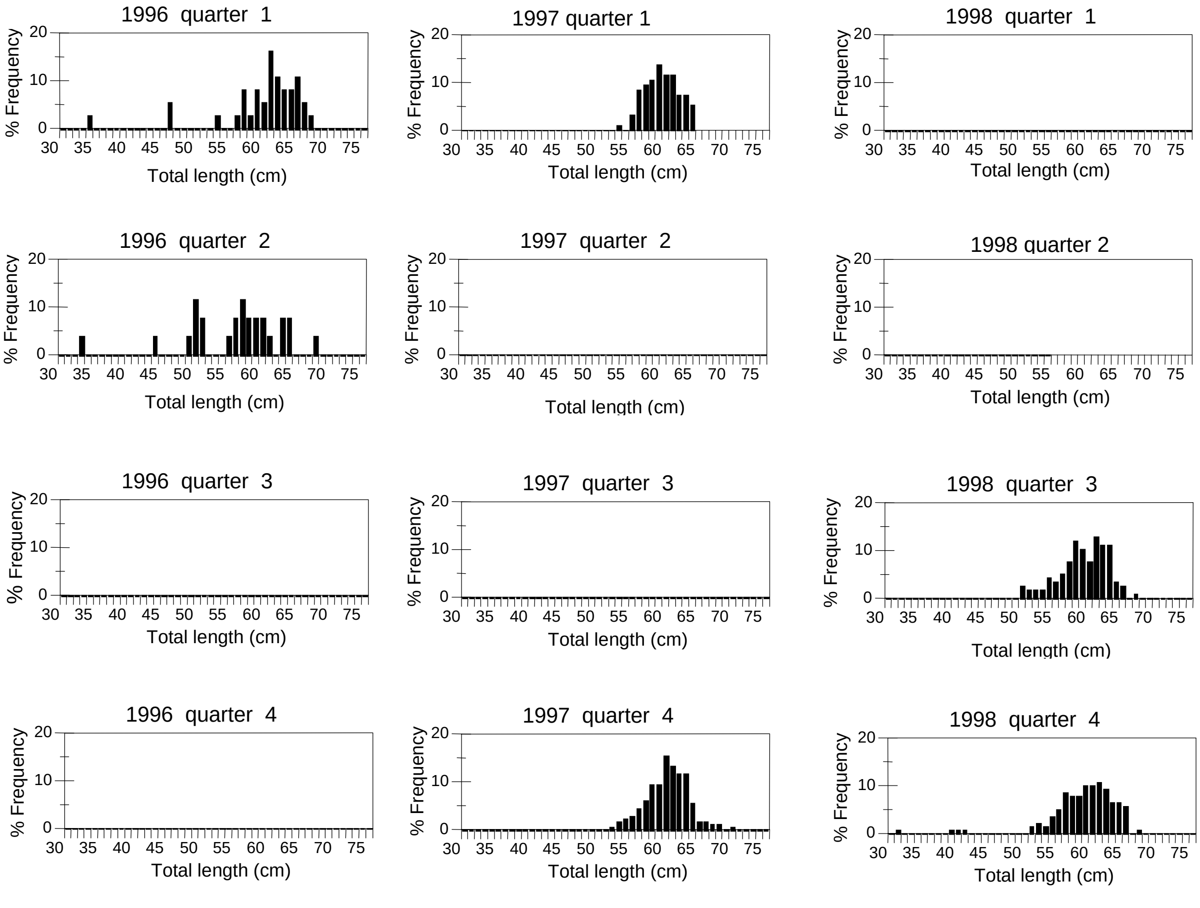


Figure 37. Orange roughy in Sub-areas VI and VII, quarterly landings from French vessels landing in Scotland (FRS data) (EC FAIR, 99)

5.6.1.7 Natural mortality
Natural mortality was estimated to be around 0.05, using the relationship developed by Annala and Sullivan (1996) (see Section 5.3.1.4).

5.6.1.8 Assessment results
Data for assessment of this species in the north Atlantic are poor in comparison to orange roughy stocks in the Pacific Ocean. It should be noted that even the important stocks exploited in the south-west Pacific are not assessed by catch-at-age methods. These assessments mainly rely on estimates of the biomass from acoustic and trawling surveys or the two combined. Eggs surveys are also carried out to back-calculate SSB. Such data are not available for orange roughy in the North Atlantic.

For this present assessment, a modified DeLury constant recruitment model and a Schaefer production model were attempted using total international catch data for VI and VII from 1992 to 98, and French CPUE data for otter trawlers over the same seven year period. Data for Sub-areas VI and VII were analysed separately on the assumption that separate aggregations occur in each area. For comparison, an estimate of virgin biomass (B_0) for orange roughy in Sub-area VI and Divisions VIIb, c was available from studies using the swept area method on catches taken during a series of German trawl surveys. The estimate of B_0 was used to obtain an alternative estimate of MSY (see Section 5.3.1.3).

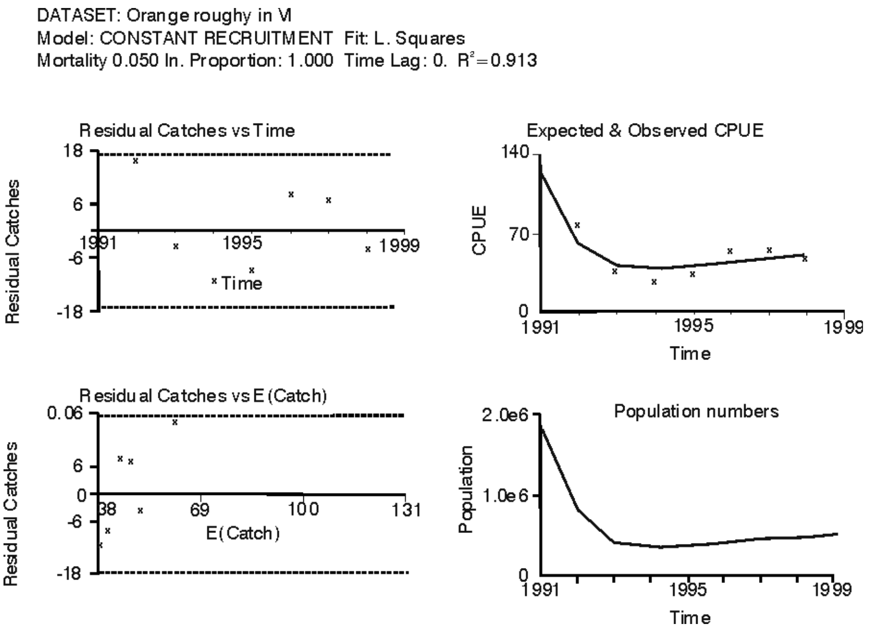
5.6.1.8.1 Orange roughy in Sub-area VI
The fit from a DeLury model was good for a range of error models, with least squares error giving a marginally better fit (R^2=0.913). The results were robust for a range of values of ratio of initial stock to virgin stock (Table 23). This fishery started on a virgin stock and it therefore seems reasonable to accept the results using an initial ratio of 1.0 (Table 23 and Figure 38) Virgin stock biomass is estimated to be around 6,000t (95% confidence limits: 5,400-6,300t). Population biomass in 1998 is estimated to be 1600t, 27% of virgin biomass (95% confidence limits: 25-29%).

The fit from a Schaefer model was also good for a range of error models, with least squares error giving a marginally better fit (R^2=0.908). The results for a range of values of ratio of initial stock to virgin stock were fairly robust (Table 24). An initial ratio of 1.0 was selected for the reasons described for the DeLury model. The results (Figure 39 and Table 24) indicate that carrying capacity (K) is estimated to be about 6,000t (95% confidence limits : 5,500-7,300t). Population biomass in 1998 is estimated to be about 1,800t, 30% of carrying capacity. MSY is estimated to be about 300t (95% confidence limits : 100–480t), equivalent to around 5% of carrying capacity.

Table 24. *Orange roughy in Sub-area VI. DeLury model*

Ratio	K (nos in millions)	q	Pop (nos in '000s)	K (ktonnes)	Pop (ktonnes)	Pop/K
1.0	1.85	0.0001	496	5.9	1.6	0.27
0.9	1.99	0.0001	501	6.4	1.6	0.25
0.8	2.15	0.0001	509	6.9	1.6	0.23

Note Popns are for the final year 1998



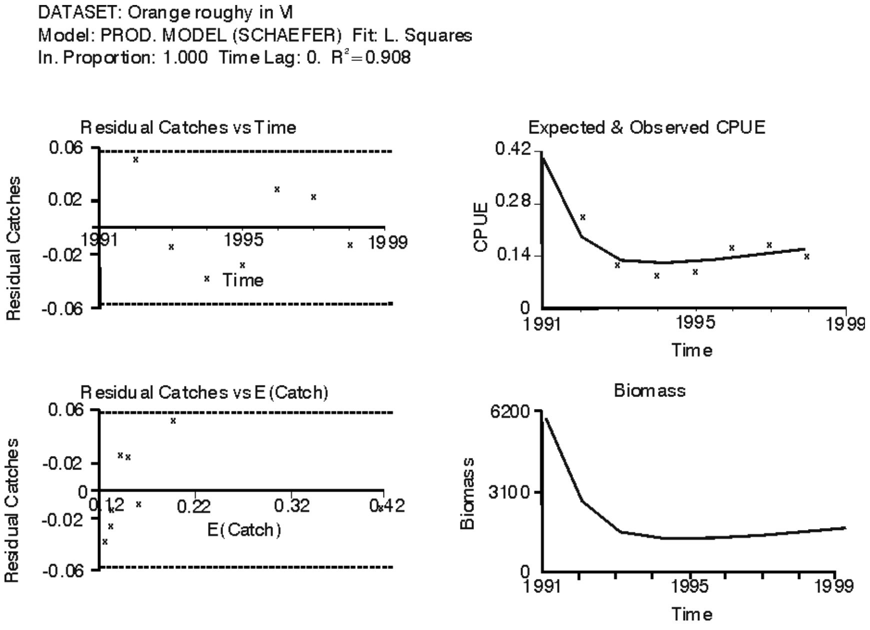
DATASET: Orange roughy in VI
Model: CONSTANT RECRUITMENT Fit: L. Squares
Mortality 0.050 In. Proportion: 1.000 Time Lag: 0. R^2=0.913

Figure 38. *Orange roughy in Sub-area VI. DeLury model*

Table 24. *Orange roughy in Sub-area VI. Schaefer model*

Schaefer	Time lag =0					
Ratio	K (ktonnes)	Q	r	MSY (tonnes)	Pop (ktonnes)	Pop/K
1.0	6.1	0.0001	0.20	300	1.8	0.30
0.9	6.6	0.001	0.21	300	1.7	0.26
0.8	7.2	0.0001	0.21	400	1.7	0.24

Note : Popn values are for the final year 1998



DATASET: Orange roughy in VI
Model: PROD. MODEL (SCHAEFER) Fit: L. Squares
In. Proportion: 1.000 Time Lag: 0. R^2=0.908

Figure 39. *Orange roughy in Sub-area VI. Schaefer model.*

5.6.1.8.2 Orange roughy in Sub-area VII

The fit from a DeLury model was very poor (R^2 >0.1) for a range of error models and input ratios of initial stock to virgin stock (results not presented).

In contrast, the fit from a Schaefer model was good for a range of error models, with log error giving a marginally better fit (R^2=0.902). However, for all options the intrinsic rate of growth (r) is high (>1) and this is highly unlikely given what is known about the biology of the species for such a slow growing species. Results are therefore not presented.

5.6.1.8.3 Orange roughy in Sub-area VI and Divisions VIIb,c

Estimates of relative density from German trawl survey data from the 1970s, calculated using the swept area method, and minimum virgin biomass (B_0), calculated by raising density estimates to total surface area assuming a catchability of 1.0, give a total value of B_0 of around 19,000t (Table 25)

Table 25. *Estimation of B_0 for orange roughy in Sub-areas VI and Divisions VIIb,c assuming a catchability of 1.0.*

	Depth band					
	400 to 600m	600 to 800m	800 to 1000m	1000 to 1200m	1200 to 1400m	Total virgin biomass (kt)
Relative density	0	0	100	570	1710	
Virgin biomass (kt)	0	0	0.8	6.4	11.8	19

Using the Beddington and Cooke procedure assuming a growth rate of 0.06 (Mace *et al*. 1990), natural mortality of 0.05, age of recruitment of 30 years and a virgin biomass of around 19,000t, MSY is estimated to be 400 tonnes ($MSY/B_0 = 0.021$).

5.6.1.9 Comments on the assessments

The results for orange roughy in VI from the DeLury model are fairly similar for virgin biomass and population size in 1998. Estimates of MSY using Schaefer are also quite believable. Stock in 1998 is estimated to be around 30% of virgin biomass. The results for orange roughy in VII from Schaefer are unreliable and are not used.

Minimum virgin biomass in Sub-area VI and Divisions VIIb,c, as estimated by the swept area method, at 19,000t is substantially greater than estimated for Sub-area VI using DeLury and Schaefer (6,000t). A value greater than 6,000t was expected because of the inclusion in the former of Divisions VIIb,c, but 19,000t is considerably higher. It should be noted that orange roughy is an aggregating species with a patchy distribution, and estimates of density from trawl stations may be unreliable when raised to all areas, even when raised by depth-band.

In contrast, estimates of MSY from the Schaefer and Beddington and Cooke models are very similar at around 300-400t. The similarity should, however, not be over-interpreted, since it is merely as a result of the combination of a high estimate of rate of increase with a low estimate of stock size for the Scheafer model, and a low estimate of growth rate with a high estimate of stock size for the swept area method.

5.6.1.10 State of stocks

The results presented in these assessments should be treated with caution because they are based on short time-series and little is known about the general distribution of orange roughy in these areas. Also commercial CPUE for highly aggregating species may not always reflect actual declines in population size. CPUE may be reflecting density within aggregations rather than overall population density. The analyses indicate that current exploitable biomass (U) of orange roughy in Sub-area VII at the end of 1998 was below U_{pa} (50% of virgin biomass) and may be close to U_{lim} (20% of virgin biomass) . The state of orange roughy in Sub-area VII is less clear. Although catch-rates in 1998 were similar to those obtained when the fishery started, these may simply reflect the sequential discovery and subsequent fishing of previously unexploited aggregations.

5.6.2 Black scabbardfish *(Aphanopus carbo)*

5.6.2.1 Distribution and general biology

The black scabbardfish occurs on both sides of the Atlantic from the Denmark Strait to about 30^{o}N (Figure 40). It is also present on the Mid-Atlantic Ridge and other oceanic rises. It appears to be most abundant in the eastern Atlantic.

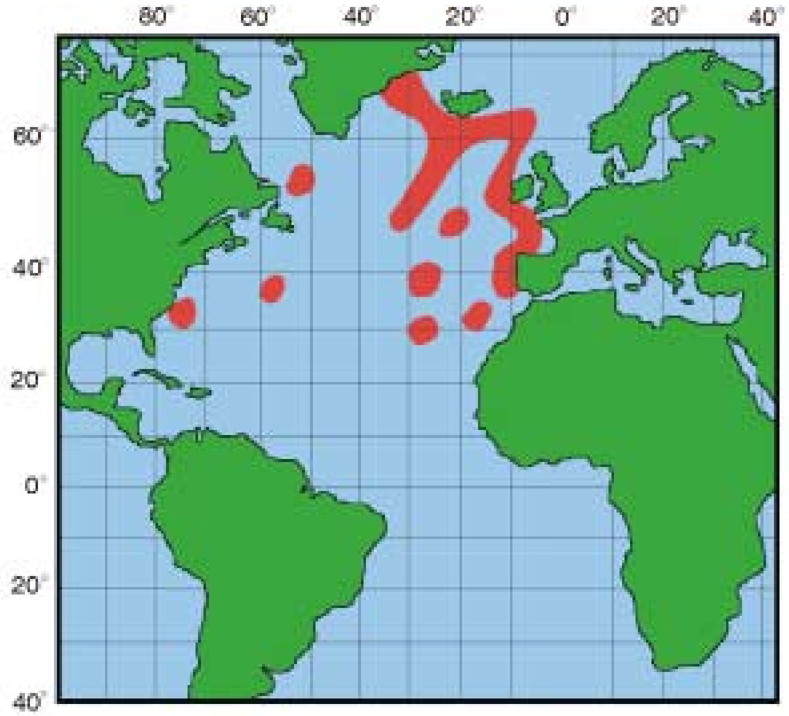


Figure 40. *Distribution of black scabbardfish (modified from Nakamura & Parin, 1983).*

The black scabbardfish is probably best described as a benthopelagic species (living pelagically but close to the seabed), which makes excursions into midwater. In bottom trawl surveys in Sub-areas VI and VII, the best catches are taken at depths between about 550 and 825 m. Although surveys indicated that it is widely distributed throughout Sub-areas VI and VII, there is a tendency for black scabbardfish to be more abundant in the north of the area. Most fish caught are sub-adults with a length range between about 80 and 110 cm and juvenile fish are very scarce. No mature fish have been reported from Sub-areas VI and VII. Mature fish are found off mainland Portugal and around Madeira. There are also Icelandic reports of mature fish on the Rejkanjes Ridge. The eggs and larvae have not been identified and juvenile fish are very rare in all areas.

The food of the black scabbardfish in the Rockall Trough is dominated by fish, particularly blue whiting. The only other organisms found in gut contents were the remains of squid.

5.6.2.2 Stock structure

Little is known of the stock structure of this species. To account for the fact that only sub-adults have been found in Sub-areas VI and VII, and that mature fish are found off mainland Portugal and at Madeira, there has been speculation that this species comprises a single stock. This hypothesis is being addressed by an EC funded project (BASBLACK Project – see Appendix 9.5), investigating microsatellite DNA and otolith microchemistry. No results are currently available.

Following the practice of the ICES Deep-water Study Group, black scabbardfish in Sub-areas VI, VII, XII and Division Vb has been assessed as a single stock unit, i.e. a 'northern component' of what may be a much larger stock (Anon., 2000).

5.6.2.3 Description of fisheries

The fishery in ICES Sub-areas VI, VII and Division Vb commenced in 1989. Most of the catch is taken in a multispecies French bottom trawl fishery together with roundnose grenadier, orange roughy and deep-water sharks.

5.6.2.4 Landings and discard data

Figure 41 shows the trends in total international landings of black scabbardfish by ICES area. Landings from Sub-area VI peaked in 1992, remained stable until 1996 and have since declined. Landings from other areas are comparatively small but have shown a recent decline.

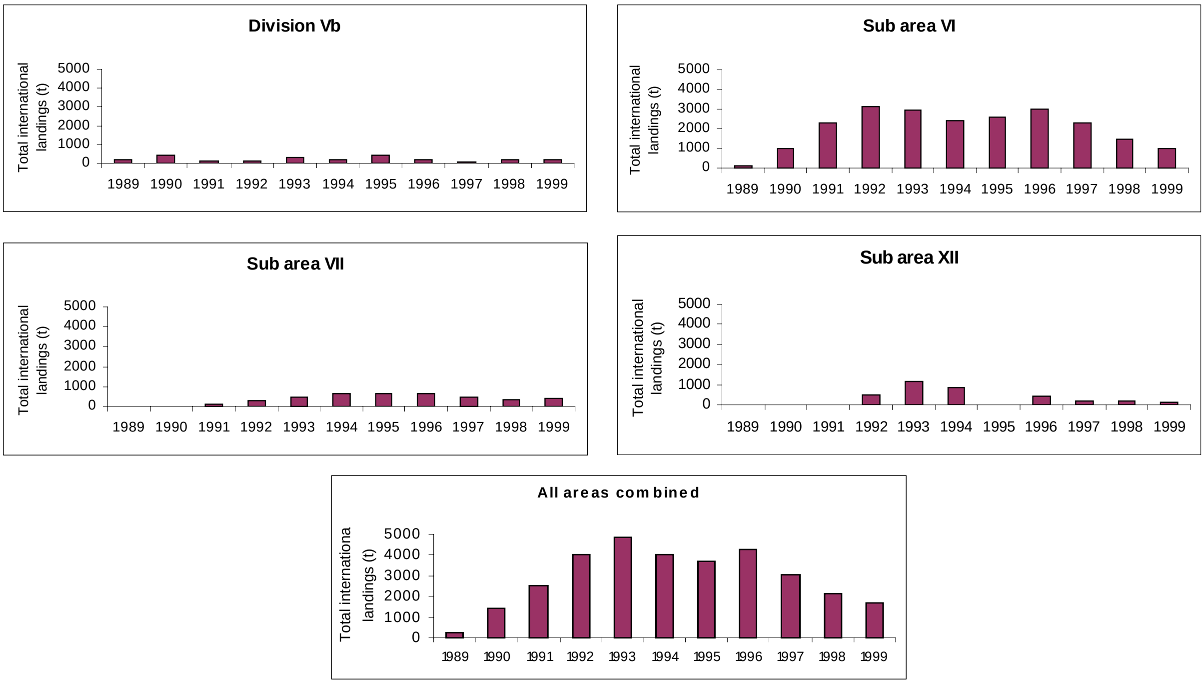


Figure 41. *Total international landings of black scabbardfish by ICES area and for all areas combined*

Discard data for black scabbardfish are sparse. However, available information suggests that quantities discarded in Sub-areas VI, VII and Division Vb are small (Dupouy *et al*. 1998, and Blasdale and Newton, 1998).

5.6.2.5 Commercial catch-effort data

Fishing effort data are only available for French trawlers fishing in ICES Sub-areas VI and VII (Figure 42). Fishing effort in VI and VII gradually increased throughout the 1990s until 1996 and then declined.

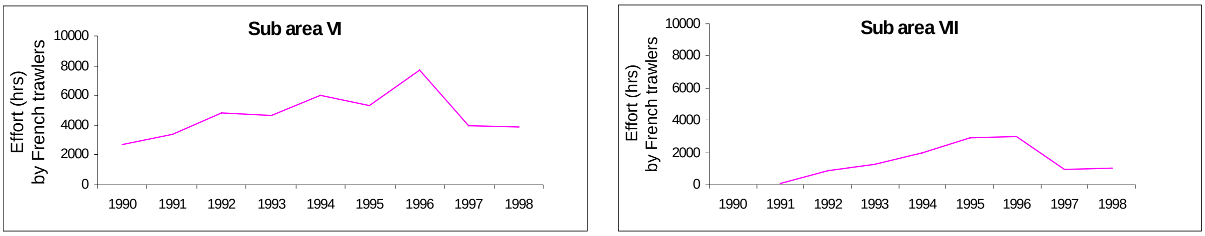


Figure 42. *Effort data from French trawlers - black scabbardfish*

French trawl CPUE data are available for the period 1989–1998 (Figure 43). CPUE in Sub-area VI, where a large proportion of the total international catch is taken, shows a strong decline across the period. CPUE has been variable in Division Vb and relatively stable at a low level in Sub-area VII. The overall trend is for a peak in 1991 followed by a consistent decline.

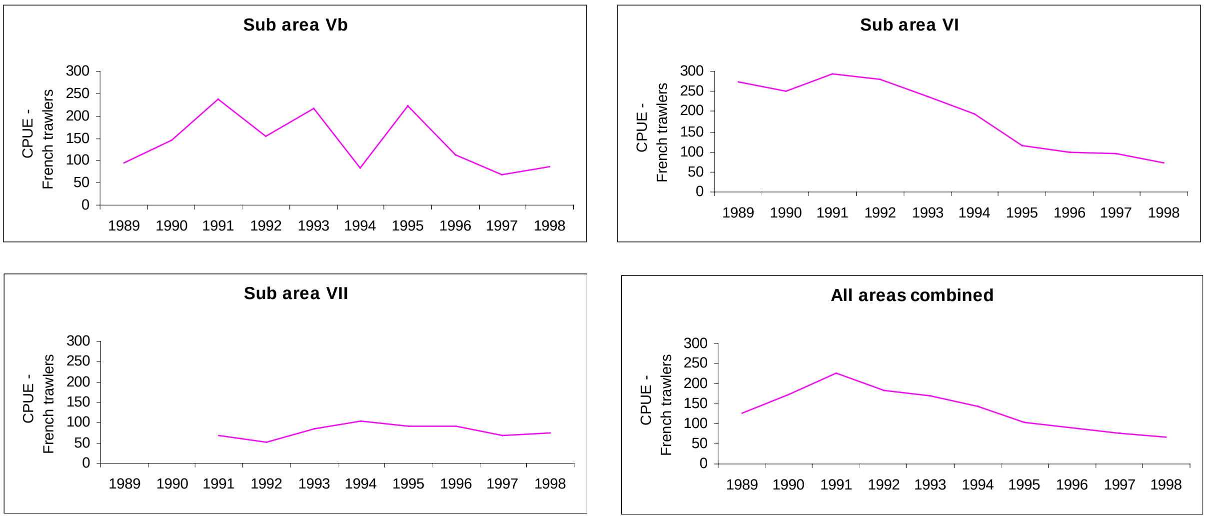


Figure 43. *Catch per unit effort (CPUE) data from French trawlers - black scabbardfish*

5.6.2.6 Length and age compositions

Length composition data for commercial landings of black scabbardfish from the west of the British Isles are sparse. Length data from a recent trawl survey of Sub-areas VI and Division VIIId are shown in Figure 44. Black scabbardfish in Sub-area VI are sub-adults and are smaller than fish taken further south in the Bay of Biscay.

The only published information on age estimation (unvalidated) of the black scabbardfish are from Madeira (Morales-Nin and Sena-Carvalho, 1996). Using whole otoliths, ages of up to eight years were estimated. An otolith exchange and a workshop on age estimation in this species was held in 1999 as part of an EC funded project (BASBLACK Project - see Appendix 9.5). There was a wide discrepancy between age estimates from whole and sectioned otoliths. The workshop concluded that the younger ages determined using whole otoliths were probably the most believable, but, in the absence of juvenile specimens and any means of validation, there must remain some doubt about the ageing of this species.

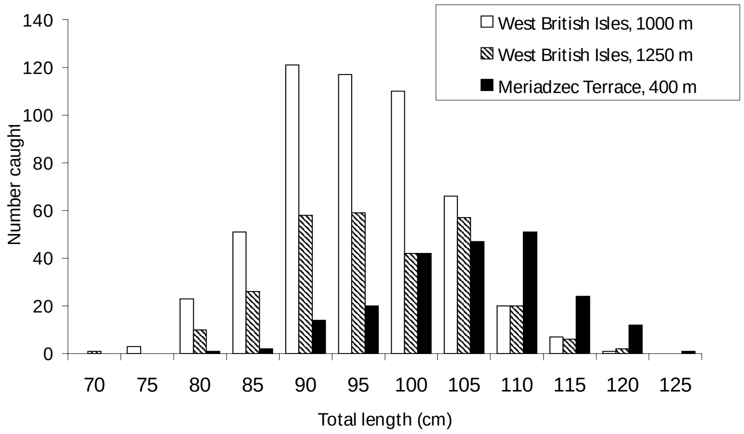


Figure 44. *Comparison of length composition of black scabbardfish from Sub-area VI at depths of 1000 and 1250 m and the Meriadzec Terrace in Division VIIId - Bay of Biscay (Thalassa survey, 1999)*

5.6.2.7 Natural mortality

Natural mortality has been calculated using Pauly’s empiric formula relating M with growth parameters and mean ambient temperatures (Martins *et al*. 1994) and is estimated at 0.17.

5.6.2.8 Assessment results for black scabbardfish in Sub-areas VI, VII, XII and Division Vb

For this assessment, DeLury and Schaefer models were fitted to total international catch data from 1989 to 98 and French CPUE data for otter trawlers for the years 1990-98. CPUE data for 1989 and 1990 were excluded because of a suspected improvement in fishing power in the early years of the fishery (see Section 5.5).

The fit from a DeLury model was good for a range of error models, with log error giving a marginally better fit (R^2=0.962) (Figure 45). The results were reasonably robust for a range of values of ratio of initial stock to virgin stock (Table 26). There was a large fishery for roundnose grenadier in Sub-area XII in the 1960s and 1970s and it is probable that large quantities of black scabbard may have been caught as a by-catch and discarded. It seems reasonable, therefore, to select an initial ratio of less than 1. At ratios of less than 0.6 the estimated biomass trend from the model shows a marked increase in 1989 and 1990 and there is no evidence to corroborate this (the French CPUE series only goes back to 1991). Taking all factors into consideration, a ratio of

0.8 seemed a reasonable compromise and the results are presented in Table 26 and Figure 45. Virgin stock biomass is estimated to be around 22,000t (95% confidence limits : 21,000-23,000t). Population biomass in 1998 is estimated to be around 4,000t, 19% of virgin biomass (95% confidence limits : 18-20%).

Table 26 . *Black scabbardfish in Sub-areas VI, VII and XII and Division Vb. DeLury model*

Ratio	K (nos in millions)	q	Pop (nos in millions)	K (ktonnes)	Pop (ktonnes)	Pop/K
1.0	15.1	0.00001	3.4	21.5	4.9	0.23
0.9	15.1	0.00001	3.2	21.6	4.5	0.21
0.8	15.1	0.00001	2.9	21.6	4.2	0.19
0.7	15.2	0.00001	2.7	21.7	3.8	0.18
0.6	15.3	0.00002	2.5	21.8	3.6	0.17

Note Popns are for the final year 1998

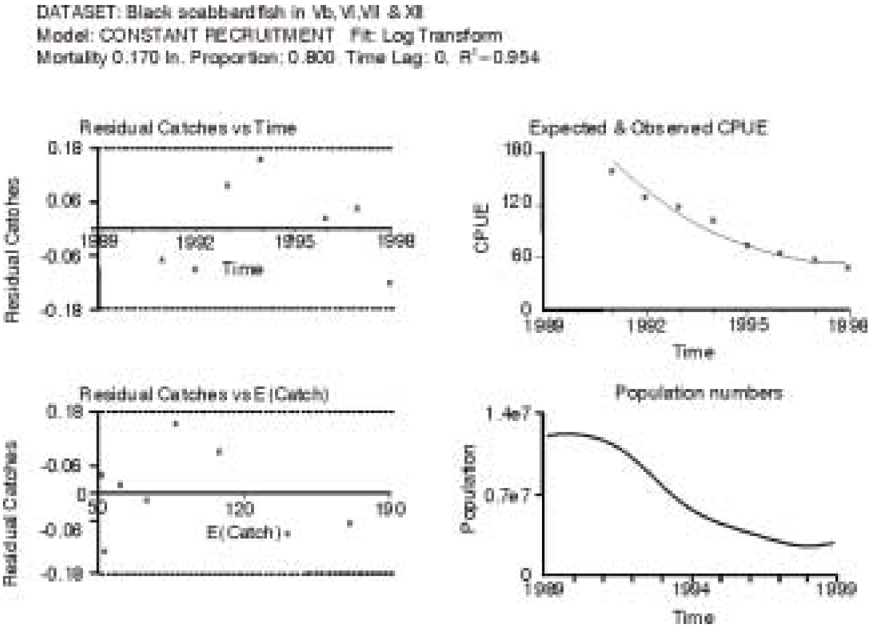


Figure 45. *Black scabbardfish in Sub-areas VI, VII, XII and Division Vb. DeLury model.*

Choice of error model had little effect on the fit for a Schaefer model. All error models gave a good fit (R^2=0.98) and log error was used throughout. The results from Schaefer for a range of values of ratio of initial stock to virgin stock were fairly robust (Table 27). An initial ratio of 0.8 was selected for the reasons described above for the DeLury model. The estimated intrinsic rate of growth (r) is quite high (0.523) but there is some ageing evidence to suggest that black scabbardfish may not be as long-lived as other deep-water fish. The results (Table 27 and Figure 46) indicate that carrying capacity is estimated to be around 19,000t (95% confidence limits: 16,000-50,000t). Population biomass in 1998 is estimated to be around 5,000t, 24% of carrying capacity. MSY is estimated to be around 2,500t (95% confidence limits: 50–2,800t) This equates to around 13% of carrying capacity.

Table 27 . *Black scabbardfish in Sub-areas VI, VII and XII and Division Vb. Schaefer model.*

Schaefer	Time lag =0					
Ratio	K (ktonnes)	q	r	MSY (ktonnes)	Pop (ktonnes)	Pop/K
1.0	22.1	0.00001	0.40	2.2	5.7	0.26
0.9	22.0	0.00001	0.41	2.2	5.4	0.25
0.8	19.4	0.00001	0.52	2.5	4.7	0.24
0.7	17.2	0.00002	0.64	2.8	4.2	0.24

Note Popns are for the final year 1998

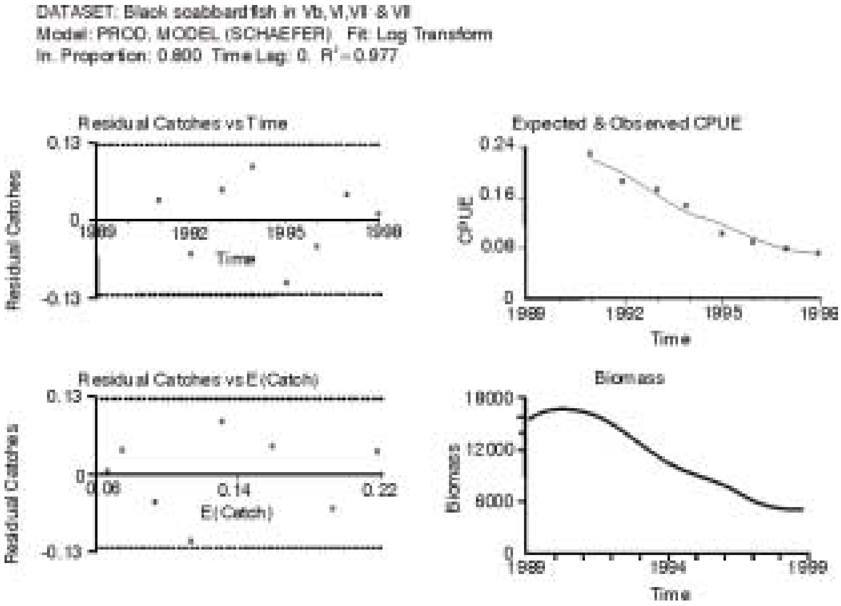


Figure 46. *Black scabbardfish in Sub-areas VI, VII, XII and Division Vb. Schaefer model.*

5.6.2.9 Comments on the assessment.

The results for black scabbardfish in Sub-areas VI,VII, XII and Division Vb from DeLury and Schaefer analyses are fairly similar for virgin biomass and population size in 1998. Stock in 1998 is estimated to be between 19 and 24% of virgin biomass. It should be noted that the 95% confidence limits about carrying capacity and MSY from the Schaefer model are very wide.

5.6.2.10 State of stock

The DeLury and Schaefer analyses indicate that exploitable biomass (U) of black scabbardfish in Sub-areas VI,VII,XII and Division Vb at the end of 1998 was below U_{pa} (50% of virgin biomass) and may have been below U_{lim} (20% of virgin biomass). However, the results presented in this assessment should be treated with caution because they are based on short time-series and little is known about stock structure and migration of this species. A possible bias in CPUE because of depth effects is also a concern. Due to its relatively short life span (Morales-Nin and Sena-Carvalho, 1996), black scabbardfish may be expected to be less sensitive to overfishing than the other deep-water species. This assessment suggests that this is not the case. One possible explanation for this is that CPUE may have been biased by changes in the depth of fishing. The abundance of this species decreases below 1200 m and the observed decline in CPUE may, in some part, be caused by trawlers fishing progressively deeper to target roundnose grenadier. Analysis of the catch and effort of one trawler suggests that this trend to fish deeper exists at least for some vessels. However, CPUE corrected for changes in depth (Girard *et al*. 2000) shows only a slightly less decreasing trend with time. Further investigations are required for other French trawlers in the deep-water fishery, but this may not be possible because depth of fishing is not recorded in EC logbooks.

5.6.3 Deep-water sharks

Most of the abundant deep-water sharks belong to two families : the Squalidae (dogfishes) and the Scyliorhinidae (catsharks). Squalidae typically produce live young and are represented by the Portuguese dogfish (*Centroscymnus coelolepis*), longnose velvet dogfish (*Centroscymnus crepidater*), black dogfish (*Centroscyllium fabricii*), leafscale gulper shark (*Centrophorus squamosus*), birdbeak dogfish (*Deania calceus*), kitefin shark (*Dalatias licha*), velvet belly (*Etmopterus spinax*), great lanternshark (*Etmopterus princeps*) and knifetooth dogfish (*Scymnodon ringens*). Scyliorhinidae typically produce large eggs in cases and are represented by the blackmouth catshark (*Galeus melastomus*), the mouse catshark (*Galeus murinus*) and *Apristurus* species**.** Landings from Sub-areas VI and VII and Division Vb comprise two main species:- the Portuguese dogfish and the leafscale gulper shark

5.6.3.1 Distribution and general biology

The Portuguese dogfish is one of the larger sharks found on the continental slope to the west of the British Isles. It can be distinguished from others by its deep chocolate brown colour and its skin, which is very smooth from head to tail. It is distributed along the continental shelf on both sides of the Atlantic. It is also found around Madeira and the Azores, in the Mediterranean and down the west coast of Africa (Figure 47). There is evidence that it is also found in the Pacific. In surveys of the Rockall Trough the Portuguese dogfish has been caught at depths between 665 and 1750m. Peak abundance occurs at around 1000m. Reproduction is ovoviviparous and 13 to 16 young are produced in a litter. Japanese investigations of this species in the Pacific suggest a two year gestation period. Fish and squid dominate the diet of Portuguese dogfish in the Rockall Trough.

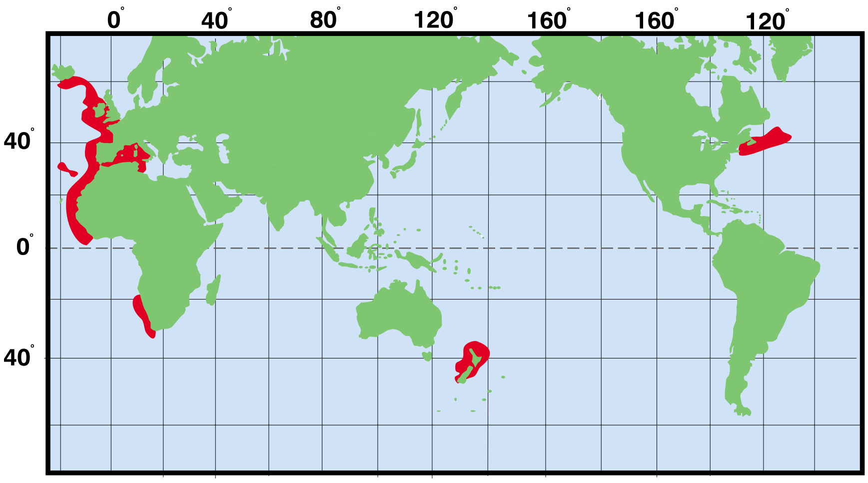


Figure 47. *Distribution of the Portuguese dogfish*

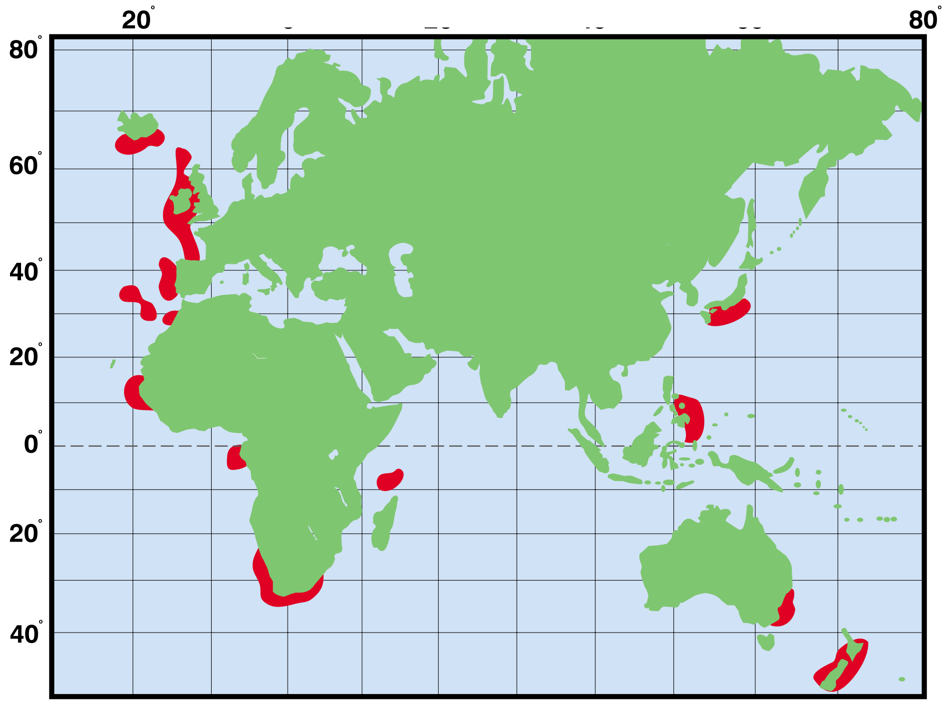


Figure 48. *Distribution of the leafscale gulper shark*

The leafscale gulper shark is greyish in colour and has denticles (scales) on short stalks giving it a velvety appearance. It is found in the eastern Atlantic from Iceland to Senegal and also off Madeira and the Azores (Figure 48). It is also found along the continental slope of southern Africa, in the western Indian Ocean and in the western Pacific from Japan to New Zealand, In trawl surveys of the Rockall Trough, the leafscale gulper shark has been caught at depths between 450 and 1020m. Reproduction is ovoviviparous and there are reports of between 5 and 16 young produced in a litter. The dominant component of the diet of this shark in the Rockall Trough is fish, including blue whiting.

5.6.3.2 Stock structure

There is no information available on the stock structure of deep-water elasmobranchs. Catches from ICES Sub-areas VI and VII and Division Vb comprise mainly Portuguese dogfish and the leafscale gulper shark. Although these species are widely distributed in the Atlantic (and possibly highly migratory), deep-water sharks in these areas (all species) have been treated as a single assessment unit. This is an interim measure and it is acknowledged that as more information on stock structure becomes available it is probable that future assessments of deep-water sharks will encompass a much larger geographical area.

5.6.3.3 Description of fisheries

The main fishery for deep-water sharks in the ICES area is in Sub-areas VI and VII. Sharks are an important component of catches in French trawl fisheries for deep-water species in these areas. Deep-water sharks are also taken as a by-catch in long-line fisheries for ling, tusk and hake. From time to time, depending on market prices, there is also a small directed long-line and net fishery.

5.6.3.4 Landings and discard data

Landings of deep-water sharks are rarely identified to the species level. Landings are often described as ‘sharks various’ and may even include pelagic sharks such as the porbeagle. The Portuguese dogfish and the leafscale gulper shark were until very recently not recorded as separate species but appeared in French landings statistics as ‘siki’. Furthermore, in several fisheries, depending on market prices, livers, oils, fins and shark skins are landed and carcasses are discarded. Trends in landings of deep-water sharks by ICES area (Figure 49) show that landings increased dramatically in the early and mid-1990s. In Sub-area VI, where most of the landings are taken, landings peaked in 1996 and have since declined. Landings from Sub-area VII have been smaller and more variable.

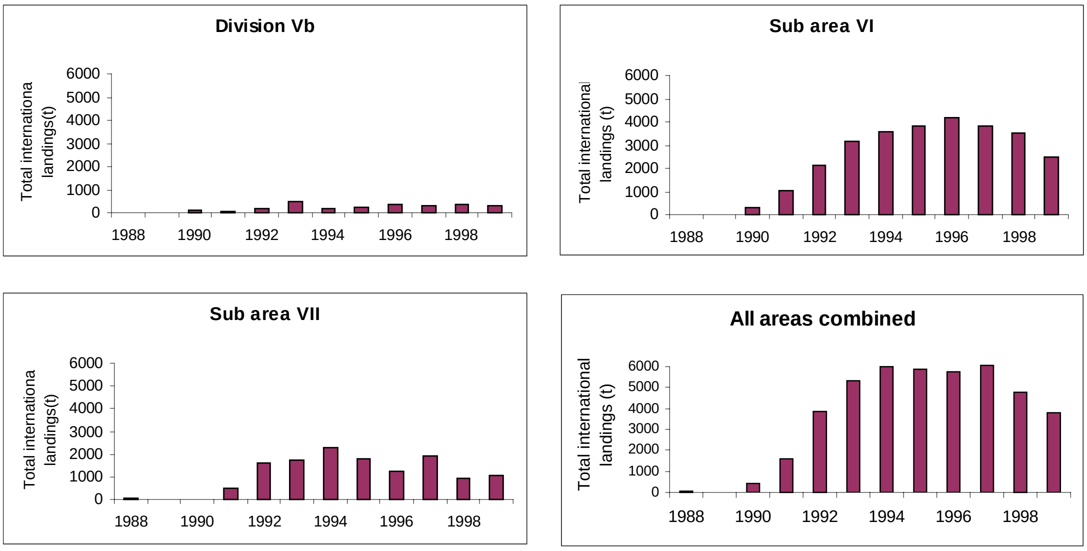


Figure 49. *Total international landings of deep-water sharks (all species) by ICES area and for all areas combined*

5.6.3.5 Commercial catch-effort data

Fishing effort data are only available for French trawlers fishing in ICES Sub-areas VI, VII and Division Vb (Figure 50). Fishing effort in Sub-area VI increased dramatically in the early 1990s and has been stable since 1993. A similar pattern is seen Sub-area VII until the mid-1990s, and then effort declined and stabilised at a lower level. Fishing effort in Division Vb has slowly increased.

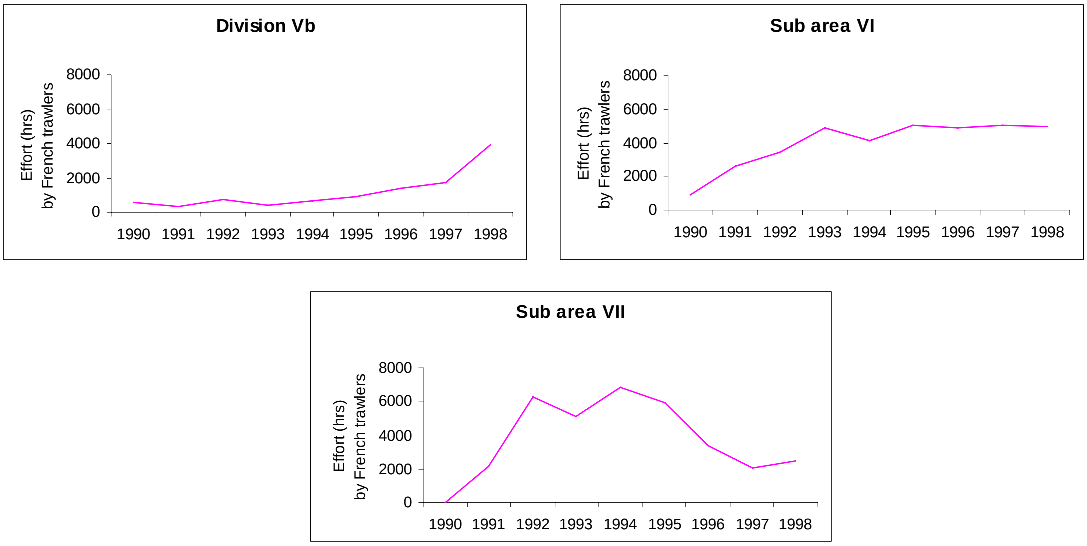


Figure 50. *Effort data from French trawlers - deep-water sharks.*

French trawl CPUE data are available for the period 1989–1998 (Figure 51). CPUE in Sub-area VI, where a large proportion of the total international catch is taken, peaked in 1991 and has since gradually declined. CPUE has been reasonably stable in Sub-area VII but has declined in Division Vb in recent years.

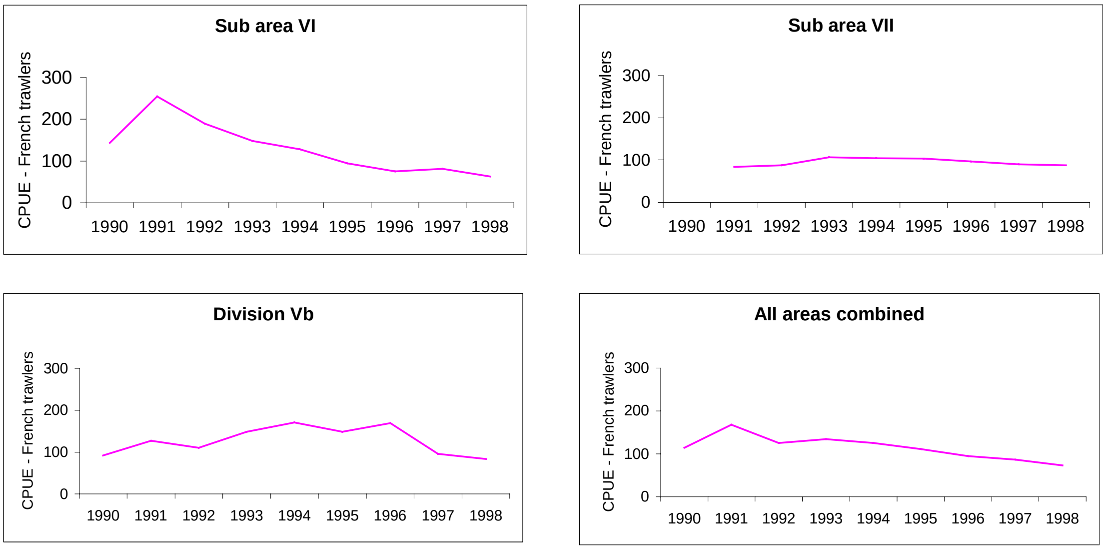


Figure 51. *Catch per unit effort (CPUE) data from French trawlers, C. coelolepis and C. squamosus.*

5.6.3.6 Length and age compositions

Length data from commercial landings of deep-water sharks are not available for all years. Furthermore, there are no regular annual survey data available. The length composition of male and female *Centroscymnus coelolepis* and *Centrophorus squamosus* in the French commercial landings from Sub-areas VI and VI in 1995 and 1996 are shown in Figures 52 and 53. Differences in length composition between years are considered to be due to changes in the geographical distribution of fishing rather than changes in stock structure. The length composition of *Centroscymnus coelolepis* from a French trawl survey in 1999 is shown in Figure 54.

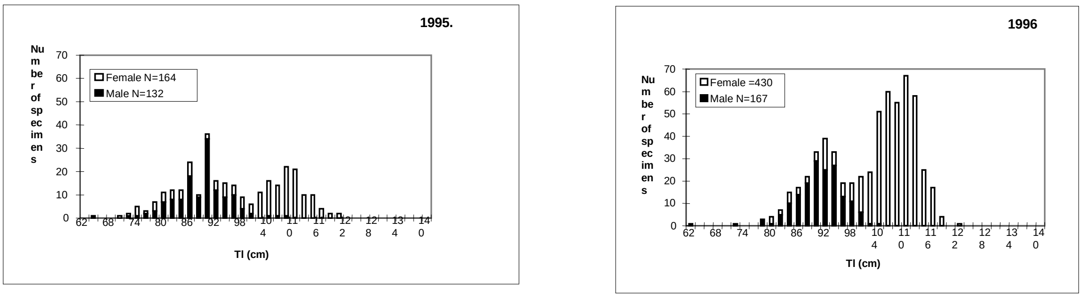


***Figure 52**.* *Size structure in the French landings of Centroscymnus coelolepis in 1995 and 1996 from Sub-areas VI and VII.*

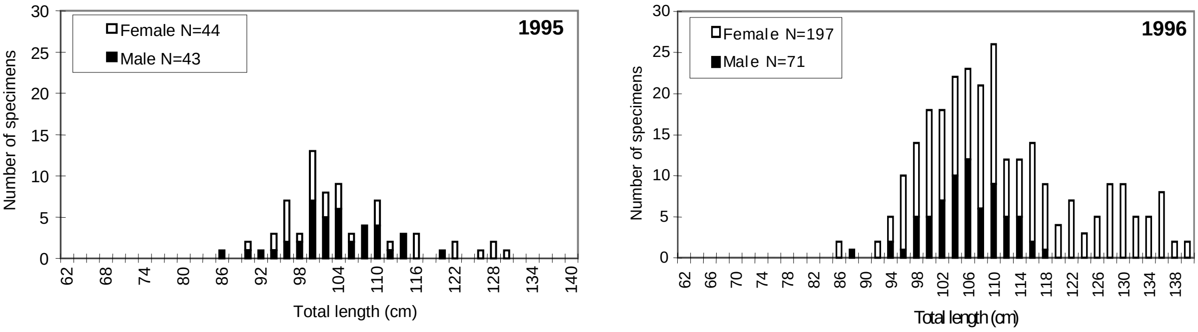


***Figure 53**.* *Size structure in the French landings of Centrophorus squamosus in 1995 and 1996 from Sub-areas VI and VII.*

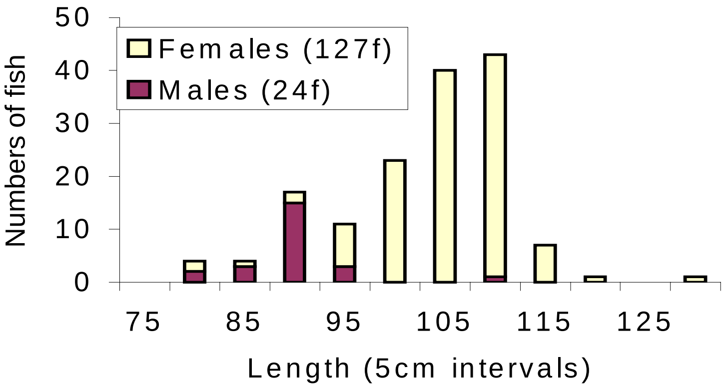


***Figure 54**.* *Centroscymnus coelolepis in Sub-area VI. Length composition of French survey catches at 1000m and 1250m in 1999*

Age estimates for *Centrophorus squamosus*, obtained from the first and second dorsal spines, indicate ages of up to 53 years for males and 68 years for females (Clarke, unpublished data). These estimates have not been validated and should be treated with caution.

5.6.3.7 Natural mortality

Natural mortality for *Centrophorus squamosus* was estimated to be around 0.08, using the relationship developed by Annala and Sullivan (1996) (see Section 5.3.1.4).

An estimate of M was not available for *Centroscymnus coelolepis*. The above method cannot be used because there are no age data available for this species.

5.6.3.8. Assessment results for deep-water sharks in Sub-areas VI and VII and Division Vb.

Schaefer and DeLury analyses were attempted using total international landings data (all species) for the period 1989-98 and French trawl CPUE data for *C. coelolepis* and *C. squamosus* for the years 1991 and 1998. CPUE data for 1990 were excluded because of a suspected improvement in fishing power in the early years of the fishery (see Section 5.5). Taking into account possible levels of natural mortality, it seems reasonable to fit the Delury model with values of M of 0.05 and 0.1.

The fit from a DeLury model was good for a range of error models and values of M, with log error giving a marginally better fit (R^2=0.9). The results were reasonably robust for a range of values of ratio of initial stock to virgin stock (Tables 28 and 29). Prior to the development of a shark fisheries in Sub-areas VI and VII and Division Vb, *C. squamosus* was caught as a by-catch in the blue ling fisheries in Sub-area VI and Division Vb and the redfish *(Sebastes mentella)* fishery in Division Vb, from both of which it was discarded. It is believed that the quantities involved were not large and for the DeLury model a ratio of initial to virgin stock of 0.9 was used (Figure 55). Using these parameter values, virgin stock biomass of all sharks is estimated to be between 50,000 and 62,000 t (95% confidence limits: 45,000-71,000t). Population biomass in 1998 is estimated to be between 20,000 and 25,000t, 40% of virgin biomass.

Table 28 . *Deep-water sharks in Sub-areas VI, VII and Division Vb. DeLury model (M=0.05)*

Ratio	K (nos in millions)	q	Pop (nos in millions)	K (ktonnes)	Pop (ktonnes)	Pop/ K
1.0	7.3	0.000003	3.2	59.1	25.8	0.44
0.9	7.6	0.000003	3.1	61.8	24.9	0.40
0.8	8.0	0.000003	2.9	64.6	23.8	0.37

Note Popns are for the final year 1998

Table 29. *Deep-water sharks in Sub-areas VI, VII and Division V. DeLury model (M=0.1)*

Ratio	K (nos in millions)	q	Pop (nos in millions)	K (ktonnes)	Pop (ktonnes)	Pop/ K
1.0	6.1	0.000003	2.6	49.7	21.4	0.43
0.9	6.2	0.000003	2.5	50.0	20.1	0.40
0.8	6.2	0.000003	2.3	50.2	18.5	0.37

Note Popns are for the final year 1998

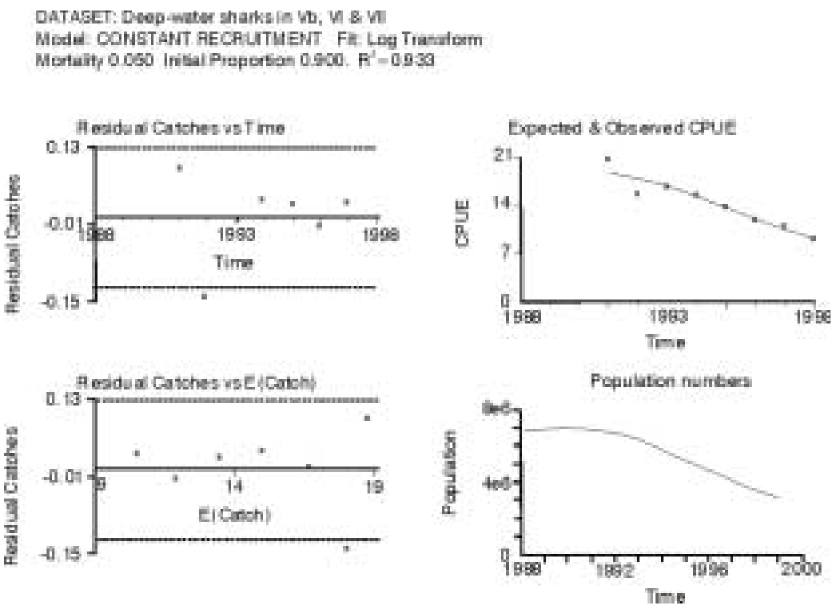


Figure 55. Deep-water sharks in Sub-areas VI, VII and Division Vb. DeLury model (M=0.05)

The fit from a Schaefer model was good for a range of error models, with log error giving a marginally better fit (R^2=0.936). Estimates of carrying capacity and population in 1998, for range of values of ratio of initial stock to virgin stock, are given in Table 30. An initial ratio of 0.9 was selected for the reasons described for the DeLury model. The results (Table 30 and Figure 55) indicate that carrying capacity is around 73,000t (95% confidence limits: 37,000-93,000t). Population biomass in 1998 is estimated to be 29,000t, 40% of carrying capacity. MSY is estimated to be around 500t (95% confidence limits: 20–4200t). It should be noted that the model is very sensitive to the initial ratio used. Using an initial ratio of 0.8 gives much higher values of r and MSY and lower values of K and population in 1998. From a biological point of view, the lower values of r are more compatible with a low value of natural mortality assumed for these species.

Table 30. *Deep-water sharks in Sub-area VI, VII and Division Vb. Schaefer model*

Schaefer	Time lag =0					
Ratio	K (ktonnes)	q	r	MSY (ktonnes)	Pop (ktonnes)	Pop/K
1.0	67.8	0.000002	0.03	0.5	30.3	0.45
0.9	72.6	0.000002	0.03	0.5	29.2	0.40
0.8	55.2	0.000003	0.16	2.2	21.7	0.39

Note : Popn values are for the final year 1998

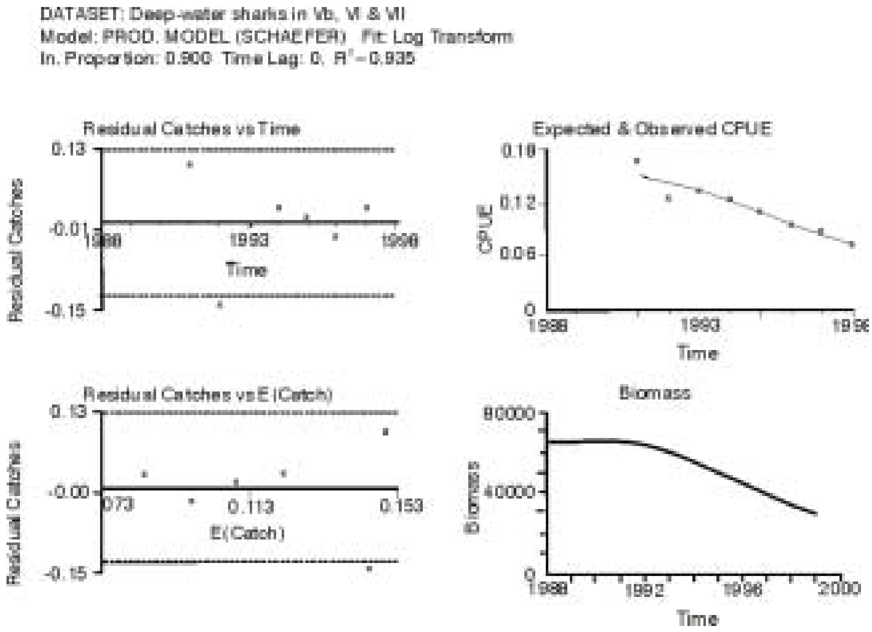


Figure 55. *Deep-water sharks in Sub-area VI, VII and Division Vb. Schaefer model.*

5.6.3.9 Comments on the assessments

The DeLury and Schaefer analyses give quite similar estimates of virgin biomass and population biomass in 1998 of all deep-water sharks in Sub-areas VI, VII and Division Vb at around 50-70,000t and around 20-30,000t, respectively, although it should be noted that the confidence limits from Schaefer are very wide. Estimates of MSY from the Schaefer model appear to be poorly estimated and have extremely wide confidence limits. The declining trend in overall French trawl CPUE in Sub-areas VI and VII and Division Vb (Figure 55) is largely driven by a strong decline in Sub-area VI (Figure 51). *C. squamosus* and *C. coelolepis* show differing distributions by depth with peak catches-rates occurring at 1000m and 1300m, respectively. From anecdotal comments from fishing skippers, it is known that the French fleet has fished progressively deeper, down to depths of 1500m (targeting other deep-water species as well as sharks), and it is possible that this may have introduced a bias in CPUE values. However, it could also be argued that vessels have fished deeper because of falling catch-rates (of sharks, for example) in shallower depths. It is not possible to adjust for depth in the GLM model of CPUE because depth of fishing is not formally reported.

5.6.3.10 State of stock

The DeLury and Schaefer analyses indicate that exploitable biomass (U) of deep-water sharks in Sub-areas VI,VII and Division Vb at the end of 1998 was below U_{pa} (50% of virgin biomass). However, the results presented in this assessment should be treated with caution because they are based on short time-series and little is known about the stock structure and migration of deep-water sharks in these areas. A possible bias in CPUE because of depth effects is also a concern.

It is known that *C. coelolepis* and *C. squamosus* are widely distributed in the Atlantic and, as more information becomes available, it may be appropriate to carry out assessments of stock over a wider area, to include landings from Sub-areas IX and X, for example.

5.6.4 Roundnose grenadier *(Coryphaenoides rupestris)*

5.6.4.1 Distribution and general biology

The roundnose grenadier is confined to the North Atlantic where it is widely distributed (Figure 56).

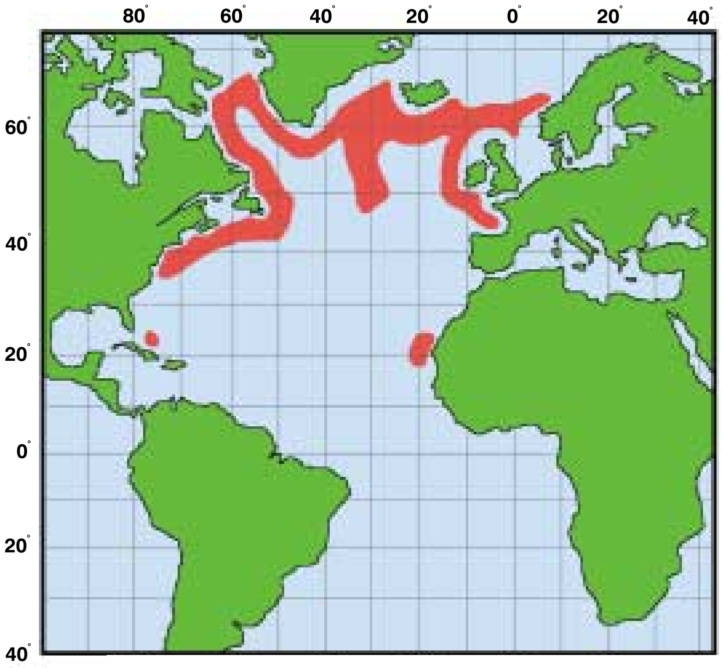


Figure 56. *Distribution chart of roundnose grenadier* ***(modified from Cohen at al,1990)***

It occurs along the continental slope northwards from 37^{o}N off the USA to about 66^{o}N off Canada and then along the slope of Baffin Island and West Greenland to Iceland. Its distribution extends down the Reykjanes Ridge and onto the Mid Atlantic Ridge and eastwards along the slope to the south of the Faeroe Islands and then south as far as about 40^{o}N. Roundnose grenadier also occurs in deep shelf troughs off Norway and in some fjords and in the Skagerrak. It is also found at a latitude of 20-25^{0}N on both sides of the Atlantic, although observations off the Bahamas comprise two specimens only.

Although roundnose grenadier has been recorded in bottom trawls from depths ranging from 180 to 2200 m, to the west of the British Isles it is generally found between about 500 and 1800 m. Pelagic captures have been reported, especially in the western North Atlantic, and Russian trawlers off Labrador have made significant catches by night with mid-water trawls. However, evidence in support of diurnal vertical migrations is contradictory.

The size composition of many deep-water fish species increases with depth, but roundnose grenadier, at least in the Rockall Trough, is an exception. The population on the upper slope (750 m) is dominated by large fish and a high proportion of these are male. At 1000 and 1250 m the population length structure is markedly bimodal, with a secondary mode of smaller fish. The modal length of these smaller fish increases with depth, such that the smallest fish are at 1000 m. At a depth of 1500 m the length mode of these smaller fish partly merges with that of the larger fish which make up a smaller proportion of the catch. The fish at 1750 m are all of intermediate size. There is an increase in the proportion of female fish with increasing depth.

Although there are differences between geographical areas, it appears that spawning can occur throughout most of the year in the Rockall Trough. The eggs of the roundnose grenadier are large (2.3-2.4 mm) and the mean fecundity of fish between 75 and 105 cm in length is around 32,000 eggs (Gordon and Hunter, 1994).

A diverse diet of mainly small pelagic and benthopelagic food organisms is a common feature of all the feeding studies on the roundnose grenadier.

5.6.4.2 Stock structure

There has been much speculation on whether the North Atlantic population of roundnose grenadier can be divided into separate stocks. To account for some apparent peculiarities in distribution, some Russian workers suggested a complex migration path for this species from the eastern Atlantic to the west and back again. Attempts to validate this, using parasites and genetics, have indicated that there might be several reproductively isolated stocks. Isolated populations probably also exist in the Skagerrak and some Norwegian fjords. For assessment purposes, however, it seems reasonable to suppose, on geographical grounds, that roundnose grenadier in ICES Sub-areas VI , VII and Division Vb should be treated as a single stock

5.6.4.3 Description of fisheries

The fishery for roundnose grenadier in the Atlantic began in the late 1960s when Russian trawlers began to exploit the dense concentrations exploratory surveys had shown existed off Canada. The fishery in the north-eastern Atlantic appears to have begun in 1973 when Russian vessels began fishing the southern part of the Reykjanes Ridge. By 1980 the landings from the north-eastern Atlantic fishery exceeded those in the north-western Atlantic. Smaller catches were also made around the Faroes and in international waters to the west of Scotland (Hatton Bank). Although the fishery was dominated by the USSR until 1978, other counties such as Germany, Faroes and Iceland also became involved. France began to land small quantities in 1988 and from then on there was a sharp increase in French landings. French trawlers now account for most of the landings of roundnose grenadier from Sub-areas VI and VII.

5.6.4.4 Landings and discard data

In Sub-area VI, where most of the landings are taken, landings peaked in 1993 and have since declined slightly (Figure 57). Landings from Sub-area VII and Division Vb have been variable but at a low level.

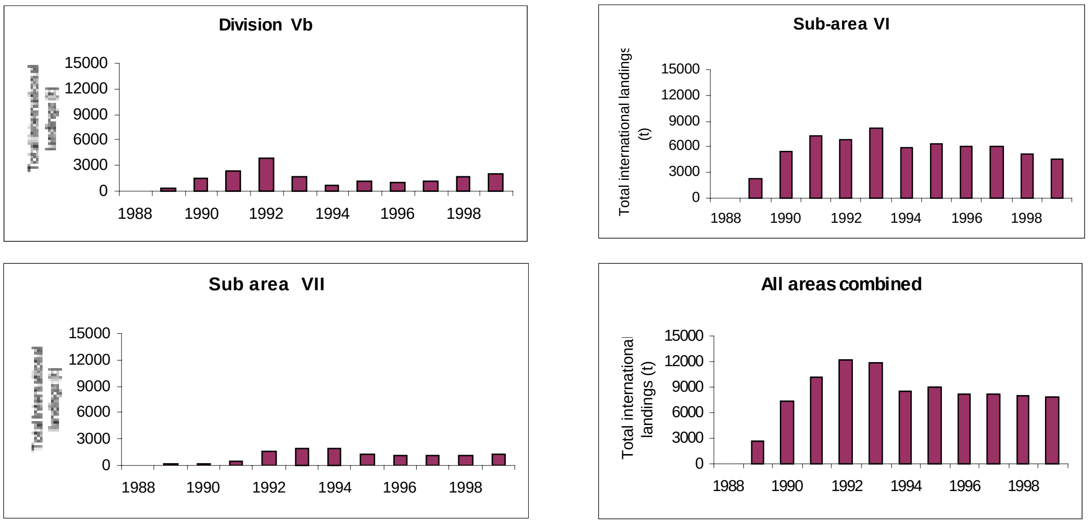


Figure 57. Total international landings of roundnose grenadier by ICES area and for all areas combined

Discards of roundnose grenadier were estimated as part of an EC Fair funded project (Anon., 1999b). Adults and juveniles are often found together on fishing grounds, and, because juveniles are too small for commercial markets, a high discarding rate can occur. In the French trawl fishery in 1996 and 1997, discards were estimated to be 30% of landings by weight and 60% of landings by number. For stock assessment purposes, total international catches from ICES Sub-areas VI, VII and Division Vb, most of which are by French trawlers, have been calculated by raising total international landings for each year by a factor of 30%.

5.6.4.5 Commercial catch-effort data

Fishing effort data are only available for French trawlers fishing in ICES Sub-areas VI and VII and Division Vb (Figure 58). Fishing effort in Sub-area VI increased steadily throughout the early 1990s, peaked in 1996 and then declined slightly in recent years. In contrast effort in Sub-area VII peaked in 1992 and has since gradually declined. Following an initial peak in 1990, fishing effort in Division Vb declined throughout the mid-1990s before increasing again in recent years.

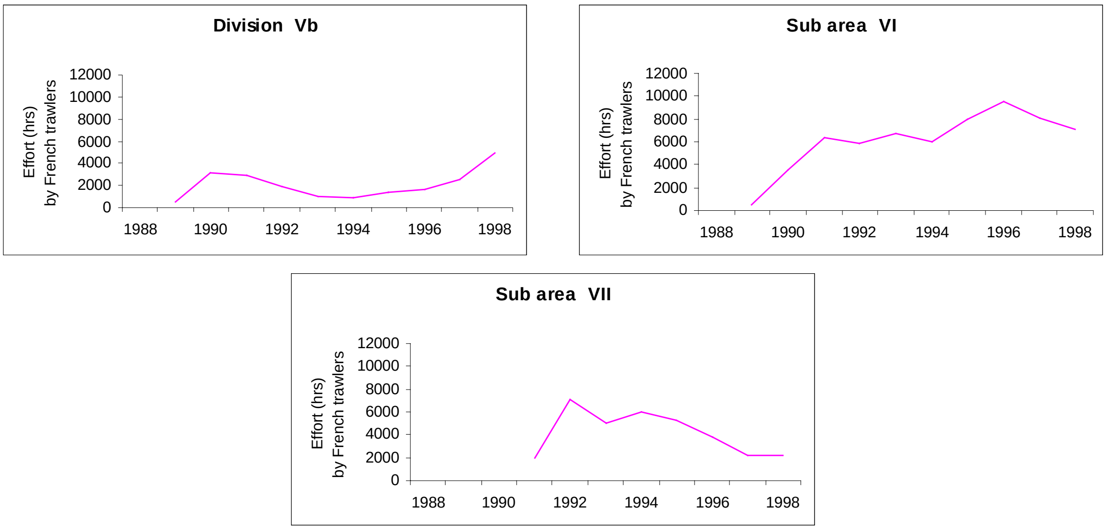


Figure 58. *Effort data from French trawlers - roundnose grenadier*

French trawl CPUE data are available for the period 1989–1998 (Figure 59). CPUE in Sub-area VI and Division Vb has gradually declined following an initial peak in the early 1990s. CPUE in VII has been stable, albeit at a comparatively low level.

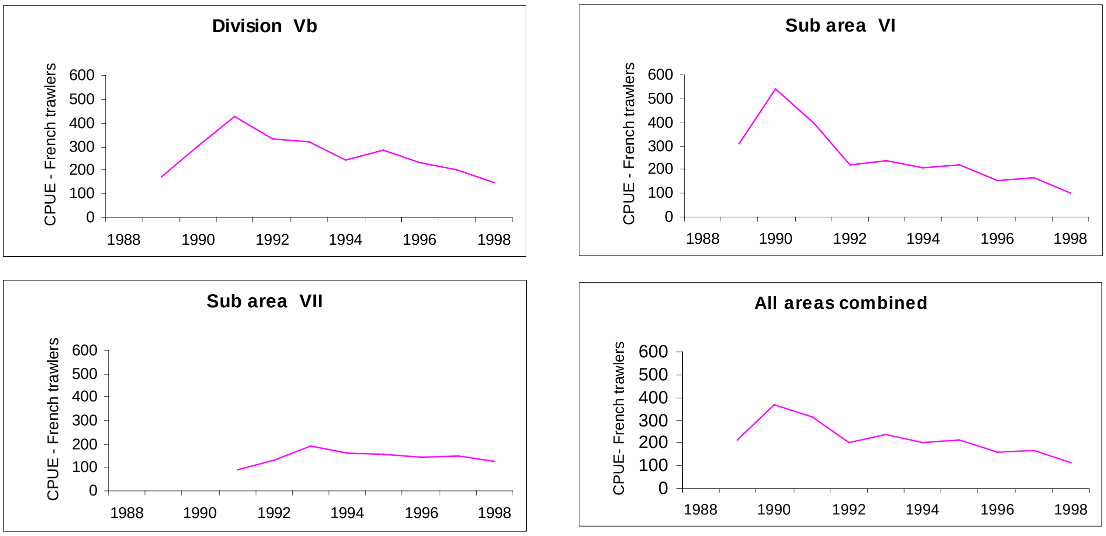


Figure 59. *Catch per unit effort (CPUE) data from French trawlers - roundnose grenadier*

5.6.4.6 Length and age compositions

The long, tapering tail of the roundnose grenadier can cause problems with length measurement. The loss (and sometimes the subsequent regeneration) of the end of the tail is common as result of predation or trawl damage. Three measurements have been used at various times for this species. Pre-anal fin length measured from the tip of the snout to the beginning of the anal fin is now accepted as the standard, although even this has problems. Some studies have used pre-anal length and this is sometimes assumed to be the same as pre-anal fin length. Other measurements that have been used are head length and total length.

Time-series data of length compositions (measured as pre-anal fin length) of French trawl landings show a gradual decrease in size with time (Figure 62). This could be caused by changes in discarding rates, although all available evidence indicates that discarding rates were fairly constant across the time period, or, given the vertical distribution of this species (see Section 5.6.4.1), by changes in the depth of fishing. However, fisheries independent trawl survey data indicate that there has been a real change in population composition. SAMS trawl surveys in 1985 and German surveys in the 1970s (pre-exploitation) when compared with SAMS and French surveys in 1999 (post-exploitation) show a similar change in size composition (Figure 17 in Section 4.4.3 and Figures 60 and 61).

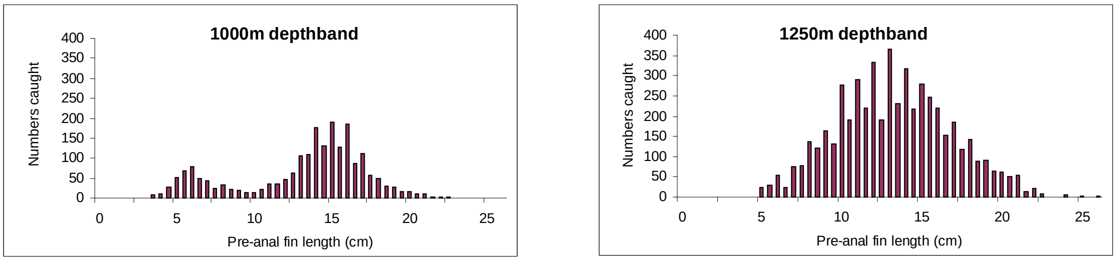


Figure 60. *Length composition of roundnose grenadier observed during a French trawl survey in VI and VII, 1999*

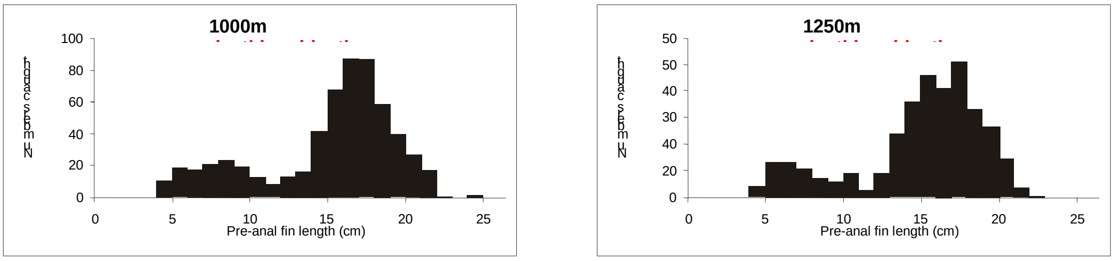


Figure 61.. *Length composition of roundnose grenadier observed during a German trawl survey in late 1970s (modified from Ehrich, 1983)*

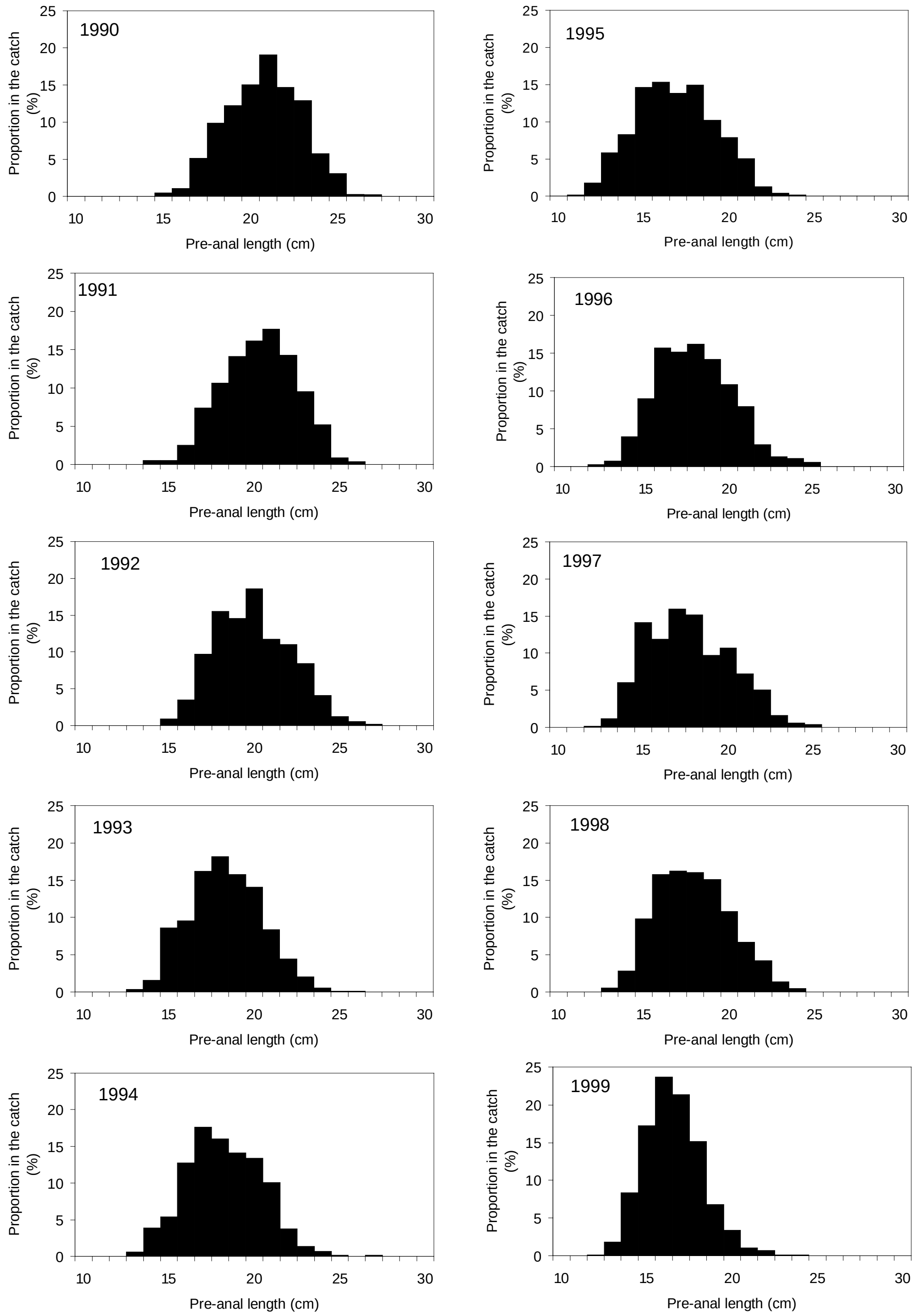


Figure 62. *Size distribution of roundnose grenadier in French trawl landings from ICES Sub-areas VI and VII from 1990 to 1999 (unsexed)*

Age estimates of roundnose grenadier have only been validated up to about 6 years. In early Russian studies, ages were estimated by reading fish scales. However, in recent years otoliths have been used. Ages (unvalidated) of up to about 40 years are quite common and ages of over 70 years have been reported.

5.6.4.7 Natural mortality

Natural mortality for roundnose grenadier was estimated to be around 0.1, using the relationship developed by Annala and Sullivan (1996) (see Section 5.3.1.4).

5.6.4.8. Assessment results

5.6.4.8.1 Roundnose grenadier in Sub-areas VI and VII and Division Vb.

A Schaefer analysis was carried out on total international catch data for the period 1990-98 and French trawl CPUE data for the same period. CPUE data for 1989 were excluded because of a suspected improvement in fishing power in the early years of the fishery (see Section 5.5). Total international catch data included discards which were estimated as 30% of annual landings. A DeLury model was not fitted due to difficulties converting biomass to numbers when discards are included in the catch data.

The fit from a Schaefer model was very similar for a range of error models (R^2=0.855). A log transform error model was chosen as this gave more realistic estimates of intrinsic growth rate (approximately 0.12 compared to 0.5 for a least squares error model). The estimated parameter values were reasonably robust for a range of ratios of initial stock biomass to population carrying capacity (Table 31). Historical fisheries information suggests that by-catches of this species in these ICES areas prior to 1990 were quite small, and it was therefore assumed that initial biomass was 90% of carrying capacity (Figure 63). Carrying capacity is estimated to be about 130,000t (95% confidence limits: 54,000-230,000t). Population biomass in 1998 is estimated at about 40,000 t, equivalent to 30% carrying capacity. MSY is estimated to be about 4,400t (95% confidence limits: 10-10,000t), so that MSY/B_0=0.03.

Table 31. *Roundnose grenadier in Sub-areas VI, VII. and Division Vb. Schaefer model.*

Schaefer	Time lag =0					
Ratio	K (ktonnes)	q	r	MSY (ktonnes)	Pop (ktonnes)	Pop/K
1.0	129	0.000003	0.12	3.8	43.0	0.33
0.9	129	0.000003	0.14	4.4	39.0	0.30
0.8	148	0.000003	0.11	4.0	41.3	0.28
0.7	153	0.000003	0.12	4.6	37.3	0.24

Note : Popn values are for the final year 1998

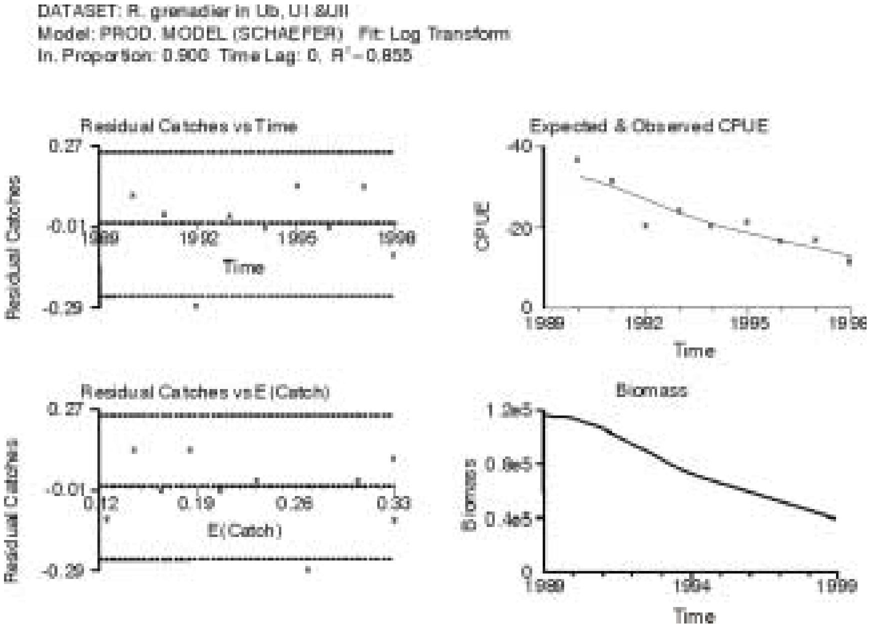


Figure 63. *Roundnose grenadier in Sub-areas VI, VII. and Division Vb. Schaefer model.*

5.6.4.8.2 Roundnose grenadier in Sub-area VI and Divisions VIIb,c

Estimates of relative density from German trawl survey data from the 1970s, calculated using the swept area method, and minimum virgin biomass (B_0), calculated by raising density estimates to total surface area assuming a catchability of 1.0, give a total value of B_0 of around 167,000t (Table 32).

Table 32. *Estimation of B_0 for roundnose grenadier in Sub-area VI and Division VIIb,c assuming a catchability of 1.0.*

	Depth band					
	400 to 600m	600 to 800m	800 to 1000m	1000 to 1200m	1200 to 1400m	Total virgin biomass (kt)
Relative density	0	600	9760	5480	4050	
Virgin biomass (kt)	0	4	74	61	28	167

Using the Beddington and Cooke procedure (see Section 5.3.1.3), assuming a growth coefficient (K) of 0.1 (Kelly *et al*. 1997), natural mortality of 0.1, age of recruitment to the fishery of 15 years and a virgin biomass of around 167,000t, MSY is estimated to be around 6,800t ($MSY/B_0 = 0.041$).

5.6.4.9 Comments on assessment

The fit from the Schaefer model to data from Sub-areas VI,VII and Division Vb was reasonably good. Stock biomass in 1998 is estimated to be about 30% of carrying capacity. However, it should be noted that the confidence intervals for carrying capacity and MSY are very wide.

Minimum virgin biomass in Sub-area VI and Divisions VIIb,c, as estimated by the swept area method, at 167,000t is larger than the point-estimate for Sub-areas VI,VII and Division Vb from Schaefer (130,000t), but is within the wide confidence limits for the estimate.

The estimate of MSY from the Beddington and Cooke procedure, at 6,800t, is also larger than the estimate from Schaefer, at 4,000, but is again within the wide confidence limits for the estimate.

5.6.4.10 State of stock

The results from these assessments should be treated with caution due to the wide confidence limits about estimates. However, in the absence of further information, and in line with the precautionary approach, it seems prudent to heed the results from the Schaefer analysis. These indicate that exploitable biomass (U) of roundnose grenadier in Sub-areas VI,VII and Division Vb at the end of 1998 was below U_{pa} (50% of virgin biomass) and may be close to U_{lim}.(20% of virgin biomass), given the uncertainty in the estimates. Note that the same conclusion can be drawn by considering the CPUE indices directly.

5.6.5 Blue ling *(Molva dypterygia)*

5.6.5.1 Distribution and general biology

There is some doubt about the taxonomy of the blue ling in ICES Sub-areas VI and VII. In some keys or guides the blue ling in the deeper waters to the west of Scotland and northwards is generally referred to as *Molva dypterygia*. From southern Ireland to the Mediterranean the blue ling is replaced by *Molva macrophthalma*, sometimes called either the Mediterranean ling or the Spanish ling. There is some debate as to whether *Molva dypterygia* and *M. macrophthalma* are in fact distinct species. Some authorities have described them as sub-species, *Molva dypterygia dypterygia* and *M. d. macrophthalma* while others believe that they are the same species but that there is a gradual, but consistent change in some minor morphological characters with latitude. For the present study, the latter has been assumed (Figure 64).

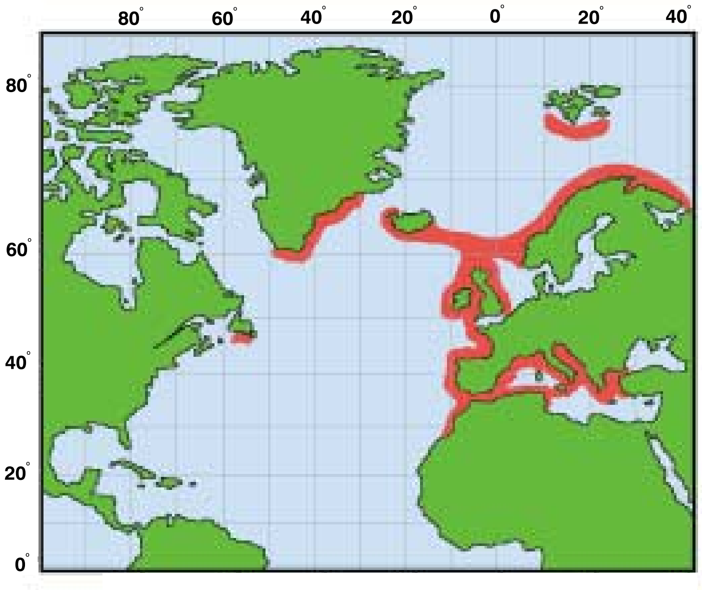


Figure 64. *Distribution of blue ling.*
Modified from Cohen et al, 1990)

Blue ling has a depth range from about 400 to 1200 m with a peak of abundance at about 800 m. Seasonal differences in depth distribution have been reported. Survey catches are dominated by large fish, usually between about 80 and 120 cm. Juvenile fish are usually absent from catches despite the use of fine mesh codends in surveys. Only around Iceland are juveniles caught regularly in trawl surveys.

The diet of blue ling is dominated by fish. Items of lesser importance include some cephalopods and crustaceans such as euphausids and *Pandalus* spp.

The blue ling spawns in the Rockall Trough from about February to June. About 50% of males and females reached maturity at ages of 6.5 and 7.5 years respectively (unvalidated age estimates). Fecundity ranges from about 1 to 3.5 x 10^6 eggs for fish between 95 and 135cm, respectively. The eggs and larvae have not been described but the post larvae have been found at depths of 1000 m off Scotland in May. The young stages remain pelagic up to about a length of 8 cm. Seasonal spawning aggregations especially around the offshore banks, are important to the fishery.

5.6.5.2 Stock structure

There is no information available on the stock structure of blue ling in the Atlantic. On the basis of differences in growth rate and age at maturity, it has been suggested that there are at least two adult stocks in the North Atlantic, one at East Greenland and Iceland (excluding east Iceland) and the other to the west of the British Isles and the Faroes. Following the practice of the ICES Deep-water Study Group, for assessment purposes blue ling in Sub-areas VI, VII and Division Vb has been assessed as a single stock unit.

5.6.5.3 Description of fisheries

The main fishery is by French trawlers in ICES Sub-areas VI and Division Vb, targeting pre-spawning and spawning concentrations in the northern parts of the Rockall Trough. France also lands blue ling as a by-catch in mixed deep-water trawl fisheries. Some blue ling is also landed as a by-catch in the Faroese trawl fisheries for ling and tusk in Sub-area VI and Division Vb.

5.6.5.4 Landings and discard data

Total international landings from Division Vb fluctuated between 5,000 and 10,000t during the 1980s, but have since declined to about 1,500-3,000t in recent years (Figure 65). However, preliminary landings statistics for 1999 were almost 5,000 t.

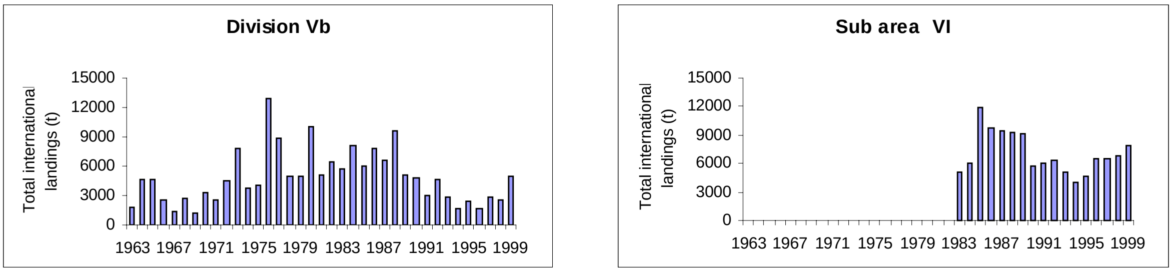


Figure 65. *Total international landings of blue ling by ICES area*

Total international landings from Sub-area VI peaked at about 13,000 t in 1985, and have remained between 4,000-7,000 t in the 1990s. The preliminary landing figures for 1999 were almost 8,000 t. French trawlers used to take more than 95% of the total catch, but in recent years the share of the total catches by UK trawlers has increased considerably.

The landings from Sub-area VII are very small. Blue ling is taken as by-catch in other fisheries.

It should be noted that total international catch data in the period 1963-1988 (Figure 65) comprises data for Division Vb only. In the early years of this fishery, blue ling was landed together with ling *(Molva molva*) under the name ling. The split between the two species in the early years has so far only been assessed for Division Vb.

Information on discard rates is sparse, but given that blue ling fisheries frequently target pre-spawning and spawning concentrations, discarding rates are thought to be low.

5.6.5.5 Commercial catch-effort data

Fishing effort data are only available for French trawlers fishing in ICES Sub-areas VI, VII and Division Vb (Figure 66). Fishing effort in Vb peaked in the late 1980s and early 1990s, declined to relatively low levels in the mid-1990s.and then increased slightly in recent years. Fishing effort in Sub-area VI shows an overall upward trend with time.

French trawl CPUE data are available for the period 1985–1998 (Figure 67). CPUE in Sub-area VI and Division Vb has gradually declined following an initial peak in the mid-1980s. CPUE in VII has been stable, albeit at a comparatively low level.

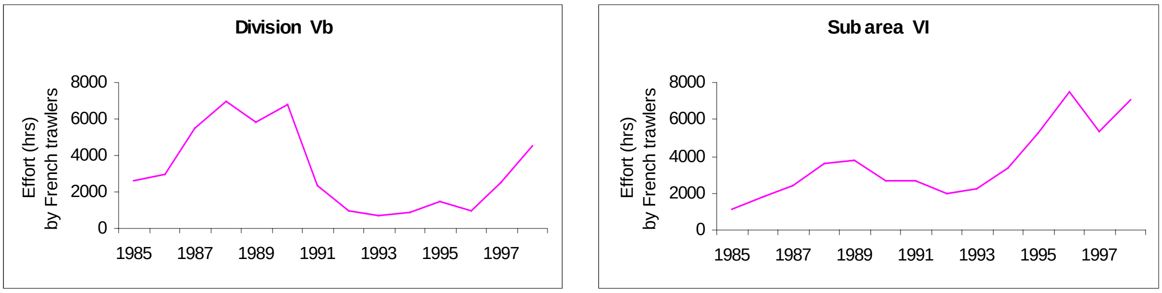


Figure 66. *Effort data from French trawlers - blue ling*

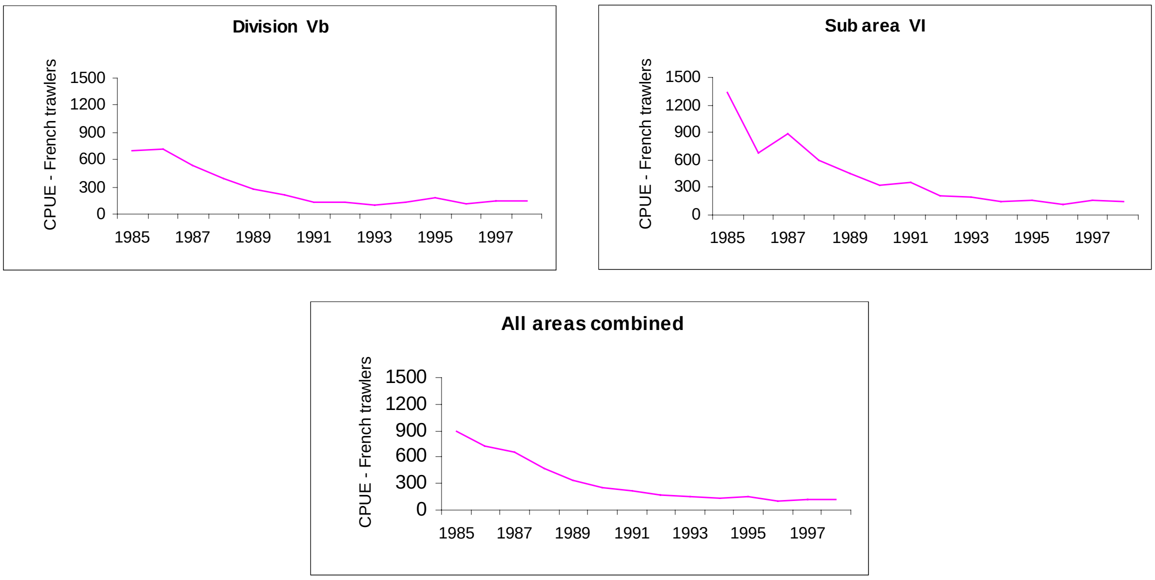


Figure 67. *Catch per unit effort (CPUE) data from French trawlers - blue ling.*

5.6.5.6 Length and age compositions

Length composition data are available for Faroese landings from Division Vb (1993-99) and French landings from Sub-areas VI, VII and Division Vb. For reasons of space, only the French data are shown (Figure 68). Both data series indicate that the proportion of larger fish in landings has decreased in recent years.

Age determination of blue ling by way of otolith reading has not been straightforward. While there is general agreement on the interpretation of the ring structure in the otoliths of the smaller blue ling, there are some difficulties with estimating the age of the larger fish. The youngest fish in the landings are considered to be about 6 to 8 years old. Most are between about 8 and 16 and the oldest are thought to be about 30 years.

5.6.5.7 Natural mortality

Natural mortality for blue ling was estimated to be around 0.15, using the relationship developed by Annala and Sullivan (1996) (see Section 5.3.1.4)

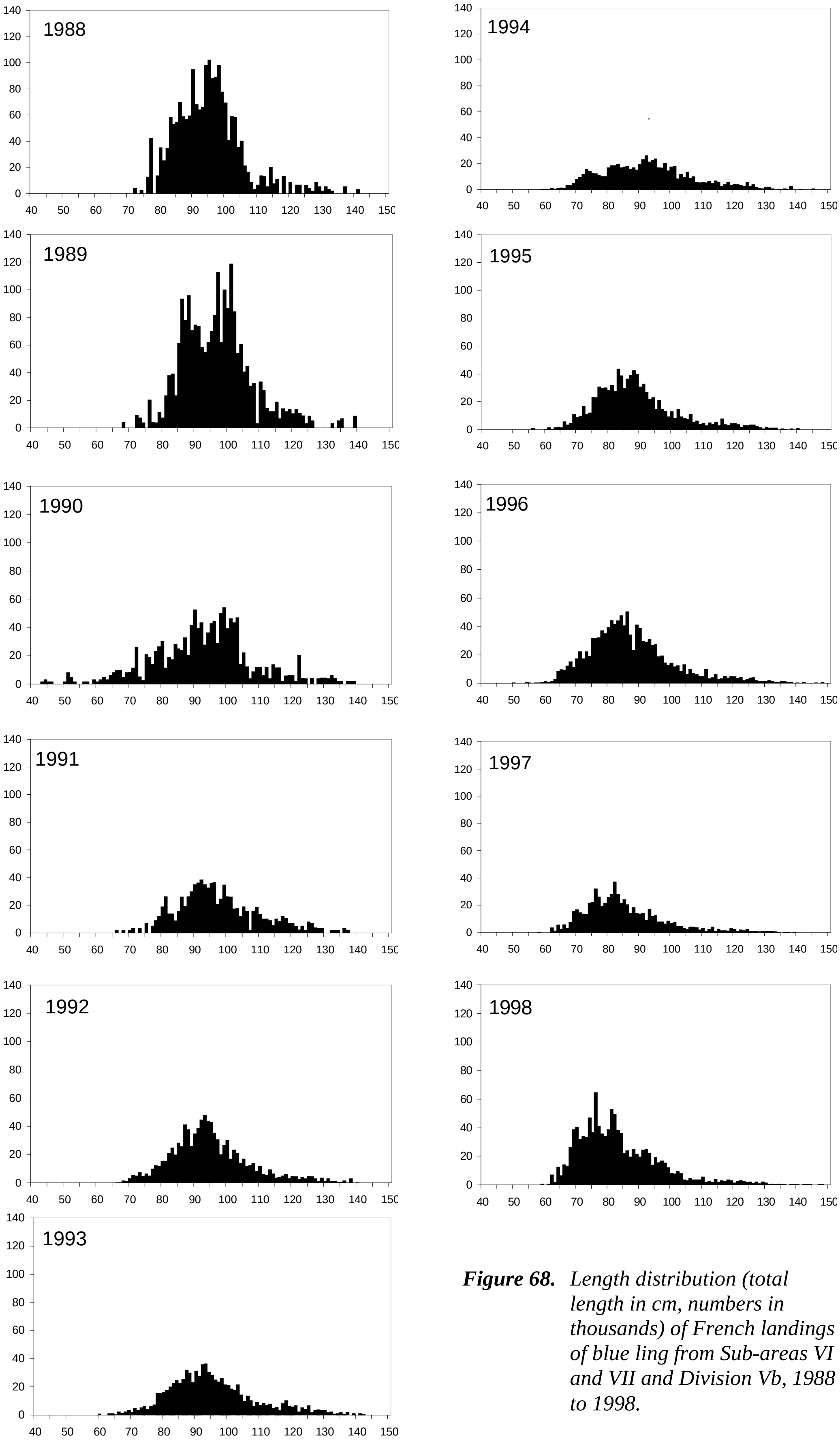


Figure 68. *Length distribution (total length in cm, numbers in thousands) of French landings of blue ling from Sub-areas VI and VII and Division Vb, 1988 to 1998.*

5.6.5.8. Assessment results

5.6.5.8.1 Blue ling in Sub-areas VI, VII and Division Vb.

DeLury and Schaefer models were attempted using total international catch data for Sub-areas VI , VII and Division Vb (1963-98) and CPUE from French trawlers (1988-98) in these areas.

The results for the DeLury model were very unreliable, reflecting a poor fit by the model ($R^2<0.1$) for a range of assumptions of initial proportion of stock to virgin biomass and error models (results not presented).

The results from Schaefer were also unreliable. The fit was reasonable but estimates of the intrinsic rate of growth (r) and MSY were extremely variable (results not presented).

5.6.5.8.2 Blue ling in Sub-area VI and Divisions VIIb,c

Estimates of relative density from German trawl survey data from the 1970s, calculated using the swept area method, and minimum virgin biomass (B_0), calculated by raising density estimates to total surface area assuming a catchability of 1.0, give a total value of B_0 of around 45,000t (Table 33).

Table 33. *Estimation of B_0 for blue ling in Sub-area VI and Division Vb,c assuming a catchability of 1.0.*

	Depth band					
	400 to 600m	600 to 800m	800 to 1000m	1000 to 1200m	1200 to 1400m	Total virgin biomass (kt)
Relative density	210	850	3800	730	180	
Virgin biomass (kt)	1	6	29	8	1	45

Using the Beddington and Cooke procedure (see Section 5.3.1.3), assuming a growth coefficient (K) of 0.15, natural mortality of 0.15, age of recruitment of 6 years and a virgin biomass of around 45,000t, MSY is estimated to be around 2,600t ($MSY/B_0 = 0.058$).

5.6.5.9. State of stock

All available evidence from the trends in catches and CPUE series indicates that the blue ling stock in Sub-areas VI and VII and Division Vb is at a low level. Length distribution data also indicate that the proportion of large fish in the landings has decreased in the most recent years.

Using French trawl CPUE as an index of exploitable biomass, current exploitable biomass (U) of blue ling in Sub-areas VI, VII and Division Vb at the end of 1998 is considered to be below U_{lim} (20% of virgin biomass).

5.6.6 Greater forkbeard *(Physis blennoides*)

5.6.6.1 Distribution and general biology

The greater forkbeard is widely distributed in the eastern Atlantic and in the Mediterranean (Figure 69).

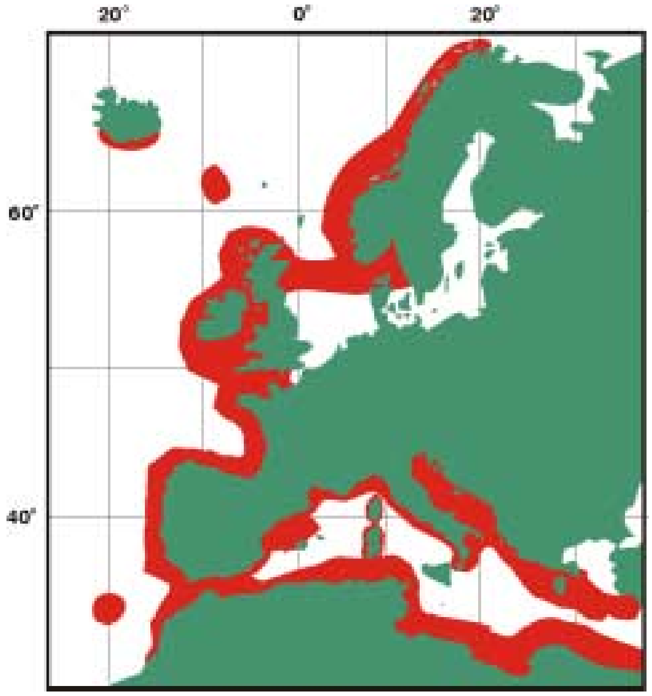


***Figure 69**. Distribution of greater forkbeard*

It extends from about 69^{o}N off the coast of Norway to Cape Blanc (West Africa), including the south-west coast of Iceland. It is also reported from Madeira, the Azores and various Mid-Atlantic Ridge seamounts, the Skagerrak and Kattegat, and occasionally in the North Sea. It is also widely distributed in the Mediterranean.

Over its geographical range, the greater forkbeard has a wide depth distribution, but to the west of the British Isles it occurs between about 250 and 1000m. Juvenile fish are more coastal and live on the continental shelf.

Diet consists mainly of crustaceans, especially decapods.

5.6.6.2 Stock structure

Very little is known about stock structure.

5.6.6.3 Description of fisheries

Although the greater forkbeard is widely distributed throughout the ICES area, catches are never large. It is very much a by-catch species in international long-line and net fisheries targeted at hake, megrim, anglerfish, ling and blue ling.

5.6.6.4 Landings and discard data

International landings, available for Sub-areas VI and VII combined, have been relatively stable throughout the 1990s with a slight increase in recent years (Figure 70), mainly due to an increase in Spanish and UK landings.

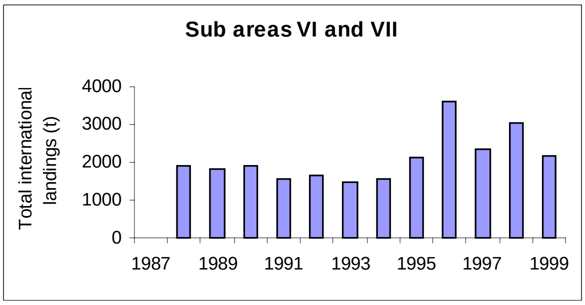


Figure 70. *Total international landings of greater forkbeard from Sub-areas VI and VII*

There is no discard information available for greater forkbeard in these areas.

5.6.6.5 Commercial catch-effort data

Fishing effort data are only available from Basque trawlers (‘Baka’) prosecuting a mixed fishery in ICES Sub-areas VI and VII (Figure 71). Fishing effort was reasonably stable over the period 1994-98.

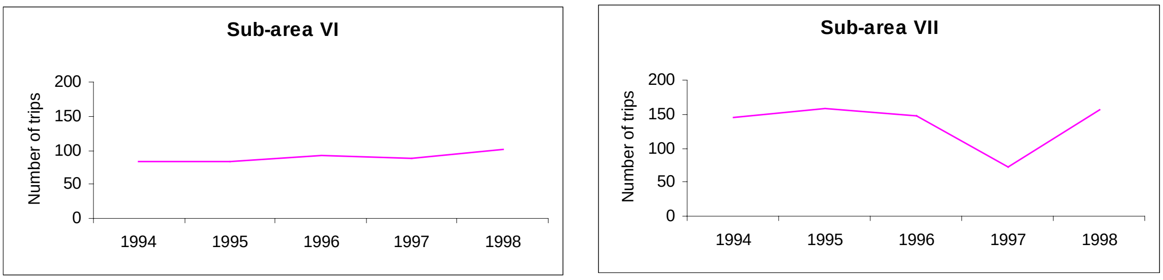


Figure 71. *Trends in fishing effort of Basque trawlers fishing in Sub-areas VI and VII - greater forkbeard*

Basque trawl CPUE data are available for the period 1994–1998 (Figure 72). These data should be treated with caution because a coarse measure of effort (number of trips) has been used and consequently these data do not take into account possible changes in trip duration or fishing power. CPUE in Sub-area VI show a gradual decline before stabilising in recent years. In Sub-area VII, CPUE has been fairly stable at a much lower level than in VI.

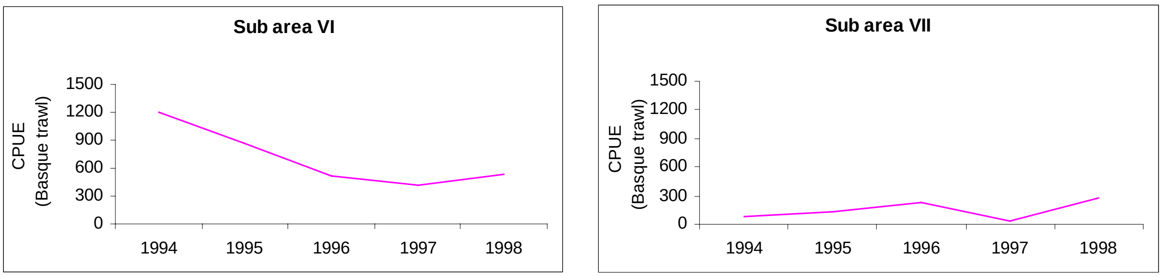


Figure 72. *Trends in CPUE of Basque trawlers fishing in Sub-areas VI and VII - greater forkbeard*

Length and age data for greater forkbeard are sparse. A wide length range of fish is caught in research surveys, but commercial landings generally comprise fish of between 40 and 60 cm. Preliminary analysis from the sampling of landings from Sub-area VI carried out at Scottish ports indicates that variations observed in quarterly length frequencies are probably a function of movements of fishing effort up or down the continental slope as well as seasonal movements of fish stocks (Anon., 1999b). In recent years, landings comprise a greater proportion of smaller fish. It appears most likely that a change in market conditions has led to small fish, which would previously has been discarded being retained and landed
(Anon., 1999b).

Growth is slow in the north-eastern Atlantic, with 6 year old males and females measuring only 25 and 28 cm. The maximum age is about 20 years. All ages are unvalidated.

5.6.6.7 Natural mortality
An estimate of natural mortality is not available.

5.6.6.8. Assessment results
An assessment was not attempted due to a lack of reliable CPUE in all areas.

5.6.6.9 State of stock(s)
The state of the stock(s) of the greater forkbeard in areas to the west of Britain is not known. Consideration of the commercial CPUE shows that the most recent estimates of CPUE are below 50% of the maximum value at the start of the series in Sub-area VI. Greater forkbeard are caught mainly as a by-catch species and as such could be managed indirectly by management measures on other species.

5.7 Discussion
Two general issues with regard to the assessments presented above are worth considering: assumptions about natural mortality, and assumptions about the CPUE indices.

Estimates of natural mortality (M) are notoriously difficult to obtain, even for well-studied fish stocks. Some parameter-estimates may be sensitive to the estimate of M (e.g. absolute population level in the DeLury model, MSY/B_0-estimates from the Beddington-Cooke method). Other estimates, for example, the ratio of current to unexploited population size, will tend to be far less sensitive to the estimate of M. Estimates of the relative levels of depletion (biomass in 1998 relative to biomass at the start of exploitation) should be fairly robust, since they are essentially dominated by the information in the CPUE series.

This assertion, however, relies on the basic assumptions that (a) the commercial CPUE is proportional to the population abundance, and (b) that the coefficient of proportionality (i.e. catchability) is constant over the time period considered. The first assumption is very difficult to test quantitatively, particularly when very little data are available. Qualitatively, violation of the first assumption is often considered likely for highly aggregating species, and the relationship is then considered to be such that population size drops more rapidly than CPUE would suggest (Hilborn and Walters, 1992). At this stage, it is sufficient to flag this issue to be borne in mind as more data are collected.

With regard to the second assumption, the CPUE data have been standardised to remove factors which may have lead to changes in catchability. It is not, however, always feasible to correct for all possible factors, either because data may not be available, or because factors (such as learning) may not be easy to measure. If catchability has not been constant, it is far more likely that it has increased than decreased, and if this is the case, then any declines in CPUE would tend to under-estimate the declines in population size. This would have knock-on effects on estimates of other parameters, such as production rate and hence MSY.

6 Recommendations for further work

Future trawl surveys

Very few fisheries exist where it is still practical to make a comparison between pre-exploitation and post-exploitation situations. It is suggested that the RV Cirolana be chartered to repeat the trawl surveys carried out in the 1970s using the Lowestoft Granton trawl. Surveys by the French RV Thalassa, using an Arrow trawl, were carried out in 1996 and 1999, and it would be useful for further analyses of size-spectra to calibrate this vessel and gear against the Cirolana and the Granton trawl.

French trawl CPUE data from commercial vessels

It was noted above that the CPUE data used in all the assessments carried out in this study are those available for the French trawl fleet. Thus, the assessments rely heavily on the quality of these data. These CPUE series are calculated using a multiplicative model taking into account month and ICES Sub-area effects, weighted by fishing effort. It would be useful for future assessments to have information on the confidence limits about annual estimates of CPUE, so that an informed judgement can be made as to the magnitude of any changes with time in relation to background noise.

Deep-water survey database

In this study it was only feasible to construct a deep-water survey database for the Hebridean continental slope. A considerable quantity of data exists for other deep-water areas to the west of Britain. Some of these data have been validated and are well structured, others appear not to have been fully validated and contain a considerable number of inconsistencies and anomalies. It is estimated that about one man-year would be required to validate these data and build a database, a task which would, for some survey-series, almost certainly require going back to the original paper records from each survey. It is suggested that this work be expedited so that future investigations of the effects of fishing on fish assemblages to the west of Britain can make full use of available data.

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9 Appendices

9.1 List of participants (Table 34).

Name	Address	Phone	Fax	E-mail
Philip Large (Contract Leader)	CEFAS Lowestoft Laboratory Pakefield Road Lowestoft, Suffolk NR33 0HT UK	+44 1502 562244	+44 1502 524511	p.a.large@ cefas.co.uk
Dr Marinelle Basson	CSIRO Marine Research GPO Box 1538 Hobart, Tasmania 7001 Australia	+613 62325 082	+613 62325 053	Bassonbravington@hotmail.com
Dr Daniel Duplisea	CEFAS – as above	As above	As above	D.Duplisea@ Cefas.co.uk
Dr Jim Ellis	CEFAS – as above	As above	As above	J.R.Ellis@ Cefas.co.uk
Brian Rackham	CEFAS – as above	As above	As above	B.D.Rackham@ Cefas.co.uk
Dr John D.M. Gordon	SAMS Dunstaffnage Marine Laboratory, Oban PA34 4AD Scotland, UK	+44 1631 559222	+44 1631 559001	Jdmg@ dml.ac.uk
Pascal Lorance	IFREMER 150,quai Gambetta BP 699 6231 Boulogne-sur-Mer France	+33 321 99 56 10	+33 321 99 56 01	Pascal.lorance@ Ifremer.fr
Prof. John Pope	NRC (Europe) Ltd The Old Rectory Burgh St Peter Beccles Suffolk,UK	+44 1502 677377	+44 1502 677377	Popejg@ Aol.com
Dr Odd Aksel Bergstad	Institute of Marine Research Flodevigen Marine Research Stn N-4817 His Norway	+47 370 59 019	+47 370 59 001	Odd.aksel. bergstad@imr. no

9.2 Descriptions of the fishing gears used on deep-water trawl surveys to the west of Britain.

SAMS Granton Trawl (GT)

This three-bridle trawl was designed for RRS *Challenger* by the Fisheries Research Services, Marine Laboratory, Aberdeen. The headline and footrope were both 20.6m in length and the central section of the foot rope (7.2m) had 380mm solid rubber bobbins. The mesh size decreased from 140mm knot to knot in the wings, to 40 mm in the codend. The codend was lined with a fine mesh blinder of 12mm and this was used for all the hauls except for the two 1979 hauls. The trawl was designed to be fished with 50m bridles between the otter boards and the dan leno but, until October 1976, this was reduced to 14m for ease of working. The abbreviation GT(S) is used for the version with short bridles and GT(L) for the version with standard 50m bridles. The length of the legs from the dan leno to the wing end of the trawl was 2.7m. Standard 9 foot (2.7 by 1.4m) single keel "Fearnaught" otter boards were used. Whenever possible a warp to depth ratio of 3:1 was used and the net towed at 3.5 to 4 knots (1.8-2.0 m/sec). It should be noted that for some of the deepest hauls in the 1250m bathymetric zone *Challenger* sometimes had difficulty in towing at the desired speed. The duration on the bottom was taken from the time paying out ceased until the start of hauling and, until October 1976, was approximately 1.5 hours. When the standard 50m sweeps were used, the duration on the bottom was decreased to 45 min. When fished with 50m bridles the designer of the trawl estimated that the wing end spread would be 12.6m and the headline height would be 1.8m. Reducing the bridles would increase the wing end spread to 15m but reduce the headline height to 0.9m (Gordon and Duncan, 1995a).

SAMS Semi-balloon Otter Trawl (OTSB)

The semi-balloon trawl had a headline of 14m and the mesh size reduced from 44 to 37mm with a 13mm blinder in the codend. The trawl was supplied by the Marinovitch Trawl Company (Biloxi, Mississippi, USA) and has been described in detail by Merrett and Marshall (1981). Until the September 1983 cruise, it was only fished on the single deep wire (13mm diameter) of RRS Challenger at speeds of 2-2.5 knots. The otter boards were connected to the main single warp by 50m bridles. From November 1984, the semi-balloon trawl was fished either on the single wire (OTSB(S)) or on paired trawl warps 22mm diameter (OTSB(P)) at the same towing speeds. Comparative fishing trials between the two methods of deployment were carried out on several cruises and the results have been published by Gordon and Bergstad (1992). This paper also compares the catches with those of the SAMS Granton trawl and a later paper compares the catches of the OTSB(S) and the GT(L) between the Rockall Trough and the Porcupine Seabight (Gordon et al. 1996).

The arrival of the trawl on the bottom and the moment when the trawl left the bottom after the start of hauling, were monitored by an IOS door mounted acoustic beacon on the September 1983 and November 1984 cruises. The distance travelled by the trawl during this period, as indicated by the satellite navigator, multiplied by the path width gave the area swept by the trawl. The path from wing end to wing end was assumed to be 8.6m (Merrett and Marshall, 1981). After April 1985 cruise the acoustic beacon was not available and the time on the bottom was estimated from previous experience.

In 1985, and to a lesser extent in 1994, some experiments were carried out to investigate the effects of attaching artificial lights to the headline of the semi-balloon trawl. The most representative series was in 1985 using the OTSB (S) at a depth of 1000 m. A preliminary analysis by Pascoe (1990) showed differences in the mean number of fish of some families, but the results were never rigorously tested. A recent multivariate analysis has shown that the lights had little effect on the total fish assemblage, but that the catch-rates of a few individual species were increased (Gordon *et al*. submitted).

Cirolana Granton trawl

Full details of the trawl and its rigging for the 1973 and 1974 *Cirolana* cruises are given by Bridger (1978). The trawl was a small Granton with a 23.8m headline and a 35.4m groundline. The codend had a 110mm mesh and was fitted with a small mesh (size unspecified) blinder to retain small fish. Heavy rubber bobbins were used. The fishing methods are also described and it is important to note that in the deepest hauls, the towing speed had to be reduced to keep the gear on the bottom. Towing speed ranged from 2.1 to 3.6 knots, but was less variable over the depth range 725-1000 m, where the majority of the hauls were made (Bridger, 1978). This would have reduced the area trawled compared with shallower hauls and in hauls at depths greater than 1000 m, the biomass expressed in kg/hr may have been underestimated.

Walther Herwig Trawls

Two Granton trawls, a BT140 and a BT 200, were used. The following descriptions are from Merrett *et al*. (1991a,b)

The BT140 had a headline of 31.2m and a footrope of 20m. The horizontal opening (wing end spread) was estimated as 20m and the headline height at 3m. The bridles were 36.6m and the doors were flat with and area of 4.2m. The meshes decreased from 80mm in the wings to 30mm in the codend. The codend liner was of 12mm mesh. The diameter of the bobbins ranged from 23 to 53cm. The trawl was towed at approximately 4 knots (Ehrich, 1983).

The BT200 had a headline of 39.1m and a footrope of 25m. The horizontal opening was estimated as 24m and the headline height at 6m. All the other parameters were as for the BT 140.

French Arrow trawl

The Arrow trawl has a headline of 47.4m long and footrope of 26.8 m. fitted with 50cm rubber bobbins. It was fitted with a codend liner of 20mm stretched mesh size. Trawl doors were Morgere WV12 weighing 2200kg each. The footrope weighed 4000kg. Buoyancy was about 500kg from 190 floats. Different combination of floats and aeroplane Morgere were used throughout the cruises (aeroplane Morgere are textile kites which increase flotation at increasing towing speed). At a towing speed of around 3 knots, the Arrow trawl has an average wing spread of about 30m and an average vertical opening of 7m. The door spread is about 150m.

9.3 ***Table 35***. *Species codes used in the detrended correspondence analyses (Section 4.4.3).*

Species number	SAMS SYN code	Scientific name	Common name
1	ACARB	*Aphanopus carbo*	Black scabbardfish
2	ALBAIR	*Alepocephalus bairdii*	Baird's smoothhead
3	ALDRO	*Aldrovandia sp.*	
4	ALROST	*Alepocephalus rostratus*	Risso's smoothhead
5	ALSP	*Alepocephalus sp.*	Smoothheads
6	APRIST	*Apristurus sp.*	Catsharks
7	AROST	*Antimora rostrata*	
8	BBROS	*Brosme brosme*	Tusk
9	BCAER	*Breviraja caerulea*	Blue ray
10	BDUB	*Bathypterois dubius*	Spiderfish
11	CCOEL	*Centroscymnus coelolepis*	Portuguese dogfish
12	CCREP	*Centroscymnus crepidater*	Longnose velvet dogfish
13	CFAB	*Centroscyllium fabricii*	Black dogfish
14	CGUENT	*Coryphenoides guentheri*	Gunther's grenadier
15	CHIMSP	*Chimaera sp.*	Rabbitfishes
16	CMED	*Coryphaenoides mediterranea*	
17	CMONS	*Chimaera monstrosa*	Rabbitfish
18	COCCA	*Coelorhynchus labiatus*	Spear-snouted grenadier
19	CRUP	*Coryphaenoides rupestris*	Roundnose grenadier
20	CSQUAM	*Centrophorus squamosus*	Leafscale gulper shark
21	CTHOM	*Cottunculus thomsonii*	Pallid sculpin
22	DCALC	*Deania calceus*	Birdbeak dogfish
23	EPRINC	*Etmopterus princeps*	Greater lantern shark
24	ETELES	*Epigonus telescopus*	
25	GCYNO	*Glyptocephalus cynoglossus*	Witch
26	GMACRO	*Gaidropsarus macrophthalmus*	
27	GMUR	*Galeus murinus*	Mouse catshark
28	HATLAN	*Hoplostethus atlanticus*	Orange roughy
29	HDACT	*Helicolenus dactylopterus*	Rockfish
30	HJOHN	*Halargyreus johnsonii*	
31	HJOHNI	*Halosaurus johnsonianus*	
32	HMIR	*Hydrolagus mirabilis*	Large-eyed rabbitfish
33	IBLACH	*Ilyophis blachei*	
34	LBOSC	*Lepidorhombus boscii*	Four spotted megrim
35	LEQU	*Lepidion eques*	
36	LMUR	*Lycenchelys muraena*	
37	LPISC	*Lophius piscatorius*	Anglerfish
38	LYCOD	*Lycodes sp.*	
39	MACS	*Macrourid sp.*	Grenadiers
40	MATLAN	*Melanostigma atlanticum*	
41	MDYPT	*Molva dypterygia*	Blue ling
42	MMORO	*Mora mora*	
43	MPOUT	*Micromesistius poutassou*	Blue whiting
44	MXYIOS	*Myxine ios*	White-headed hagfish
45	NAEQU	*Nezumia aequalis*	Smooth grenadier
46	NBONAP	*Notacanthus bonapartei*	Shortfin spiny eel
47	NCHEM	*Notacanthus chemnitzii*	Snubnosed spiny eel

Table 35. *Species codes used in the detrended correspondence analyses (continued)*

48	PBLEN	*Phycis blennoides*	Greater forkbeard
49	PHYST	*Paraliparis hystrix*	
50	PRISSO	*Polyacanthonotus rissoanus*	Smallmouth spiny eel
51	RFYLL	*Raja (Rajella) fyllae*	Round ray
52	RNID	*Raja (Dipturus) nidarosiensis*	Madeira ray
53	SKAUPI	*Synaphobranchus kaupii*	Cut-throat eel
54	SLEPID	*Scopelosaurus lepidus*	
55	TMURRY	*Trachyrhynchus murrayi*	Murray's longsnout grenadier
56	XCOP	*Xenodermichthys copei*	Bluntsnout smoothhead
57	ZOAR	*Zoarces viviparus*	Viviparus eelpout

9.4 Technical appendix for investigations of long term trends inferred from survey indices of relative biomass and abundance (Section 4.6)

9.4.1 Lists of species included in grouped analyses:-

***Table 36**. List of species included in the 'Exploited' group.*

Scientific name	SAMS SYN Code	Common name
Aphanopus carbo	ACARB	Black scabbardfish
Argentina silus	ASILUS	Greater argentine
Brosme brosme	BBROS	Tusk
Centroscymnus coelolepis	CCOEL	Portuguese dogfish
Centrophorus squamosus	CSQUAM	Leafscale gulper shark
Chimaera monstrosa	CMONS	Rabbitfish
Conger conger	CCONG	Conger eel
Coryphaenoides rupestris	CRUP	Roundnose grenadier
Epigonus telescopus	ETELES	
Glyptocephalus cynoglossus	GCYNO	Witch
Helocolenus dactylopterus	HDACT	Rockfish
Hoplostethus atlanticus	HATLAN	Orange roughy
Lepidorhombus boscii	LBOSC	Four spot megrim
Lepidorhombus whiffiagonis	LWHIFF	Megrim
Lophius piscatorius	LPISC	Anglerfish
Merluccius merluccius	MMERLU	Hake
Molva dypterygia	MYDPT	Blue ling
Molva molva	MMOLV	Ling
Phycis blennoides	PBLEN	Greater forkbeard
Raja (Rajella) fyllae	RFYLL	Round ray
Raja (Dipturus) nidarosiensis	RNID	

All species not in the above list were included in the 'Unexploited' group.

***Table 37**. List of Scyliorhinidae (catsharks) included in the 'SCYLIO' group.*

Scientific name	SAMS SYN Code	Common name
Galeus melastomus	GMELAS	Blackmouth catshark
Galeus murinus	GMUR	Mouse catshark
Galeus species	GALSP	
Apristurus microps	AMICRO	
Apristurus species	APRIST	

***Table 38.** List of Squalidae (dogfishes) included in the 'SQUAL' group.*

Scientific name	SAMS SYN Code	Common name
Centroscymnus coelolepis	CCOEL	Portuguese dogfish
Centroscymnus crepidater	CCREP	Longnose velvet dogfish
Centroscyllium fabricii	CFAB	Black dogfish
Centrophorus squamosus	CSQUAM	Leafscale gulper shark
Deania calceus	DCALC	Birdbeak dogfish
Dalatias licha	DLICH	kitefin shark
Etmopterus princeps	EPRINC	Great lanternshark
Etmopterus spinax	ESPIN	Velvet belly
Scymnodon ringens	SRING	Knifetooth dogfish

9.4.2 Gear Groupings

Table 39. *The gear grouping chosen for the CPUE analyses.*

Code	Gears	Vessel
GFR	200BT, 140BT	Walther Herwig
ENG	LWGT	Cirolana
SAM	GT(L),GT(S),OTSB(P)	Challenger
SAS	OTSB(S)	Challenger
IFR	ARROW	Thalassa

The distinction between ‘SAM’ and ‘SAS’ is made because the OTSB(S) gear is considered a ‘scientific’ gear, whereas the other SAM gears are considered as ‘commercial’ gears. Note that this gear grouping implicitly takes vessel into account, and also gives a relatively good set of linkages, or comparisons, between the different gear groups over the time period 1973-1999.

9.4.3 CPUE model descriptions

All the statistical analyses in Section 5 are done in ‘S-PLUS’ (MathSoft Inc.), and further information can be found in the S-PLUS guides, Venables and Ripley (1997), McCullagh and Nelder (1989), and Hastie and Tibshirani (1990).

Three types of models were considered: generalised linear models, generalised additive models and linear mixed effect models. Although the details and assumptions differ, the approach to fitting the models to data was similar. During exploratory analyses, the main explanatory variables were identified. A set of nested models were then fitted to the data, and analyses of variance was used to explore whether the removal (or addition) of a term significantly affects the fit of the model. In the descriptions of the different models (below), equations for the so-called ‘full’ models are given. These ‘full’ models give the maximum number of terms that were fitted to the data. It would be difficult to justify including more terms given the nature of the dataset. Also, note that no attempts were made to identify a single ‘optimal’ model.

In the descriptions of the models applied to CPUE data, the following abbreviations are used:

lncpue = ln (CPUE in weight) by unique station
d = mean depth
y = year
g = gear-grouping factor
e = Gaussian error term (by unique station), ~ $N(0,\sigma^2)$, independently

Generalised Linear Models

Generalised linear models (GLM’s) are an extension of the familiar linear regressions. Linear models assume that the data have Gaussian (normal) errors, whereas GLMs can be fitted to data with error distributions such as binomial, Poisson etc. Given that the final analyses are based on an assumed Gaussian error structure, the GLM’s can be thought of as standard linear models. Note, however, that although the models are linear, they can include terms of higher order (for example, polynomials) in the explanatory variables.

The GLM formulation for the full model:

$$\text{lncpue} = a_0 + a_1{*}d + a_2{*}d^2 + b_1{*}y + b_2{*}y^2 + b_3{*}y^3 + g + e$$

where the ‘a’ and ‘b’s are parameters to be estimated. The ‘g’s are factor terms estimated relative to a specified gear group (SAM).

Generalised Additive Models

Generalised additive models extends the GLM by fitting nonparametric functions to estimate the relationships between the response and explanatory variables. Smoothing operations (e.g. smoothing splines) are used to estimate the nonparametric functions from the data.

The GAM formulation for the full model:

$$\text{lncpue} = s(d) + s(y) + g + e$$

where ‘s’ denotes a smoothing spline (cubic B-spline; see S-PLUS guide)

An issue which affects GAMs is how much smoothing to use in the nonparametric functions. The amount of smoothing is directly related to the number of degrees of freedom, and the ‘s’ function allows the user to specify how many degrees of freedom (dof) should be used. Intuitively, it makes sense to think about the problem in the following way. If the data are thought to have very little measurement (or other) error, and consist mainly of ‘signal’, then it would not be unreasonable to use a small amount of smoothing (i.e. large number of dof). On the other hand, if the data are very noisy, and contain a large amount of measurement or other error, then it would be prudent to use quite a lot of smoothing (i.e. low number of dof). The survey dataset falls in the latter category. All the GAM models fitted with the default number of dof (4). This allows enough flexibility to reveal non-linear relationships, but avoids over-fitting ‘peaks’ and ‘troughs’ in the data which may simply be due to noise.

Linear Mixed Effects models

Linear mixed effects are related to generalised linear models, but are more flexible in the way in which they treat the error structure of the data. In the case of GLMs, a single source of error is assumed, but in the case of mixed effects models, there can be several sources of error. The simplest example where a mixed effects model may be appropriate is when there are two stages of sampling. At the first stage units are selected at random from a population and at the second stage a number of measurements is made on each unit sampled in the first stage. In terms of the survey dataset, one could consider the first stage as the selection (at random) of a gear-group, and the second stage as the ‘measurement’ of CPUE from several hauls by that gear-group. The term ‘mixed effects’ is derived from the inclusion of ‘fixed effects’ which are not considered to be affected by the selection of units in the first stage of the process, and ‘random effects’ which are affected by the selection in the first stage.

Although it is possible to construct complex models which include ‘random effects’ in many different terms, we consider a simple LME. We assume that the relationship between lncpue and mean depth, and between lncpue and year are not affected by the choice of gear group, but that the intercept is affected by the choice of gear group.

The LME formulation for the full model:

$$\text{lncpue} = (a_0 + \alpha_i) + a_1 * d + a_2 * d^2 + b_1 * y + b_2 * y^2 + b_3 * y^3 + e$$

where the ‘a’ and ‘b’s are intercept and slope parameters to be estimated and each α_i is the effect in intercept, associated with the ‘i^{th}’gear grouping.

It is assumed that the α_i are independent and identically distributed with a $N(0,\sigma^{*2})$ distribution independent of the *e* (the '*' in σ^{*2} emphasises that this variance is different from the variance of *e*).

9.4.4 Results and diagnostics for CPUE analyses

9.4.4.1 Exploited species group

The GAM models are useful for revealing underlying structures, so results for the full GAM model (Equation A2) are presented first. Figure 73 shows the nonparametric functions with regard to the explanatory variables. The dashed lines are pointwise twice-standard-error curves. It is important to note that, because of the pointwise nature of the standard error curves, direct comparisons between intervals at the start and end of the series are not valid.

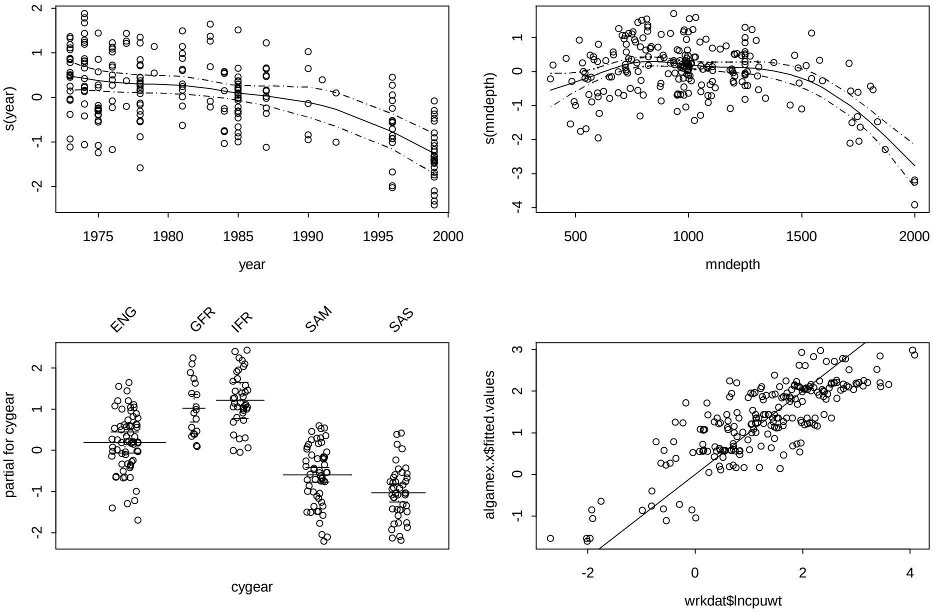

Figure 73. *GAM model nonparametric functions for lncpue of exploited species and: year (top left panel), mean depth (top right), gear group effects (lower left). Fitted values are plotted against observed values in the lower right panel. (Note: mndepth=mean depth, cygear=gear group)*

There is a wide spread in the residuals (also see Figure 74), but no distinct patterns are evident. There may be a slight tendency for a higher variance in residuals at shallow than at deep depths, but this could also be due to the paucity of data at the deeper depths.

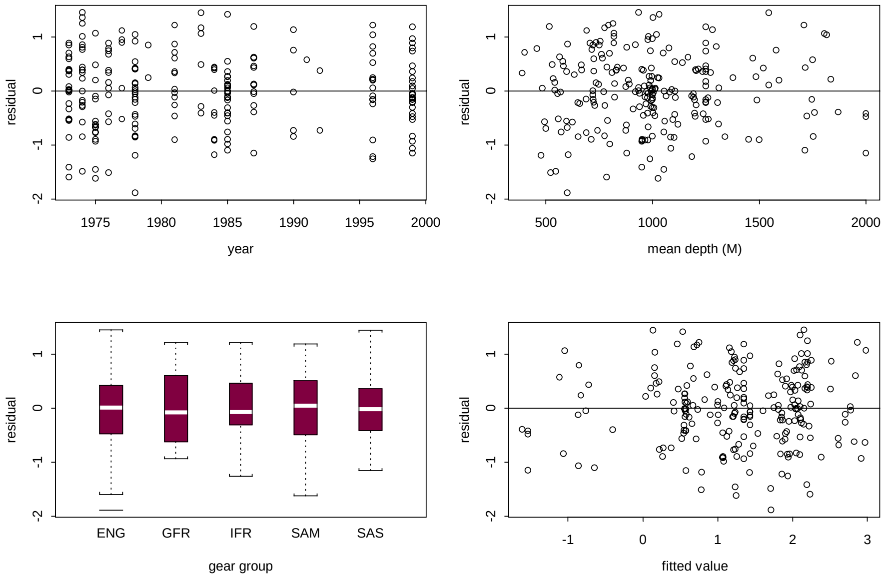

Figure 74. *GAM model residuals plotted against: year (top left), mean depth (top right), gear group (lower left) and fitted values (lower right) for exploited species.*

Analysis of variance (ANOVA) results for a suite of nested GAM models show that the year effect is highly significant (Table 40).

Table 40. GAM Analyses of Deviance Table for exploited species. Abbreviations are: Resid=residual, Df=degrees of freedom, Dev=deviance. The first model with 'Terms' of 1, simply estimates the mean of the data.

```
Response: lncpuwt
                  Terms   Resid  Resid    Df   Dev    Pr(Chi)
                           Df      Dev
1                     1  223.0  307.4
2              s(depth)  218.9  226.3 4.000   81.1   <0.00001
3         s(depth)+gear  214.9  115.2 4.000 111.0   <0.00001
4 s(year)+s(depth)+gear  210.9  102.9 4.001  12.3    0.01504
```

Since the GAM model suggest a 2nd order polynomial as a parametric form for the lncpue-mean depth relationship, and a 2nd or 3rd order polynomial for lncpue-year, these forms were tried in the GLM. Residuals for the full GLM model (i.e. with 3rd order polynomial for year) again show wide scatter, but no clear patterns (Figure 75).

ANOVA results for the GLM models (Table 41) confirm that a 2nd order polynomial term in depth greatly improves the model fit. Strictly-speaking, the model with linear term in depth need not even have been considered, since the GAM, as well as, a priori knowledge of the surveys suggest a dome-shaped relationship for lncpue with depth. The results also confirm the strong year effect, particularly in 1st and 2nd order terms. The 3rd order term is not as highly significant.

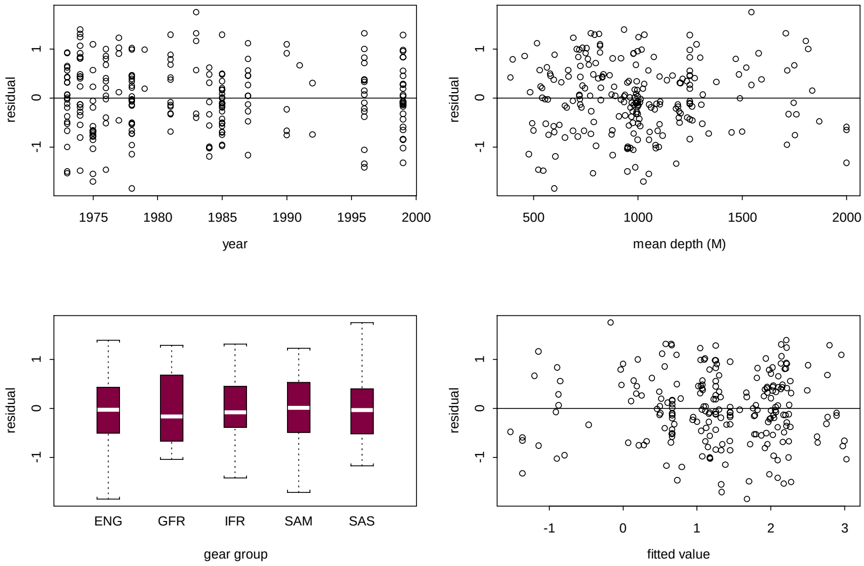

Figure 75. *Full GLM model residuals plotted against: year (top left), mean depth (top right), gear group (lower left) and fitted values (lower right) for exploited species.*

Table 41. *GLM Analyses of Deviance Table for exploited species. Abbreviations are: Resid=residual Df=degrees of freedom, Dev=deviance. Poly(x,n) defines an n^{th} order polynomial in x.*

```
Response: lncpue
                 Terms           Resid Resid  Df   Dev FValue Pr(F)
                                   Df   Dev
1                              1 223  307.4
2                          depth 222  264.0  1  43.3   75.1 <0.0001
3                 poly(depth,2) 221  238.9  1  25.1   43.4 <0.0001
4            poly(depth,2)+gear 217  125.2  4 113.7   49.2 <0.0001
5       year+poly(depth,2)+gear 216  116.8  1   8.4   16.2 <0.0001
6 poly(year,2)+poly(depth,2)+gear 215  111.9  1   4.8    9.3  0.0025
7 poly(year,3)+poly(depth,2)+gear 214  110.1  1   1.7    3.4  0.0629
```

ANOVA results for the LME models again strongly suggest that there is a time-trend (Table 42). Recall that the gear effect is taken into account as a random effect, and therefore does not appear as an explicit term under ‘Model’. Residuals for the full model are shown in Figure 76.

Table 42. *LME Analyses of Deviance Table for exploited species. Abbreviations are: df=degrees of freedom, AIC=Akaike Information Criterion, logLik=log likelihood, L.Ratio=log likelihood ratio.*

```
Response: lncpue
        Model                 df   AIC    logLik  L.Ratio   p-value
1              poly(depth,2)  5  540.0   -265.0
2 poly(year,2)+poly(depth,2)  7  520.1   -253.0    23.8     <.0001
```

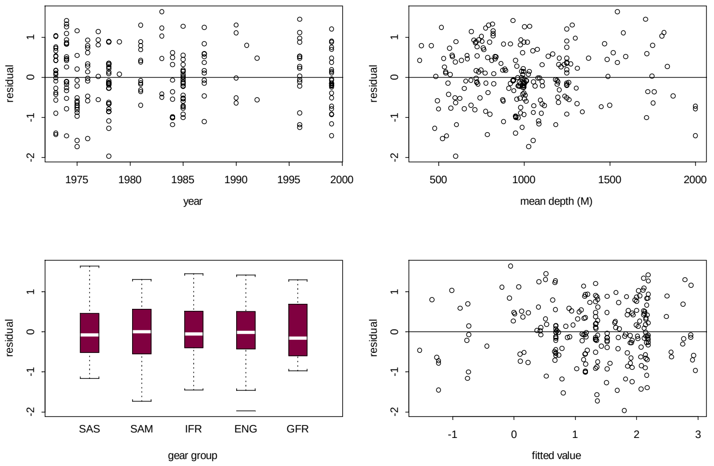

Figure 76. *Full LME model residuals plotted against: year (top left), mean depth (top right), gear group (lower left) and fitted values (lower right) for exploited species.*

Comparison of results from the three full models show that gear effects (relative to the 'SAM' gear group, Figure A5) are very similar. The mean depth effects (Section 4.6.3.3.1, Figure 22) are also very similar. It is encouraging to note that, as one may expect, the SAM scientific gear (SAS, representing OTSB(S)) has the lowest relative gear factor.

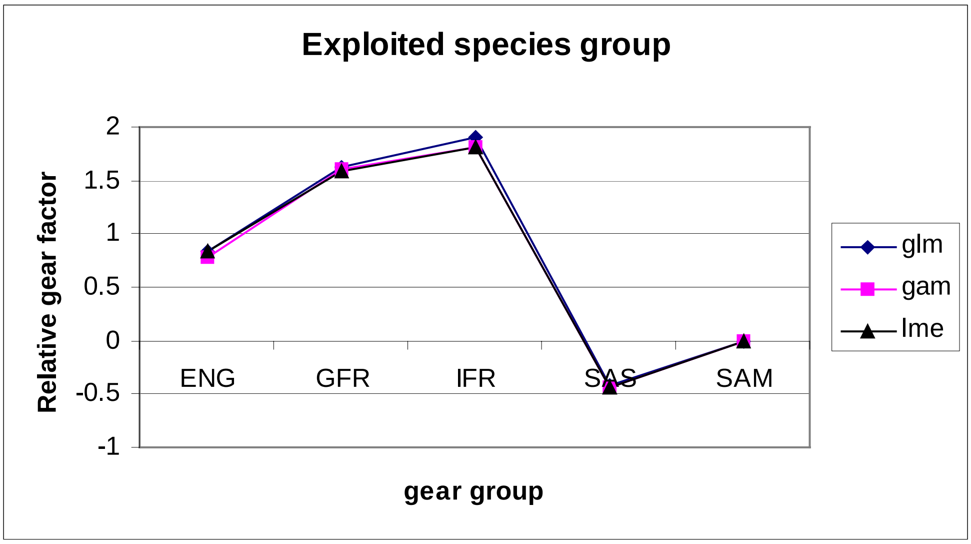

Figure 77. Gear factors relative to SAM gear group for the three full models fitted to lncpue data for the exploited group of species.

9.4.4.2 Unexploited species group

The GAM estimates of nonparametric functions (Figure 78) show some decline over time, and a dome-shaped relationship with mean depth. The residual plots (Figure 79) show much wider scatter than similar plots for the exploited species, and there is some indication of non-constant variance of the residuals. For example, residuals plotted against mean depth appear to show lower variance at deep depths. As noted above, this may simply be a result of the paucity of data at the deepest depths. There is, however, also some indication of increased variance with increasing fitted value.

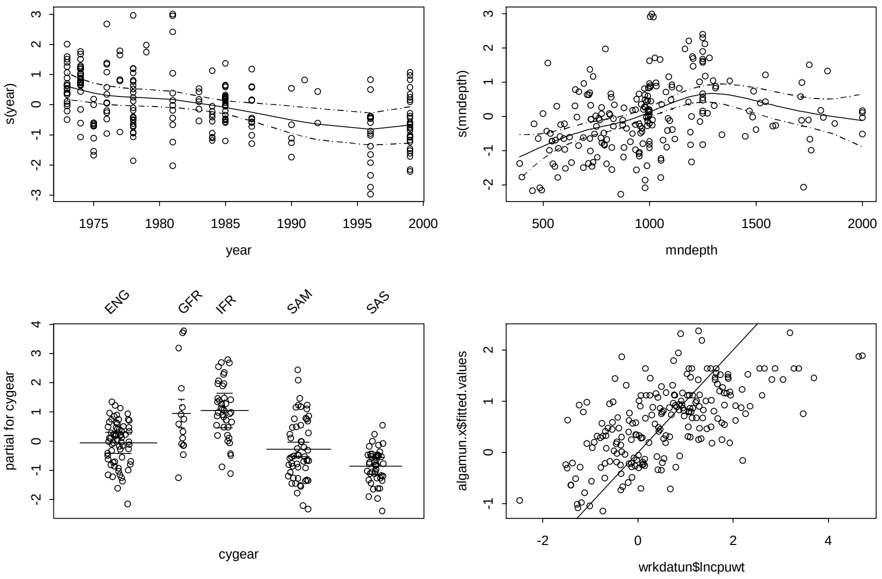

Figure 78. *GAM model nonparametric functions for lncpue of unexploited species and: year (top left panel), mean depth (top right), gear group effects (lower left). Fitted values are plotted against observed values in the lower right panel. (Note: mndepth=mean depth, cygear=gear group).*

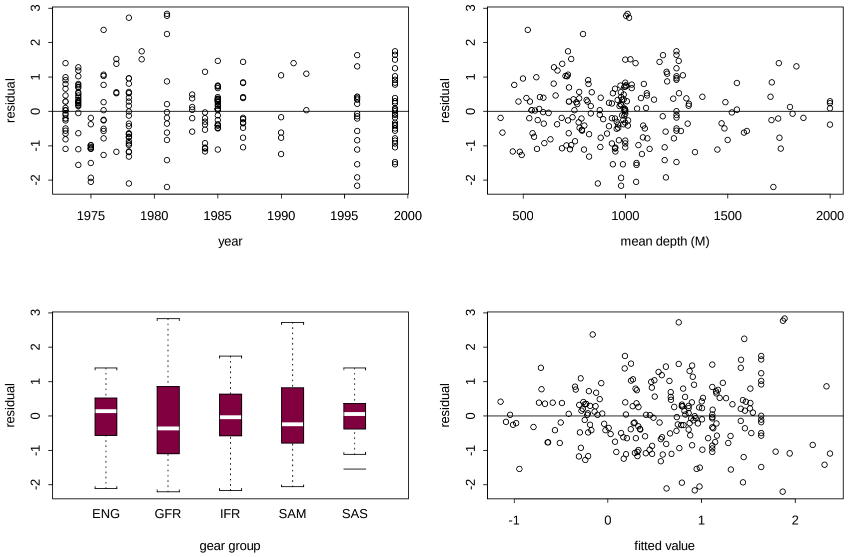

Figure 79. *GAM model residuals plotted against: year (top left), mean depth (top right), gear group (lower left) and fitted values (lower right) for unexploited species.*

ANOVA results (Table 43) show that the inclusion of year significantly improves the model fit.

Table 43. *GAM Analyses of Deviance Table for unexploited species.*

```
Response: lncpuwt
                    Terms  Resid   Resid  Df       Dev   Pr(Chi)
                            Df      Dev
1                       1  217.0   308.7
2               s(depth)  212.9   271.5 4.000   37.19  <0.0001
3          s(depth)+gear  208.9   191.8 4.000   79.68  <0.0001
4 s(year)+s(depth)+gear  204.9   181.8 4.001    9.97   0.0408
```

The GAM analysis suggests that a linear term in year may be sufficient. The ANOVA results for the suite of GLM models does not reject this notion, since the addition of a 2nd order term in year does not significantly improve the model fit (Table 44). The so-called ‘full’ GLM and LME models for the unexploited group contain only a linear term in year.

Table 44. *GLM Analyses of Deviance Table for unexploited species.*

```
Response: lncpuwt
                      Terms          Resid Resid  Df Dev FValue  Pr(F)
                                      Df    Dev
1                                  1  217   308.7
2                              depth  216   300.2  1   8.4   9.1   0.0027
3                         depth+gear  212   218.1  4  82.1  22.1  <0.0001
4                poly(depth,2)+gear  211   199.5  1  18.6  20.1  <0.0001
5           year+poly(depth,2)+gear  210   193.8  1   5.6   6.1   0.0140
6 poly(year,2)+poly(depth,2)+gear  209   193.3  1   0.5   0.5   0.4484
```

Residual plots (Figure 80) for the GLM model are similar to those for the GAM, with a wide spread of residuals and some indications of possible variance patterns. This should not bias the parameter-estimates, but estimates of variance may be somewhat inaccurate.

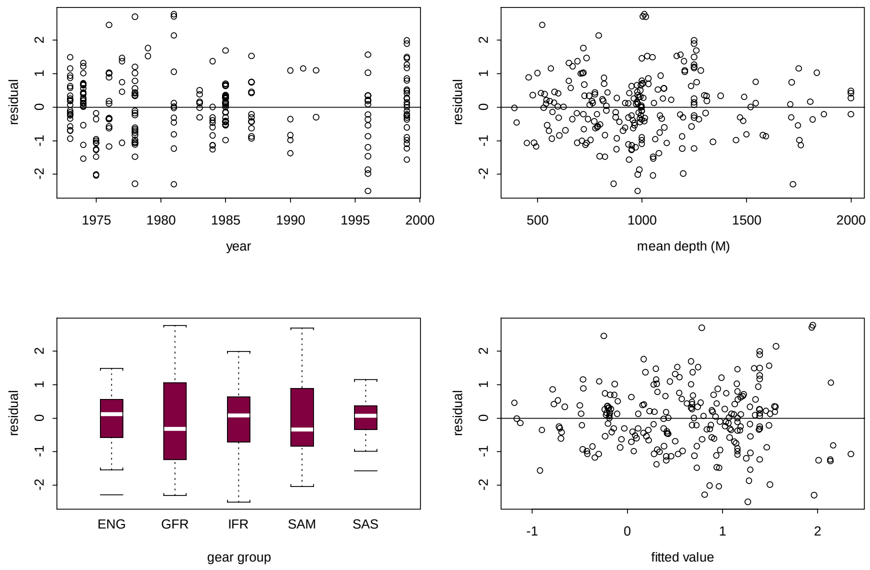

Figure 80. *Full GLM model residuals plotted against: year (top left), mean depth (top right), gear group (lower left) and fitted values (lower right) for unexploited species.*

ANOVA results for the LME model are given in Table 45. Residual plots for the LME model are again similar to Figures 79 and 80, and are not shown.

Table 45. *LME Analyses of Deviance Table for unexploited species.*

```
       Model          df     AIC      logLik   L.Ratio   p-value
1      poly(depth,2)   5    626.50   -308.25
2 year+poly(depth,2)   6    623.06   -305.53    5.44      0.0197
```

Relative gear factors for the unexploited group are very similar for the three models (Figure 81). Comparison of Figures 77 and 81 shows a high degree of consistency in relative gear factor between the exploited and unexploited groups.

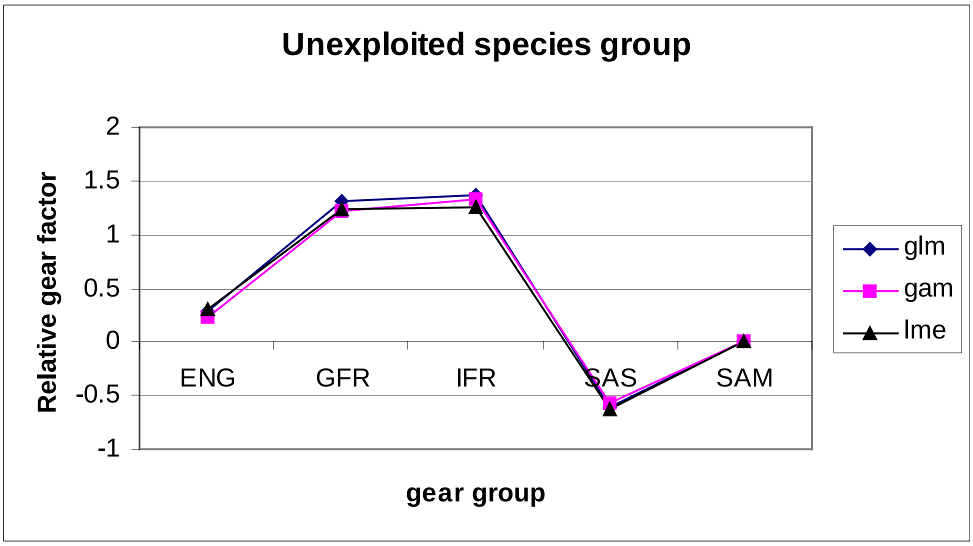

Figure 81. *Gear factors relative to SAM gear group for the three full models fitted to lncpue data for the unexploited group of species*

9.4.4.3 Roundnose Grenadier (*Coryphaenoides rupestris*)

Results for the GAM model shows a dome-shaped relationship with mean depth, and a significant time effect (Figure 82, Table 46). The shape of the time-trend is not that evident from Figure 82, because the year effect is plotted in terms of lncpue rather than CPUE, (e.g. Figure 31 in Section 4.6.3.3.5) and because the plot includes residuals which are very widely scattered.

Table 46. *GAM Analyses of Deviance Table for roundnose grenadier.*

```
Response: lncpuwt
            Terms         Resid     Resid     Df    Deviance  Pr(Chi)
                           Df        Dev
1                     1  206.00    351.09
2          s(depth)+gear 197.99    231.61   8.000 119.48   <0.00001
3 s(year)+s(depth)+gear  193.99    209.25   4.001  22.36    0.00017
```

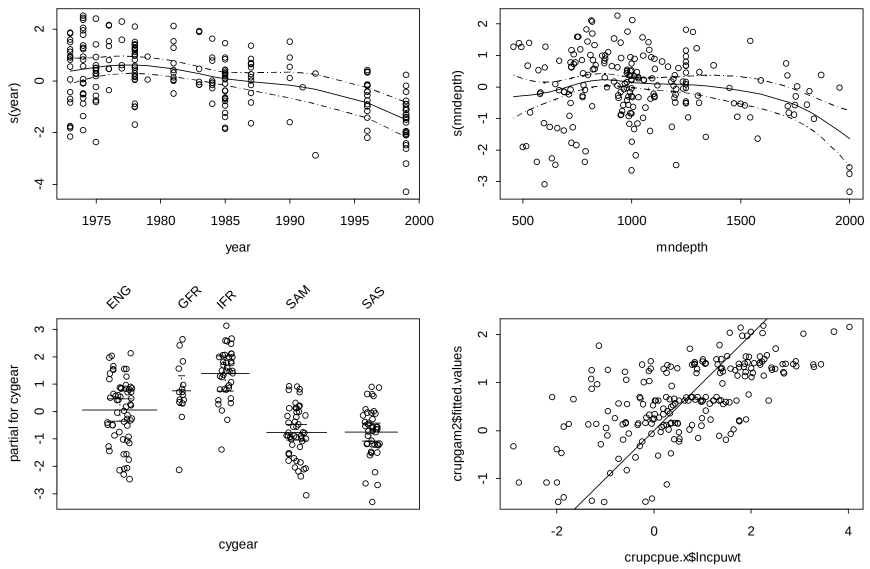

Figure 82. *GAM nonparametric functions for lncpue of roundnose grenadier and: year (top left panel), mean depth (top right), gear group effects (lower left). Fitted values are plotted against observed values in the lower right panel. (Note: mndepth=mean depth, cygear=gear group).*

Results for the GLM analyses are given in Table 47 and Figure 83. Residuals of the GLM model with 2^{nd} order term in year appears to show more positive residuals at deeper depths, so the model was also fitted to data for depths only up to 1375m (Figure 84).

Table 47 *GLM Analyses of Deviance Table for roundnose grenadier.*

```
Response: lncpuwt
                       Terms      Resid Resid  Df Dev  FValue Pr(F)
                                   Df    Dev
1                          1     206   351.0
2               poly(depth,2)    204   324.2  2 26.8 12.0 >0.0001
3          poly(depth,2)+gear    200   240.9  4 83.3 18.7 >0.0001
4     year+poly(depth,2)+gear    199   229.5  1 11.4 10.2  0.0015
5 poly(year,2)+poly(depth,2)+gear 198 220.2  1  9.2  8.3  0.0043
```

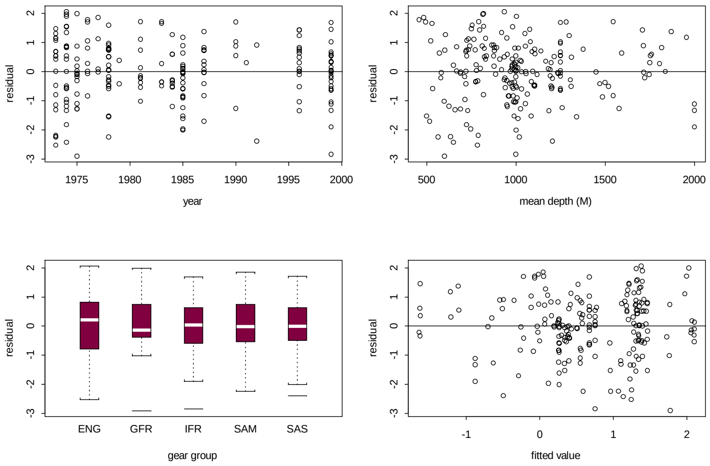

Figure 83. *GLM model residuals for roundnose grenadier plotted against: year (top left), mean depth (top right), gear group (lower left) and fitted values (lower right).*

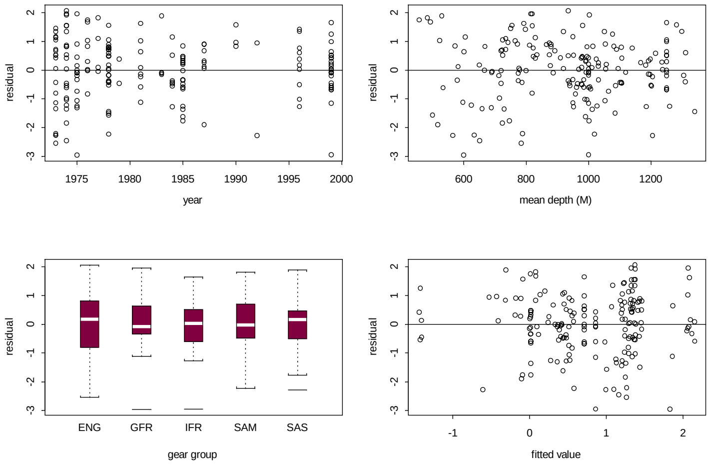

Figure 84. *GLM model residuals for roundnose grenadier at depths <1375m only, plotted against: year (top left), mean depth (top right), gear group (lower left) and fitted values (lower right).*

Residuals for the analyses of the restricted depth range show a much more even spread of residuals, as expected. There are still some extreme, low residuals. Estimates of coefficients are also somewhat different compared to the model applied to all depths, as illustrated by the year-effect in Figure 85. It is interesting to note the similarity between gear-group effects for roundnose grenadier and the other species groups, particularly for the restricted depth range (Figure 86).

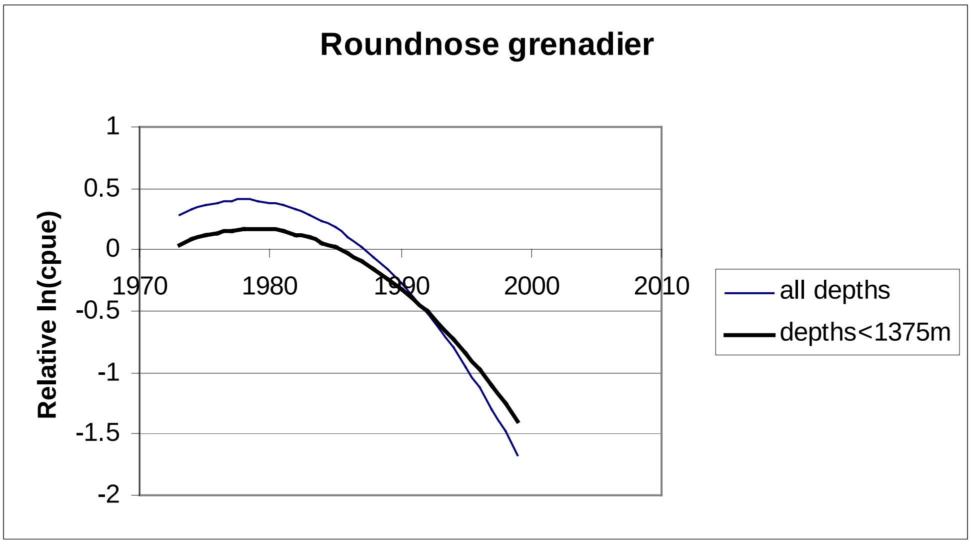

Figure 85. *Relative lncpue predicted at 1000m, for gear type SAS, showing differences in time trend for the GLM fitted to all depths and to depths<1375m.*

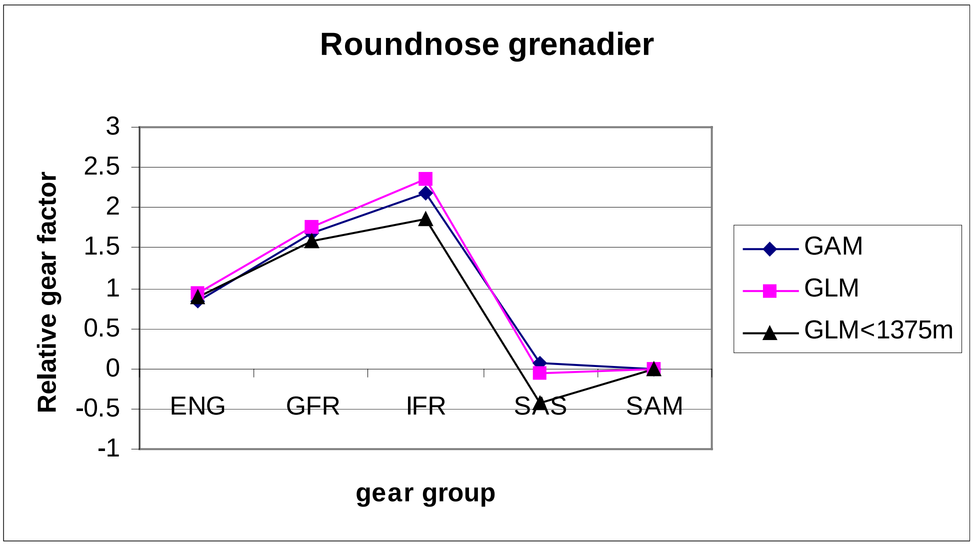

Figure 86. *Gear factors relative to SAM gear group for three models fitted to lncpue data for roundnose grenadier. 'GLM<1375m' refers to the GLM fitted to data from hauls shallower than 1375m only.*

9.4.5 Presence/absence model details

The presence/absence models use the proportion of non-zero hauls in each year as the response variable. Two models are fitted, and results compared. The first model simply estimates the overall mean of the data. The second model fits a time factor to the response variable, and an ANOVA comparison is used to determine whether the time trend is significant. In both cases, it is assumed that the data are from a binomial distribution, so that fitted values from the model are essentially the probabilities of observing a non-zero haul (either on average, or in a given year).

This analysis is straightforward in S-PLUS 2000, with the 'glm' routine, specifying family as binomial. The results are given in Section 4.6.4.3.

Note all references in the appendices are included in the main reference section (Section 7).

9.5 Recent studies of deep-water species

EC FAIR 95-655 Developing deep-water fisheries: data for their assessment and for understanding their interaction with and impact on a fragile environment (Deep-fisheries)

In December 1995 The European Commission funded a three year DGXIV FAIR project entitled "Developing deep-water fisheries: data for their assessment and for understanding their interaction with and impact on a fragile environment (CT 95/655). The project aimed to describe these fisheries, ensure that existing survey data were worked up and archived, scientifically record the species being landed or discarded and investigate aspects of the biology of both target and non-target species. The project which had 13 partners covers the continental margin from Iceland to Greece and the inputs of partners from Iceland, Norway, United Kingdom, Ireland, Germany, France, Spain and Portugal are relevant to the ICES area. The final report was accepted by the Commission in December 1999 and it is anticipated that it will be made generally available on a web-site.

Under task 1 partners from Iceland, Norway, United Kingdom, Spain and Portugal provided detailed descriptions of the deep-water fisheries of their countries. Task 2 involved the compiling of mainly historical survey data and where appropriate its analysis. This was undertaken by Iceland, United Kingdom, Ireland, Germany, and Spain. Task 3 was concerned with collecting and analysing discard data. France and the United Kingdom sent observers on commercial trawlers fishing for deep-water species to the west of the British Isles. Norway collected data on the discards from the deep-water longline fisheries. Task 4 recognised that many deep-water species tend to be landed by grouped categories, for example deep-water sharks, and therefore involved sampling the landings. This was being carried out by Iceland, France, United Kingdom and Portugal. The final task, which involved all partners, carried out research on the biological parameters of deep-water species. The work content varied considerably between partners but the key elements were distribution, age estimation, growth and reproduction.

The final report of this project was available to the ICES Deep-Water Study Group meeting in February, 2000.

EC DGXIV 97/84 Environment and biology of deep-water species *Aphanopus carbo* ***in NE Atlantic: basis for its management (BASBLACK)***

This project, which is being funded by the European Commission (DGXIV in support of the Common Fisheries Policy), began in early 1998. The project is co-ordinated by Portugal and also has partners from Spain and the United Kingdom. The main objectives are to review the available information on black scabbardfish, establish a sampling programme of landings, investigate stock discrimination, investigate biological parameters (especially growth, feeding, and reproduction); collect relevant data on the habitat and environment, monitor the levels of bioaccumulation and establish a system of data management. Some preliminary results of this project were made available to the ICES Deep-Water Study Group meeting in February, 2000.

EC DGXIV 97/81 Seasonal changes in biological and ecological traits of demersal and deep-water fish species in the Azores

This project, which is being funded by the European Commission (DGXIV in support of the Common Fisheries Policy), began in early 1998 and is co-ordinated by Portugal with the United Kingdom as a partner. The overall objective is to improve current knowledge on age estimation, growth and reproduction of some of the commercially important demersal and deep-water species exploited in the Azores. Investigations are also being carried out on stock discrimination using micro-satellite DNA. The ecological studies include the relationship between local hydrography, topography, life-history parameters, and spatial scales of genetic differentiation in deep-sea fish for a better understanding of the population biology of the target species. The vertical and horizontal migrations, changes in the feeding habits and some other aspects of the biology of the target species between seamounts and islands margins are also being studied.

EC FAIR 98/4365 Otolith microchemistry as a means of identifying stocks of deep-water demersal fish (Otomic)

This project is co-ordinated by the United Kingdom with Spain as a partner. The objective is to use the chemical signal embedded in the otoliths to discriminate between stocks of deep-water species. The underlying principle is that otoliths are inert objects and during their life incorporate a chemical signature of water mass in which they live. Differences in chemical composition, especially in the nucleus, could indicate different origin and hence stock. The project involves both the Atlantic and the Mediterranean. The species involved are the roundnose grenadier (*Coryphaenoides rupestris*), *Nezumia aequalis*, hake (*Merluccius merluccius*), bluemouth (*Helicolenus dactylopterus*).

DGXIV Study Contract 99/55 Development of elasmobranch assessment (DELASS)

This project, which is funded by the European Commission (DGXIV in support of the Common Fisheries Policy), began in January 2000 is co-ordinated the Netherlands (RIVO) and has 16 partners from 10 countries. The overall objective is to improve the scientific basis for the management of the fisheries on elasmobranch species. The project is selective for groups of elasmobranch species. The deep-water sharks to be considered are *Centroscymnus coelolepis, Dalatias licha* and *Galeus melastomus.*