DEEPFISH Project:

Applying an ecosystem approach to the sustainable management of deep-water fisheries.

Part 1:

Development of an Ecopath with Ecosim model

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DEEPFISH Project: Applying an ecosystem approach to the sustainable management of deep-water fisheries

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A report detailing the project findings is available (DEEPFISH Project: Part 2 report), for a copy please contact Dr Kerry Howell at the University of Plymouth, UK.

French and Spanish versions of both reports are also available as pdf documents.

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Contents

Summary

The ecosystem approach to fisheries management is called for globally and ecosystem models such as Ecopath with Ecosim (EwE) provide a means by which to take a holistic view of ecosystem-fisheries interactions. The Ecopath software package, which includes time-dynamic (Ecosim) and spatial simulation (Ecospace) algorithms, essentially allows the user to construct a model of the deep-sea food-web, with fisheries acting as the ultimate predator. It allows observations on the combined effects of multiple fleets not just on target species but also on non-target groups, and in this way provides a different view of fisheries to that of traditional single species models.

This project (DEEPFISH) was established with the aim of facilitating an ecosystem approach to the management of deep-water fisheries. Specifically, the objective of the project was to develop an EwE model of the deep-water fisheries (400-2000m) in ICES Division VIa (The Rockall Trough), which could be used to: assess changes in the ecosystem that have occurred since the development of the major fisheries there in the 1980s; predict future changes as a result of continued fishing pressure under different potential management regimes.

This report describes the development of the EwE model. The data required to develop the EwE model are for each species: biomass, production, consumption, ecotrophic efficiency, diet, landings and discards for the model area. The Rockall Trough is one of the most well studied deep-sea areas in the world and as a result relatively good data are available for all these inputs for this region. However, in the construction of the model many assumptions have had to be made based on expert judgement, and these must be considered and understood when interpreting the outputs of the model.

This report is intended to accompany the short project report, which outlines the model outputs from two predictive scenarios. The first scenario examines changes in the biomass of a selection of key commercial, discard, and other deep-sea fish species that have occurred since the early 1970s to present, and future changes predicted to occur over the next 13 years (to 2020) if TACs are held at 2010 levels. The second scenario builds on the first, but examines potential interactions between fisheries through the food web by hypothetically stopping the blue whiting fishery in 2007 and observing how that action then alters the 2020 biomass predictions made in scenario 1.

This report allows the interested reader to view the model outputs in the context of the data used to construct the model. Importantly, it is intended to provide the reader with the appropriate understanding of the limitations of the data and thus the caveats attached to the model outputs.

1. Introduction

The DEEPFISH project was established with the aim of facilitating an ecosystem approach to the management of deep-water fisheries.The application of the ecosystem approach requires that there is a strong understanding of the basic interactions of a fished species with its environment. One of the most basic ways in which species interact with each other and their surroundings is through feeding relationships (who is eating whom). Gaining an understanding of the multitude of links between predators and their prey (the food web) provides a base for the development of a broader knowledge of an ecosystem.

To achieve this aim, the DEEPFISH project partners have developed an Ecopath model of the deep-water fishery off the west coast of Scotland. Ecopath is a mass-balanced trophic model. The Ecopath software package, which includes time-dynamic (Ecosim) and spatial simulation (Ecospace) algorithms, can be used to study fisheries resources in an ecosystem context, for overall ecosystem analysis, and for exploring management policy options. The software is designed to help construct a (simple or complex) model of the trophic flows in an ecosystem. Once the model is constructed it can provide an overview of the feeding (and fishing) interactions in the ecosystem, and of the resources it contains. It enables detailed analysis of the ecosystem, and through Ecosim, simulation of the effects of changes in fishing pressure over time.

We have produced an Ecopath model for ICES Division VIa within the 400 to 2000 m contours (Figure 1). This area includes the Rockall Trough and its seamounts, Anton Dohrn, Rosemary Bank and the Hebrides Terrace, and covers a total of 75,539 km². The area of Division VIa north of the Wyville-Thomson Ridge has been excluded from the model as the fauna of the continental slope north of the ridge is strongly influenced by the presence of waters of Arctic origin (sub zero temperature), and is markedly different to that south of the ridge (Bett, 2001), to the extent where it can be considered a different ecosystems. As a consequence the fisheries on either side of the Ridge are quite different (Gordon, 2001).The starting point of the DEEPFISH Ecopath model is 1974 which effectively predates the deep-water fisheries of the Rockall Trough.
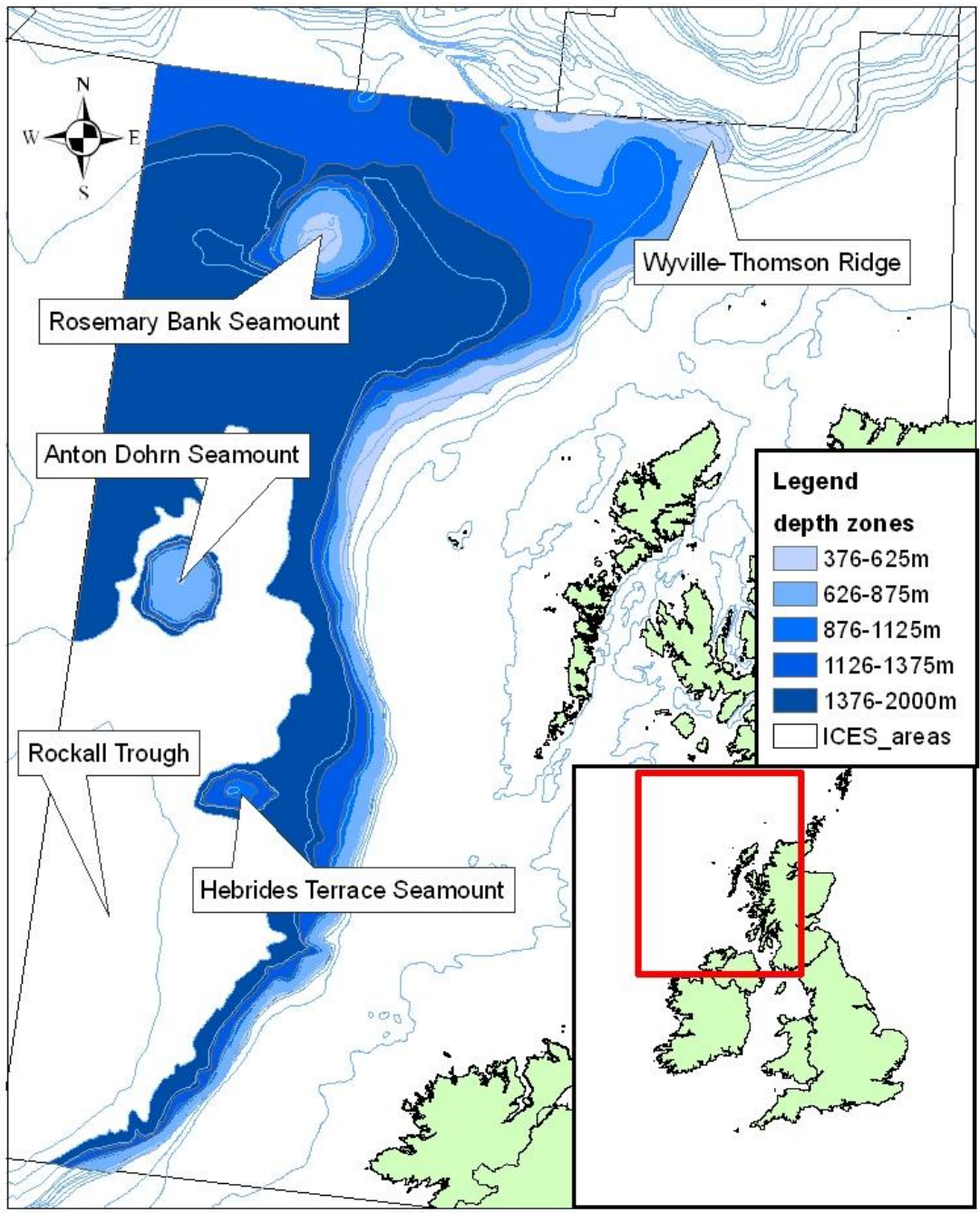
Figure 1: The modelled area within the Rockall Trough region.

2. Model inputs

The Ecopath model requires the following inputs:

For each species / trophic group present in the area / ecosystem being modelled:

- B   Biomass within ICES Division VIa ($t \cdot km^{-2}$)
- P/B   Production / Biomass within ICES Division VIa ($year^{-1}$)
- Q/B   Consumption / Biomass within ICES Division VIa ($year^{-1}$)
- EE   Ecotrophic efficiency (proportion)
- Diet composition (contribution of prey items by mass).

For each fishery occurring in the model area:

- landings ($t \cdot km^{-2} \cdot year^{-1}$)
- discard ($t \cdot km^{-2} \cdot year^{-1}$)

2.1. Trophic groups

There are approximately 110 species of bottom-living fishes occurring between 500-3000m in the Rockall-Trough area of the study site (Gordon and Mauchline, 1990), not to mention the vast invertebrate fauna and small number of marine mammal species. It would not be appropriate or desirable to attempt to model each species individually (although all species must be included in the model), thus species and groups of species have been used / defined based on the following: dominance in terms of abundance and / or biomass, commercial importance, data availability and also in the case of groupings on taxonomic similarity and/or trophic group (Table 1). We excluded all seabirds from the model, as although seabirds are known to feed on fishery discards, they do not feed at 400m depth.

Table 1: Model species / groups.

Group	Group	Species included within the group
1	Cetaceans	Cetaceans
2	Shallow sharks	*Etmopterus spinax*
		Galeus melastomus
3	Intermediate sharks	*Centroscymnus coelolepis*
		Deania calceus
		Centrophorus squamosus
		Centroscymnus crepidator
		Apristurus laurunsonii
		Apristurus spp.
4	Deep sharks	*Centrosyllium fabricii*
		Etmopterus princeps
5	Large demersals	*Brosme brosme*
		Merluccius merluccius
6	Skates and rays	*Rajella fyllae*
		Bathyraja pallida
		Bathyraja richardsoni
		Neoraja caerulea
		Leucoraja circularis
		Dipturus nidarosiensis
		Rajella bathyphila
		Rajella bigelowi
7	*Coryphanoides rupestris* L	*Coryphanoides rupestris* (adults)
8	*Coryphanoides rupestris* S	*Coryphanoides rupestris* (juveniles)
9	*Lophius piscatorius*	*Lophius piscatorius*
10	*Hoplostethus atlanticus*	*Hoplostethus atlanticus*
11	*Argentina silus*	*Argentina silus*
12	*Micromesistius poutassou*	*Micromesistius poutassou*
13	*Aphanopus carbo*	*Aphanopus carbo*
14	*Molva dypterygia*	*Molva dypterygia*
15	*Molva molva*	*Molva molva*
16	*Phycis blennoides*	*Phycis blennoides*
17	*Alepocephalus bairdii*	*Alepocephalus bairdii*
18	*Epigonus telescopus*	*Epigonus telescopus*
19	*Synaphobranchus kaupi*	*Synaphobranchus kaupi*
20	*Lepidorhombus whiffiagonis*	*Lepidorhombus whiffiagonis*
21	Mesopelagic species	Mesopelagic species
		Gadiculus argenteus thori
22	Benthopelagics	*Helicolenus dactylopterus*
		Chalinura mediterranea
		Caelorinchus caelorhincus
		Caelorinchus labiatus
		Coryphaenoides guentheri
		Halargyreus johnsonii
		Lepidion eques
		Mora moro

		Nezumia aequalis
		Trachyrhynchus murrayi
23	Benthic fish	*Chimaera monstrosa*
		Hydrolagus mirabilis
		Notacanthus bonapartei
		Polyacanthonotus rissoanus
		Antimora rostrata
24	Chimaera	*Chimaera monstrosa* *Hydrolagus mirabilis*
25	Squid and Octopus	Squid and Octopus
26	Prawns and shrimps	Prawns and shrimps
27	Gelatinous zooplankton	Gelatinous zooplankton
28	Large zooplankton: Mysids, Amphipoda, Euphausids	Large zooplankton: Mysids, Amphipoda, Euphausids
29	Small zooplankton: Ostracoda, Calanoid copepods, Cyclopoid copepods	Small zooplankton: Ostracoda, Calanoid copepods, Cyclopoid copepods
30	Polychaeta	Polychaeta
31	Echinoderms	Echinoderms
32	Other benthic inverts	Other benthic inverts
33	Phytoplankton	Phytoplankton
34	Detritus	Detritus

2.2. Fish biomass calculations

Fish biomass estimates have been calculated from German trawl survey data from the '*Walther Herwig*' (1974-1986) cruises, trawl survey data held by the Scottish Association for Marine Science (SAMS) (1975-1992), and Fisheries Research Services survey data (2000-present) (Figure 2 and see Appendix 1 for annual distribution of samples).

Twelve German trawl surveys were carried out between 200-1,200m in the Rockall Trough and on the slopes of its surrounding banks between 1974 and 1986 on the '*Walther Herwig*' (Gordon, 2003) (Figure 2). All the fish data were compiled into a single unified database as part of the German contribution to the EU FAIR deep fisheries project (Gordon, 1999).The German surveys showed some seasonal patchiness in species distributions, with three of the stations on the Hebridean Terrace fished in January, June and October, showing large catches in October only (Gordon and Duncan, 1985a). Two bottom trawls were used on '*Walther Herwig*', a BT140 and a BT 200. Basson et al. (2002) provide adescription of the gear specification based on Merrett et al. (1991): 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

The SAMS surveys started with five cruises in 1975 on the '*RRS Challenger*', using two Granton trawl hauls at depths of 750m and 1,000m. Sampling took place on the Hebridean Terrace (Gordon, 2003) (Figure 2 and Appendix 1). Between 1976 and 1979 a further 7 cruises took place, with the same gear, sampling at 500m and 1,250m as well as the standard 750m and 1,000m hauls (Gordon, 2003). In addition, deeper samples were taken with a small 8 fathom box trawl on a single warp and a 3m Agassiz trawl (Gordon, 2003). Between 1980 and 1983 SAMS sampling focused on the Porcupine Sea Bight, an area to the south of the study area. However, in 1983-1987 SAMS returned to the Rockall Trough, and used the Granton trawl to sample at 250m, while a semi-balloon trawl (OTSB) on single or paired warps, was used to sample deeper stations (Gordon, 2003). From 1990-1992 further OTSB trawling was carried out on joint benthic/fishing cruises (Gordon, 2003). The Granton trawl 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 wing end spread was estimated by the designer of the trawl to be 12.6 m although in the earliest hauls this was 15 m due to a different configuration of the bridles (Gordon and Duncan, 1985a). These different estimates were used when calculating the swept area. The OTSB had a headline of 14m and the mesh size reduced from 44 to 37mm with a 13mm blinder in the codend and has been described in detail by Merrett and Marshall (1981).Until 1983 this trawl was only fished on a single trawl warp and the catches in the Porcupine Seabight were quite different from those of the SAMS Granton Trawl and the German Bottom Trawl

(Merrett et al., 1991). In 1984 the same trawl was fished on paired trawl warps and the catch composition was quite different and more similar to that of the Granton Trawl (Gordon and Bergstad, 1992; Gordon et al., 1996).
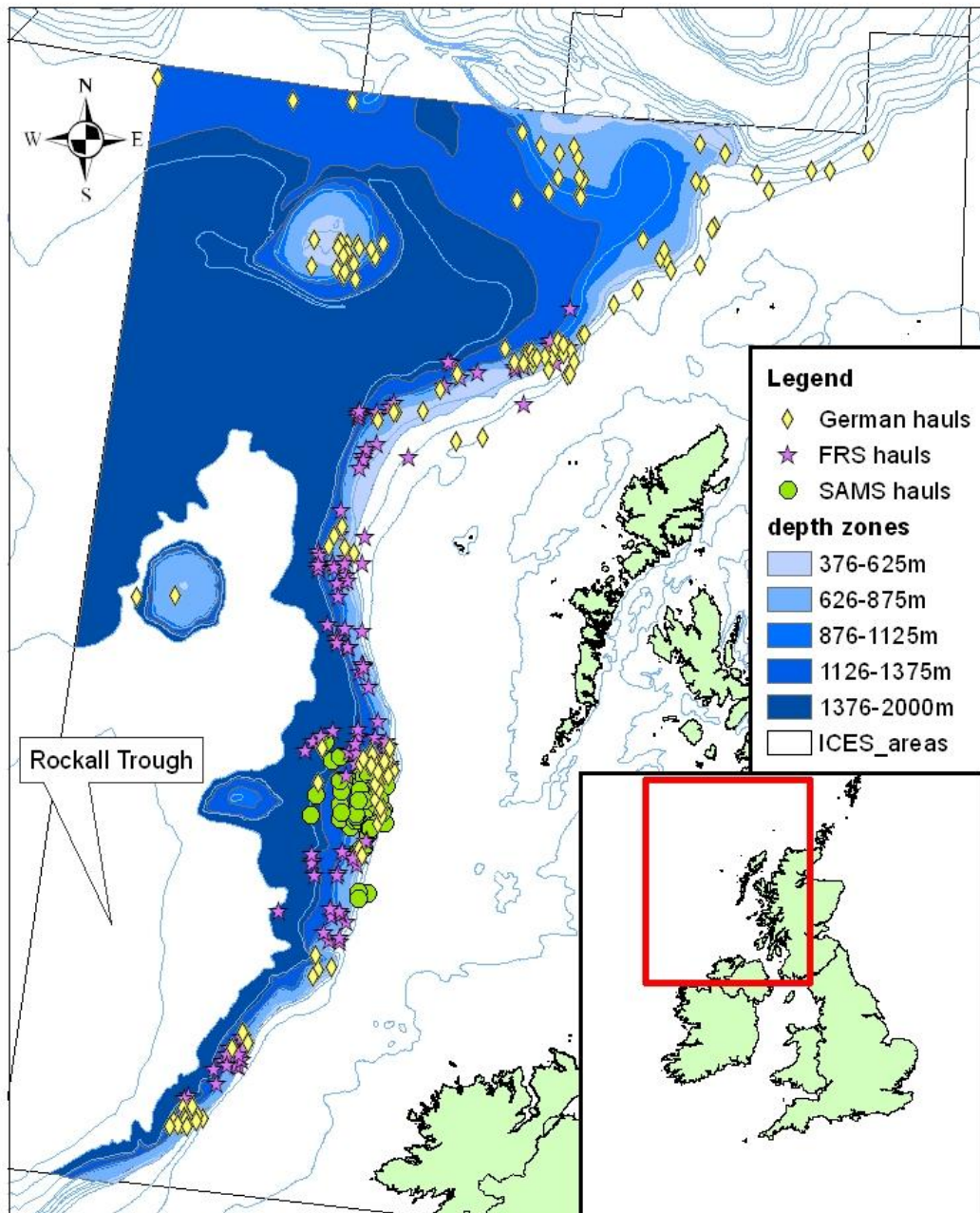
Figure 2: Distribution of trawl samples from the three key datasets.
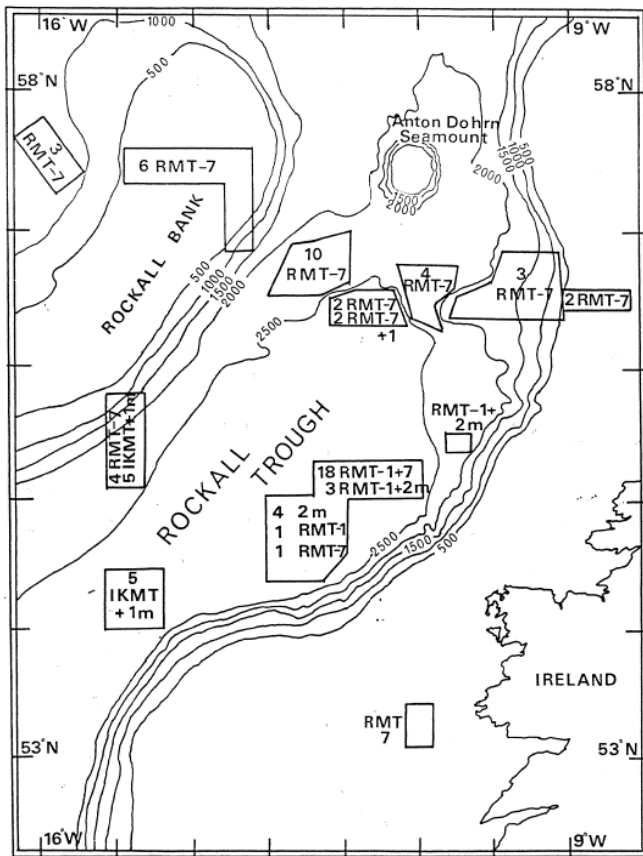
Figure 3: Sites sampled by the rectangular midwater trawls (RMT) from 1973-1978.

Pelagic fish were also sampled as part of SAMS scientific research programme in the Rockall Trough between 1973 and 1978. Sampling focused on the southeastern part of the Rockall Trough using open nets deployed from the surface to depths of approximately 630-2700 m by the '*RRS Challenger*' (Mauchline, 1983; Kawaguchi and Mauchline, 1982, 1987). Sampling was achived with Rectangular Midwater Trawls (RMT) with mouth areas of 7m² and 1m² respectively, fished as a combination net (Mauchline and Gordon, 1983b). The sites sampled are given in Figure 3.

The FRS deep-water survey dates back to 1996 although strictly comparable data are available from 1998 onwards with the advent of the current research vessel FRV *Scotia*. The survey is focused on the European continental shelf slope or shelf break. From 1998 to 2004 a biannual survey covered a core area from between 55 to 59 ° N with a depth stratification at 500, 1000, 1500 and 1800 m (Figure 2). Additional stations have also been trawled at intermediate depth strata, most notably at 750m. From 2005 the survey became annual and while retaining its core survey stations on the shelf slope, began to expand its geographic scope to the eastern flank of Rockall Bank and to the Anton Dohrn Seamount and Rosemary Bank Seamount. The survey takes place in September and has a typical duration of 14 days. The gear used comprises a Jackson Trawl with 41.5m headline length, 53.4m ground rope length, a headline height of approx 5m, and a cod-end of 100mm + 20mm blinder. For the purposes of calculating the swept area for this project the wing end spread was estimated by Scanmar 23.5 m.

Initial biomass estimates for the prefishery model (1974) were principally calculated from German trawl data, however time-series data, used to fit the model, were calculated from all three data sets, which between them provided reliable data for the years 1974-81, 1983-87, 1990, 2002, 2004-07. Use of data from three different vessels and different trawl gears has produced some challenges in terms of making the data broadly comparable. In addition the spatial extent of the annual sampling varied within and between datasets (Appendix I). The German dataset has the greatest spatial distribution of trawl data taking in the continental slope in Division VIa as well as the banks, seamounts and Wyville-Thonson Ridge. The SAMS dataset is focused almost entirely on the continental slope adjacent to the Hebrides Terrace Seamount, while the FRS dataset extends the length of the continental slope. While the SAMS and FRS datasets are fairly consistent in their annual spatial

and depth coverage the German dataset is very variable with inevitable consequences for use of these data in calculating estimates of biomass.

Gordon and Bergstad (1992) compared the catches by various trawl types, including Granton trawls (GT) and semi-balloon trawl (OTSB). The OTSB included single-warped (OTS) and pair warped (OTP) trawls. Only 22% of the variation on the fish community they tested was explained by differences in trawl types, with the greatest difference at depths greater than 750m (Gordon and Bergstad, 1992). The catches of same Granton trawl and OTSB fished on a single warp were compared with the German BT from surveys on the slope of the Porcupine Seabight (Merrett et al., 1991). Gordon et al. (1996) compared Granton and OTSB catches between the Rockall Trough and the Porcupine Seabight. Overall there was some similarity between the catches of the Granton, German BT and the OTP, the latter only being used in the Rockall Trough. However, the catch of the OTS is quite different with high catch rates of Kaup's arrowtooth eel, *Synaphobranchus kaupi*, and lower catches of larger more mobile species such as the Portuguese dogfish, *Centroscymnus coelolepis*, Baird's smooth head, *Alepocephalus bairdii,* and the black scabbard fish, *Aphanopus carbo* (Merrett et al., 1991; Gordon and Bergstad, 1992). The likely explanation for the reduced catches of larger mobile species is that the converging warps ahead of the trawl herd fish out of the path of the net instead of inwards as is the case with a conventional paired warp trawl. The reason for the preferential capture of *S. kaupi* by the OTS compared with the OTP (same net – different rig) is more difficult to explain and Gordon and Bergstad (1992) have speculated on possible reasons.

When calculating biomass estimates from SAMS data, only the paired warp Granton and later the paired warp OTSB trawls were used. Unfortunately there was no direct comparison of the two gears on the same survey. However, even with the exclusion of the single warp OTSB trawls, there is still large variability between trawls at the same bathymetric zone, possibly due to seasonal spawning aggregations of blue whiting or Baird's smoothhead or changes in annual cycles of abundance (Gordon and Duncan, 1985a).

For the calculation of biomass the model area was divided into depth bands broadly corresponding to the distribution of sample effort in the three datasets. These depth bands were: 376-625m (4,733km²), 626-875m (7,543km²), 876-1,125m (6,929km²), 1,126-1,375m (16,132km²) and 1,376-2,000m (40,202km²) (Figure 2). Hauls taken outside the model area were omitted from the analysis. Biomass for each species for each year within a dataset was calculated in the following manner:

1) For each haul the biomass in tonnes of each species collected by the haul was calculated.
2) The swept area of the haul in km^2 was calculated
3) For each species the biomass in tonnes was divided by the swept area to obtain the biomass in $t \cdot km^{-2}$
4) For each species the biomass in $t \cdot km^{-2}$ was multiplied by the area of the depth band in which it occurred to obtain the biomass of each species in the water column in that depth band as estimated from that haul
5) For each depth band the average biomass of each species in that depth band was calculated by adding all the calculated biomasses for each haul in that depth band

and dividing by the total number of hauls that occurred in that depth band
6) For each species the calculated average biomass in each of the five depth bands was summed to obtain a total biomass for each species in the modelled area* (see below for comments on German trawl data).
7) For each species the figure for total biomass in tonnes was then divided by the total area of the model to provide a figure in $t \cdot km^{-2}$ as required by the model.

In general, for all datasets, sample effort was not evenly distributed between depth bands. Within the German trawl data set, sampling of every depth band was only achieved in 1974 and 1981 (Table 2).

Table 2: Distribution of trawl data by depth band and year (spatial distribution shown in appendix 1) for a) German trawl data, b) SAMS trawl data, c) FRS trawl data.

a)

	total	500	750	1000	1250	>1375
1974	13	6	2	3	1	1
1975	6	2	2	2	-	-
1976	-	-	-	-	-	-
1977	4	4	-	-	-	-
1978	-	-	-	-	-	-
1979	12	6	2	2	2	-
1980	27	17	5	5	-	-
1981	24	7	5	5	6	1
1982	16	-	13	3	-	-
1983	21	7	7	5	2	-
1984	-	-	-	-	-	-
1985	-	-	-	-	-	-
1986	7	-	7	-	-	-

b)

	total	500m	750	1000	1250	>1375	Trawl
1975	10	2	3	5	-	-	Granton
1976	12	4	3	3	2	-	Granton
1977	5	1	2	1	1	-	Granton
1978	3	-	1	1	1	-	Granton
1979	2	-	1	1	-	-	Granton
1980	-	-	-	-	-	-	
1981	-	-	-	-	-	-	
1982	-	-	-	-	-	-	
1983	2	2	-	-	-	-	Granton
1984	10	1	1	5	1	2	OTSB(P)
1985	6	1	1	2	1	1	OTSB(P)
1986	-	-	-	-	-	-	
1987	5	1	2	-	1	1	OTSB(P)
1988	-	-	-	-	-	-	
1989	-	-	-	-	-	-	
1990	3	-	-	1	1	1	OTSB(P)

c)

	500	750	1000	1250	>1375	total
2002	-	7	7	2	7	33
2003	-	-	-	-	-	-
2004	9	2	8	-	6	25
2005	4	3	6	-	6	19
2006	9	2	10	-	8	29
2007	6	-	6	-	6	18

Species are not evenly distributed with depth, but show peaks in abundance within their known depth range and therefore within a particular depth band, as defined by this project. Failing to sample all depth bands will result in gross under estimates of fish biomass, particularly for those species that reach their peak in abundance within the unsampled depth bands. It is therefore important to try to compensate, in terms of estimating biomass, for the fish biomass occurring in the unsampled depth bands. For each species we have used the percentage of the biomass present in each depth band in 1981 to estimate the biomass of each species present in depth bands for all other years. This method assumes that within a species the distribution of the population with depth has remained constant. 1981 was chosen as the 'representative' year as: all depth bands were sampled, sample effort in terms of trawl number, was high (Table 2), and the samples were evenly distributed throughout the study area (Appendix 1). The calculation was achived in the following mannor:

1. For each species for each year the depth band in which it was most abundant and for which sample data existed was identified
2. Sampled biomass within this depth band was assumed to be equal to the percentage of the biomass calculated for that species, for that depth band from 1981.
3. Biomass in all other depth bands was then calculated by dividing the sample biomass in (2) by the percentage in (2) and multiplying by the appropriate percentage for the depth band in question using the percentages calculated from 1981 data.
4. Calculated biomass was compared with recorded biomass where available in order to validate the method used. In most cases there was good agreement between estimated values and recorded values within a depth band.
5. As with the method outlined above the calculated biomass in each of the five depth bands was summed to obtain a total biomass for each species in the modelled area
6. For each species the figure for total biomass in tonnes was then divided by the total area of the model to provide a figure in $t \cdot km^{-2}$ as required by the model.

The biomass estimates used in the fitting of the model are given in Figure 4.

Figure 4: Biomass (in tonnes) estimates used to fit the model to the data. Values between years where no points are shown have been estimated and are not used in the fitting procedure.
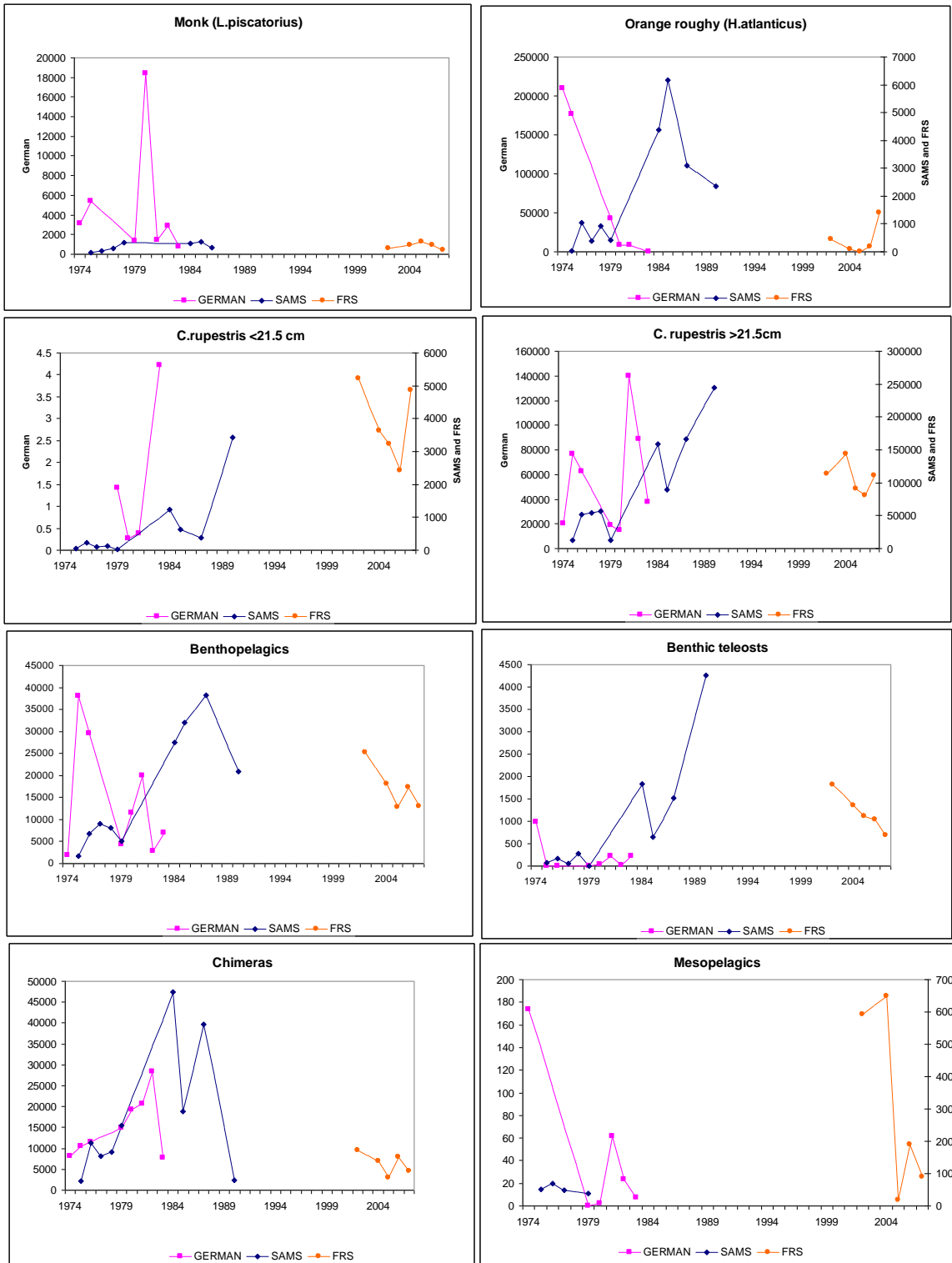
Figure 4 continued…

2.3. Fisheries

The curtailment of fishing opportunities mainly in Icelandic and Faroese waters resulting from increased exclusive fishing zones in the 1970s led to interest in assessing the potential of deep-water demersal species on the continental slopes to the west of the British Isles (Bridger 1978; Ehrich 1983). The first exploitation of the slope goes back to German trawlers that began targeting spawning aggregations of blue ling (*Molva dypterygia*) that they had found in the northern Rockall Trough in the mid 1970s (Gordon 2001; Gordon et al., 2003). Meanwhile French trawlers had traditionally exploited saithe (*Pollachius virens*) along the edge of the continental shelf. These trawlers replaced the German trawlers and exploited blue ling in deeper water. This move by the French fleet into deeper water led to discarding of other deep-water species and there began a move to develop markets for these discards such as roundnose grenadier (*Coryphaenoides rupestris*), black scabbardfish (*Aphanopus carbo*) and deep-water sharks. By 1989 these deep-water species and a few other less abundant species were being landed by a year-round bottom fishery. Currently the main trawl fishery is French with minor landings of deep-water species being made by UK and Irish vessels. There are few species of commercial value at depths greater than 1500m and the biomass decreases rapidly at depths greater than this.

In addition to the deep-water bottom trawl fishery there is also a static gear fishery. Norwegian long-liners fish along the shelf edge and upper slope between 150-450 m for ling (*Molva molva*) and tusk (*Brosme brosme*). In 1995 the Norwegians carried out an exploratory fishery in deeper waters but did not persue this further (Gordon, 2001). There is also an Anglo-Spanish long-line fishery for hake *(Merluccius merluccius*), ling and tusk with a by-catch of other deep-water species, such as blue ling and sharks.

In the late 1990's Spanish vessels operated extensive deep-water gillnets targeting monkfish (*Lophius* spp.), hake and sharks (Hareide et al*., 2005). This practice was highly criticized for its indiscrimant by-catch and high discard rate and has now been partially banned in European waters. In the other regions of the area, monkfish is targeted on the deeper slopes of Rockall Bank.

In the early 1990's French trawlers discovered large aggregations of orange roughy on the Hebridean Seamount (Basson et al., 2002; ICES 2008b). This fishery developed rapidly, however, landings declined dramatically after a couple of years. It is likely the other seamounts were also targeted, but little information on this fishery was ever documented. Orange roughy is now mainly confined to areas south of the study area where it has been targeted by Irish trawlers (ICES 2008b).

There are also semi-pelagic fisheries for blue whiting, *Micromesistius poutassou*, and argentine, *Argentina silus*, being undertaken by Ireland, Norway, Denmark, and Holland (Gordon, 2001).

2.3.1. Landings

Landing data were obtained from various sources. The landings data as adopted by ICES working groups for assessment purposes were considered more reliable than the national officially reported STATLANT landings data collated by ICES and accessible using the FishStat Plus program (FishStat Plus, 2004). However, for

some species only STATLANT data were available and thus were used. Gear type was deduced from associated text when it was not specified.

The ICES Working Group on the Biology and Assessment of Deep-sea Fisheries Resources (WGDEEP) annual reports provide landings data by species, gear type and country for many of the species included in the model. These data, however, are not always at the level of VIa. Landings data for roundnose grenadier and orange roughy are given for VI, while landings for *Chimaera monstrosa* & *Hydrolagus* spp. are aggregated to VI & VII. In addition comprehensive landings data of some less commercially popular deep-water species are not provided by this group, for example *Helicolenus dactylopterus* and *Mora moro*. For deep-water sharks and rays the ICES Working Group on Elasmobranch Fishes (WGEF) provide estimates of landings in their recent annual reports while earlier data are often in the reports of the ICES Study Group on the Biology and Assessment of Deep-sea Fisheries Resources (SGDEEP). However these landings are for the whole of VI, not just VIa and thus are likely to be too high. Thus published landings data required some modification, which are detailed below. Since 1997 most of Division VIb has been in international waters and therefore many landings by non-European Union states can be attributed to Division VIb. Under EC Council Regulation ((EC) No 2027/95) there have also been effort restrictions on both trawling and longlining that limit deep-water fishing to only a few EU member states and EC quotas and other technical measures for deep-water species were introduced in 2002 (Gordon, 2008). Legislation was introduced in 2005 to sub-divide the ICES Divisons to allow landings to be reported separately for waters under national jurisdiction and the High Seas (international waters) (Eurostat, 2005). Some countries, eg. Norway, negotiate quotas for deep-water species in exchange for quotas of other species in their own waters.

Landings for *Coryphaenoides rupestris* (Group 7) in WGDEEP (ICES 2008b) were reported for Sub-area VI rather than Division VIa, with landings given for the following countries: Germany, Ireland, England and Wales, Scotland, France, Faroe Islands, Norway, and Spain. The principle fishery for this species in VIa is the French demersal trawl fishery. As described in the previous paragraph the landings by the Faroe Islands, Norway, and Spain are largely from outside VIa. In order to obtain a landings figure for VIa (rather than area VI), French landings of *C. rupestris* (together with *Hoplostethus atlanticus*, *Phycis blennoides, Alepocephalus bairdii, Epigonus telescopus, Helicolenus dactylopterus*, and *Mora moro*) from VIa were provided by P. Lorance (IFREMER, pers. comm.). Published landings data for Germany, Ireland, England and Wales and Scotland for area VI were added to French landings from VIa, while landing of the Faroe Islands, Norway, and Spain from VI were not included. In order to separate the landings of *C. rupestris* into juveniles and adults for the model, the length frequency of landed individuals in the French deep-water fishery was used (Allain et al., 2003). No individuals of juvenile size were landed and therefore all landings were assigned to adults (Group 7).

Large demersals (hake and tusk) are primarily caught on the shelf thus much of landed biomass of these species is obtained from outside the model area (<400m). Landings for this group were therefore reduced in order to more accurately represent the biomass removed from within the model system (landings from >400m depth). Hake is principally landed above 400 m depth therefore no hake landings were

included in the model. For tusk much of the catch also occurs in the 150-400m depth area (Anon, 1999). Catch rates by depth for tusk (Anon, 1999) were used to estimate the proportion of the landings caught in the model area. Of the total landings of tusk, it was estimated that 26.76% were caught at depths below 400m in area VIa. Landings for this group were, therefore adjusted to 27% of the figure reported in WGDEEP 2008.

Prior to 1999 there was a TAC for Anglerfish (*Lophius* spp.) in Sub Area VI but not for Sub-area IV. When the newly introduced TAC became restrictive it is alleged that landings from VI were mis-reported to IV (Gordon, 2001). However the new TAC for IV reflected the mis-reported landings and as a result the area misreporting practices have become institutionalised and the statistical rectangles immediately east of the 4ºW boundary (E6 squares) have accounted for a disproportionate part of the combined VIa/North Sea catches of anglerfish (ICES 2007). Since megrim (*Lepidorhombus whiffiagonis*) are also landed with anglerfish their landings are also alleged to be mis-reported. The landings for monkfish in VIa used in this report are those extracted from ICES reports by Gordon (2006) for the UK's Strategic Environmental Assessment 7 Fish report. As with tusk, this species is also principally caught on the shelf between 100-400m, with only a small proportion being taken on the slope below 400 m (Scottish data reported in ICES, 2008c). Vessels can land monkfish from the shelf and slope on the same trip and as a result it is difficult to separate landings by depth. Using expert judgment, it was decided to use one third of the landings from the French fleet and 5% of the landings from the Scottish fleet to represent the landings of monkfish made from within the modelled area. Landings from other countries were removed. These methods were also used to alter the landings of megrim (Group 19) as it is fished by the same fleets and occupies the similar depths as monkfish.

Semipelagic trawls targeting blue whiting *M. poutassou* (Group 12) can be carried out down to 800m. However, spawning aggregations along the shelf edge, which take place between approximately 200-400m, are targeted (Was et al., 2008). In order to calculate the proportion of *M. poutassou* caught deeper than 400m the mean catch rate by depth was used (ICES, 2005). On average, 15% of the catch was caught at depths greater than 400m. Therefore, all landings of *M. poutassou* were adjusted by this amount.

Landings for shallow sharks (Group 2), intermediate sharks (Group 3), deep sharks (Group 4), and *Hoplostethus atlanticus* (Group 10) were given for Sub-area VI. As the fleets reporting these landings fish mainly in Division VIa no further modification of these data were undertaken.

No correction was made for landings of *Chimaera monstrosa* & *Hydrolagus* spp. thus landings of these species are likely to be too high.

2.3.2. Discards

Here we refer to discards as the small commercial species and non-commercial species of all sizes that are caught but not landed. Discard data used in the model are given in Appendix 2.

<u>Mixed demersal trawl fishery</u>

Dupouy et al. (1998) estimated for 1996 that the total landings for the French trawl fishery West of British Isles and Ireland was close to 13,500 t with total discards estimated by on board observers as being close to 12,000 t. Allain et al. (2003) estimated the annual discards of the French trawl fishery at 17,500 t in 1996 and 1997 with total landings at around 19,000 t in 1997. The latter authors recorded the total discarding rate, by weight, for pooled data as 52.4% with a mean total discarding rate by haul of 48.5%±21.1 (range: 2.4%-82.4%). Dupouy et al. (1998) commented that for the French trawl fishery at least, one could consider that for a tonne of fish landed, there is a tonne of fish discarded, all species taken into account. Connolly and Kelly (1996) however, calculated substantially lower discarding rates of 7,530 t for 1995 compared to an estimated 17,000 t landed.

Rates of discarding and the species composition of discards vary with depth. Allain et al. (2003) found that the mean total discarding rate for grenadier rose significantly from 25.1% in the 800 m depth stratum to 55.4% in the 1000 m stratum and non-significantly to 60.9% in the 1200 m stratum. Observations of the number of species discarded in the deep-water trawl fishery ranges from 25-85 (Connolly and Kelly, 1996; Blasdale and Newton, 1998; Dupouy et al., 1998).

Within the French deep-water trawl fishery, Dupouy et al. (1998) and Allain et al. (2003) found three species to numerically dominate the annual discards: *Deania calceus, Coryphaenoides rupestris* and *Alepocephalus bairdii*. Blasdale and Newton (1998) found for French vessels landing in Scotland, *Coryphaenoides rupestris* and *Alepocephalus bairdii* represented over 50% of species discarded per trip by weight and over 40% by numbers. Connolly and Kelly (1996) however, found from experimental deep-water trawling that the deep-water sharks *Deania calceus* and *Centroscymnus crepidater*, and the roundnose grenadier *Coryphaenoides rupestris* dominated the annual discard figures in terms of % by weight. The latter authors acknowledged that their figures for *Alepocephalus bairdii* were likely to be an underestimate due to incomplete seasonal coverage of the discard data. These studies demonstrate that *C. rupestris, A. bairdii* and to an extent *D. calceus* are the most important species discarded in terms of both weight and numbers in the Rockall Trough demersal trawl fishery. Discarded *C. rupestris* are generally undersized ranging from pre anal length 4 to 16 cm.

The biomass and composition of discards have been calculated for 1995 using the ratio of discarded fish to grenadier landings calculated from Allain et al. (2003) multiplied by the 1995 grenadier landings for Division VIa (see section 2.3.1. for calculation of grenadier landings). The calculated biomass of *C. rupestris* discarded in 1995 has then been used to calculate the biomass of species discarded from the French vessels landing in Scotland in 1995 using the % by weight values of discards per trip given in Blasdale and Newton (1998).

Although we initially also calculated discards using the ratios of species discarded to *C. rupestris* landed given in Connolly and Kelly (1996), these data have not been used in the model. Both the composition and biomass of discards calculated from Connolly and Kelly (1996) differed significantly from that calculated from Allain et al. (2003) and Blasdale and Newton (1998). Specifically, the high biomasses of *Galeus melastomus* and *Etmopterus spinax* (shallow sharks) and *Centrophorus squamosus* (intermediate sharks) discarded according to this study led to problems in fitting the model: i.e. catch data (landings + discards) could not be supported by the biomass data. These species were not recorded discards in either Allain et al. (2003) or Blasdale and Newton (1998). In addition the discard data in Connolly and Kelly (1996) were derived from experimental trawls not fisheries observer data. For these reasons the Connolly and Kelly (1996) discard data were not considered further.

For each species identified by Allain et al. (2003) as a discard species the total biomass discarded in area VIa in 1995 has been calculated by averaging the values calculated for each species using both Allain et al. (2003) and Blasdale and Newton (1998). Where a species was not present in Blasdale and Newton (1998), only the values from Allain et al. (2003) were used (i.e. not the average).

The total weight of species discarded by the mixed demersal trawl fishery in Division VIa in 1995 calculated using data from both studies was 13,727 t compared to calculated landings of 16,380 t. This is less than the 1:1 ratio of Dupouy et al. (1998) and Allain et al. (2003), but significantly higher than the Connolly and Kelly (1996) ratio of discards to landings.

For each species the ratio of tonnes discarded per tonne of roundnose grenadier landed was calculated and these ratios used to calculate the discard biomass by species for the years 1974 to present using the grenadier landings, details of which are given in section 2.3.1.

Long-line fishery
Longline discards in the Rockall Tough are mainly composed of non-commercial shark species such as blackmouth dogfish, *Galeus melastomus*, greater lanternshark, *Etmopterus princeps, Deania calceus* and *Centroscymnus crepidater* (Clarke et al., 2005). In the shallower long-line settings the main species discarded are *D. calceus* and *G. melastomus*, whereas in the deepest settings *Centroscymnus crepidater* and *E. princeps* are most important. Clarke et al (2005) report few teleosts taken on the longline sets that were the subject of their study. The catch of longlines depends on how they are set. For example in the black scabbardfish fishery off mainland Portugal the bottom lines have flotation to keep the hooks above the seabed.

Connolly and Kelly (1996) provide data from experimental long-lines in 1995 on the mean weight in kg of species landed and discarded per long-line set. Tusk landings for 1995 in division VIa, as given in the WGDEEP 2008 report (ICES,, 2008b), have been used to calculate the number of longlines set in 1995 in VIa by dividing the weight of tusk caught in tonnes per set, by the total landings for VIa. We have then used the calculated total number of sets to calculate landings and discards of each species in VIa in 1995, based on the mean wt in kg of species landed and discarded per long-line set given in Connolly and Kelly (1996). For each species the ratio of

tonnes discarded per tonne of tusk landed has then been calculated for 1995. This ratio has been used to calculate discard weights for each species from 1974 to present based on tusk landings for VIa as given in the WGDEEP report (ICES,, 2008a) over this period.

<u>Pelagic trawl fishery</u>
One of the important fleets fishing blue whiting in Sub-area VIa are Dutch pelagic trawlers. The Report of the ICES Northern Pelagic and Blue Whiting Fisheries Working Group (WGNPBW) (ICES, 2007) gives discards from the Dutch blue whiting trawl fleet as approximately 3% by number. This working group also report discards by weight from the Spanish fleet as 13%. Although the Spanish fleet do not operate in Division VIa the model requires weight data rather than numbers data. Therefore, we have assumed that the true mass of discards lies somewhere between 3% and 13% and so have used an average value of 8% by weight of catch of blue whiting as discards. The weight of blue whiting discarded by the fishery from 1974 to 2007 has been calculated by assuming landings, reported in STATLANT for area VIa, represent 92% of total catch (8% discarded). We have assumed that discarding of other species from this fishery is negligible.

<u>Targetted Orange Roughy fishery</u>
To our knowledge there is no information of the levels of discarding from this fishery. WGDEEP (ICES,, 2008a) comment that for Sub-area VII there are no discards from the directed fishery and only 1 t discarded from the mixed fishery. Although not strictly comparable, levels of discarding from the New Zealand orange roughy fishery for the period 1999 to 2005, were in the order of 0.16 kg of discards per kg of orange roughy caught (O. Anderson, NIWA pers. comm.). An earlier analysis, for the period 1990 to 1998, showed a much lower figure, 0.06 kg (Anderson et al., 2001). The increase in the level of discarding over time has been attributed to increasing trawl duration in the orange roughy fishery in recent years as catch rates for the target species have declined. The orange roughy fishery in VIa was focused primarily on spawning aggregations. It is therefore likely that discards were minimal. For the purposes of this model we have assumed there are no discards from this fishery, although it is possible that discarding became more significant as the fishery progressed.

<u>Deep gill-net fishery</u>
There is very little information on discarding from this fishery, but discard rates are thought to be high as a result of the long soak times (Hareide et al., 2005). Rihan et al. (2005) suggest, based on catch composition from lost gear retrieval surveys, that vessels participating in these fisheries regularly land on average 60-80 t of fish per trip and that each of these vessels could conceivably be discarding something in the region of 30 t of marketable fish per trip.

Data from the Norwegian Coastguard suggest that between 54 and 71% (average 65%) of the monkfish catch per deployment (average length of gillnet per deployment 19km) is discarded (Hareide et al., 2005). Rihan et al. (2005) suggested monkfish discard rates of 50%. However, a recent UK Government report (Defra, 2007), based on observer trips in the westerly gillnet fishery for anglerfish, found discard rates of anglerfish across the four grounds examined (Rosemary Bank, Lousy Bank, North-west and west Rockall Bank) were generally very low (with the

exception of Rosemary Bank) accounting for less than 1% of the total catches of this species at each ground. These fish were discarded because they were considered too small to process.

Unpublished data from the Institute of Marine Research, Norway suggest discard rates of between 20-70% in the ling fishery on the Norwegian slope (Hareide et al., 2005). Discards of blue ling in the westerly gillnet fishery for anglerfish (Defra, 2007) were also generally high (12-60% of blue ling catch by numbers) as a result of the catch of this species being in poor condition on hauling. The principle species discarded by the westerly gillnet fishery for anglerfish is the common rabbit fish, *Chimaera monstrosa*, which accounted for between 6-50% of the catch, with all being discarded (Defra, 2007). Other species discarded by this fishery include the deep-water sharks *Centrophorus squamosus* and *Deania calceus*. Available observer data from the westerly gillnet fishery for anglerfish suggest that these species account for <1% of the catch by numbers (Defra, 2007), with 100% of *D. calceus* being discarded and up to 6% of *C. squamosus* being discarded.

With no firm estimates of landings it is impossible to estimate discard figures. For this reason we have not included discards from this fishery in the model. The EU funded DEEPCLEAN project, focused on retrieving lost gill nets in the NE Atlantic, may provide some data on which estimates of discards can be based in future.
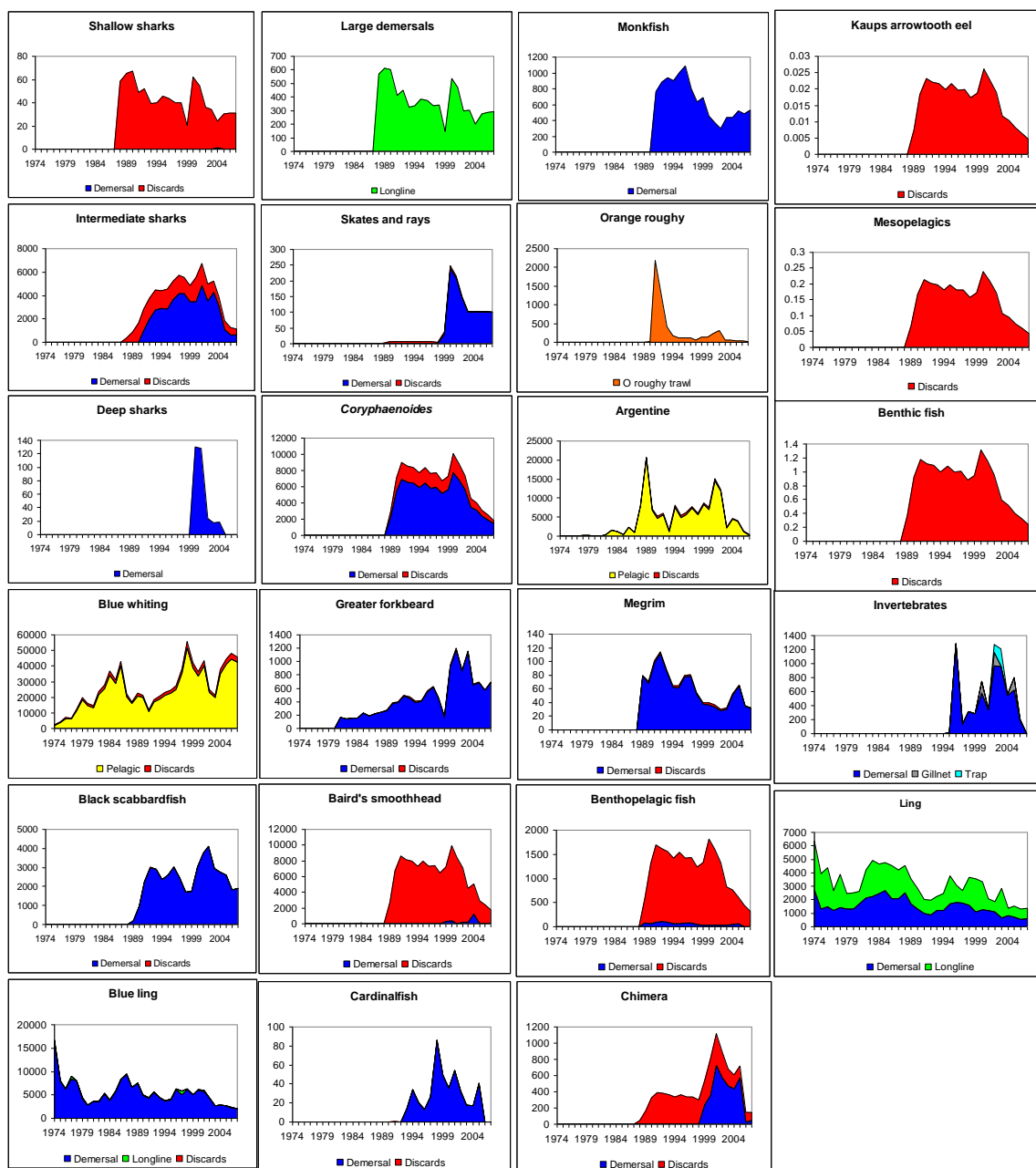
Figure 5: Landings and discards (in tonnes) of deep water species used to fit the model by gear from 1974-2007.

3. Model construction
Unbalanced model inputs and diet matrix are shown in Appendix 3

3.1. Cetaceans
23 species of cetacean have been reported in the Hebridean waters (Shrimpton and Parsons, 2000; Haggan and Pitcher, 2005). The main whale species are minke whales (*Balaenoptera acutorostrata*), killer whales (*Orcinus orca*) and long-finned pilot whales (*Globicephala melaena*). Dolphins and other Odontocetes are also present, the most common being the harbour porpoise (*Phocoena phocoena*), white-beaked dolphin (*Lagenorhynchus albirostris*), Risso's dolphin (*Grampus griseus*), common dolphin (*Delphinus delphis*) and bottlenose dolphin (*Tursiops truncates*) (Shrimpton and Parsons, 2000). However, of these species only the long-finned pilot whale, Atlantic white-sided dolphin (*Lagenorhynchus acutus*), common dolphin and sperm whales actually occur in any numbers in the deep waters off the West Coast of Scotland (Hammond et al., 2006).

There is no estimate of cetacean biomass for this area, but the biomass estimate for the Scottish shelf of 0.02 t.km^{-2}, based on the biomass from the Gulf of St. Lawrence obtained from Morissette et al. (2003) and updated with data from the Hebridean Whale and Dolphin Trust obtained from Shrimpton and Parsons (2000) was used as an initial input.

Natural mortality for a combination of cetaceans of the northwest Atlantic (Morissette et al., 2003) was estimated to range between 0.074 year^{-1} (Tanaka, 1990) and 0.075 year^{-1} (Ohsumi, 1979). Although there is no reported whaling in that area of the British Isles, there are reports of cetacean bycatch in the west coast of Scotland fisheries. As these reports have yet to be accurately quantified, the model assumes that there is no fishing mortality. With no fishing mortality we have assumed that the annual P/B was similar to the higher M value of 0.075 year^{-1}.

The daily consumption by species was calculated using:

$$R = 0.1W^{0.8} \quad (1)$$

where R is the daily ration for an individual in kg and W is the mean body weight in kg (Trites et al., 1997). Information on weight was taken from the Hebridean Whale and Dolphin Trust (Shrimpton and Parsons, 2000). The resulting daily ration was then multiplied by 365 to obtain the annual rate of consumption for whales. This value was then divided by the biomass used for the West coast model (Haggan and Pitcher, 2005), to give an annual Q/B of 6.775 year^{-1}. This value is similar to that found in other models (Mackinson, 2001; Morissette et al., 2003).

Diet:
The diet data for this group has been modified from Haggan and Pitcher (2005). Values for the following were taken straight from the diet matrix: small zooplankton, large zooplankton, prawns / shrimps, other benthic invertebrates, cephalopods. Values for the following were combined into new grouping for our model: Herring, sandeel, whiting, other demersals – combined as benthopelagics; salmon (Atlantic salmon (*Salmo salar*) and sea trout (*Salmo trutta trutta*)), haddock, saithe, cod – combined as large demersal; sprat, mackerel, other pelagics – combined as blue

whiting. The value given for sharks was split evenly between three shark groups in this model.

The total diet for cetaceans is as follows: blue whiting (64.5%), benthopelagic fish (14.1%), large zooplankton (12.9%), small zooplankton (6.9%), large demersal fish (0.783%), cephalopods (0.5%), prawns and shrimp (0.2%), other benthic invertebrates (0.05%), shallow sharks (0.0034%), intermediate sharks (0.0034%) and deep sharks (0.0033%).

3.2. Shallow sharks

The shallow shark group include two species: the velvet belly lantern shark, *Etmopterus spinax* and the blackmouth catshark, *Galeus melastomus.* Mauchline and Gordon (1983a) reported only catching *E. spinax* in the 500 and 750m bathymetric zones in the Rockall Trough. *G. melastomus* was only caught rarely and only in the shallowest bathymetric zones (500m). For both species ontogenetic differences in depth distributions have been reported(Mauchline and Gordon, 1983a; Olaso et al., 2005) with larger fish living at greater depths than smaller fish. We assume that these are the shallowest feeding sharks in the model. Their biomass of 122t (0.002 t.km^{-2}) in 1974 was obtained from the German trawl data. Basson et al. (2002) calculated the virgin stock biomass for all deep-water sharks in sub area VI, VII and Division Vb to be around 50-70,000t and for biomass to be at around 20-30,000t in 1998. The blackmouth catshark, *G. melastomus*, has been recorded as caught and discarded by trawlers on the west coast of Scotland since 1988 (Anon,, 2001a)

The natural mortality rate and Q/B ratio for these two species were calculated from Fishbase (Froese and Pauly, 2000) using an average temperature of 8°C. These values were weighted by the average biomass for these two species for all SAMS and German data between 1974 and 1990, to calculate an average M (0.26 year^{-1}) and Q/B (3.05 year^{-1}) for shallow sharks, as carnivores with aspect ratio of 1.63. As there was no fishery for shallow sharks the M was used as an estimate of P/B.

Diet:
Mauchline and Gordon (1983a) found a variety of prey, all predominantly benthopelagic, to be important in the diet of *E.spinax* in the Rockall Trough. Fish were the dominant food, with euphausiids, decapods and squid of secondary importance. The diet of smaller fish was dominated by *Meganyctiphanes norvegica* and *Maurolicus muelleri*, species that were completely absent from the diet of larger fish. The larger fish fed on *Pasiphaea tarda*, squid and species of fish other than the small *M. muelleri*. Ontogenetic differences in diet were reported by MacPherson (1980; 1981) from the western Mediterranean and Bergstad et al. (2003) from the Skagerrak. These authors also found the diet of smaller individuals to include euphausiids and decapods, with adults being much more general in their feeding, including fish, decapods, euphausiids and squid in their diet (MacPherson, 1980, 1981; Bergstad et al., 2003). The raw count data used in Mauchline and Gordon (1983a) has been converted to weight data using conversion factors developed by this project (Howell, unpublished data). These weight data have been used to calculate the diet of this species for use in the model.

Mauchline and Gordon (1983a) reported the diet of *G. melastomus* in the Rockall Trough, from limited observations of 13 individuals, to include epibenthos and micronekton. MacPherson (1980; 1981) and Carrassón et al. (1992) reported their diet from the western Mediterranean to consist predominantly of fish supplemented by squid and crustaceans. Many other studies have also found this species to feed on fish, decapod crustaceans, squid and to a lesser extent euphausiids (Thomas, 1965; Azouz and Capapé, 1971; Mattson, 1981; Olaso et al., 2005). Olaso et al. (2005) highlighted the importance of discarded blue whiting in the diet of this species. This was not identified by other authors, however, the availability of blue whiting (and thus their discards) in VIa is highly seasonal as it is principally spawning aggregations occuring in this region, unlike in the study of Olaso et al. (2005). Therefore, although the contribution of discarded blue whiting to the diet of this species may have been overlooked due to its seasonal occurance, it is unlikey to form as important as a compenent to the diet of this species in this region as in that of the Cantabrian Sea, the region of Olaso's study. Ontogenetic differences in diet have also been recorded with immature fish capturing mainly decapods and euphausiids, while the adults preferred the mesopelagic fishes, *Pasiphaea multidenta* and squid (Carrassón et al., 1992; Olaso et al., 2005). The diet of this species has been calculated based on the % by weight data presented in Carrassón et al. (1992). Data have been summed across size classes and depth bands. However, in order to represent the likely contribution of blue whiting to the diet of this species in the Rockall Trough a minimal contribution of 1% has been added in line with the calculated contribution blue whiting make to the diet of *E. spinax*.

These two diets were prorated by their biomass to give a total diet for shallow sharks of: prawns and shrimp (20%), blue whiting (20%), mesopelagic fish (16.3%), greater forkbeard (16.7%), cephalopods (14%), benthopelagic fish (10%), large zooplankton (1.6%), other benthic invertebrates (1%), gelatinous zooplankton (0.4%). In addition, 0.0001% was added as cannibalism, and obtained from small Coryphaenoides, monkfish, blue ling, cardinalfish, Kaup's arrowtooth eel and megrim.

3.3. Intermediate sharks
The intermediate sharks group include the Portuguese dogfish, *Centroscymnus coelolepis;* birdbeak dogfish, *Deania calceus;* the leafscale gulper shark, *Centrophorus squamosus;* the longnose velvet dogfish, *Centroscymnus crepidater;* Iceland catshark, *Apristurus laurussonii*, and other *Apristurus* species. The biomass of this group in 1974 was estimated from the German surveys at 73,327t (0.97 t.km^{-2}).Basson et al. (2002) calculated the virgin stock biomass for all deep-water sharks in sub area VI, VII and Division Vb to be around 50-70,000t and for biomass to be at around 20-30,000t in 1998. It is therefore likely our estimates of virgin stock biomass are too high. The leafscale gulper shark, *C. squamosus* and Portuguese dogfish *C. coelolepis*, are commercial species recorded as caught by both bottom trawl and longline since 1989 and often collectively landed as siki (Anon,, 2001c). The longnose velvet dogfish, *C. crepidater* and birdbeak dogfish, *D. calceus*, have been recorded as discards since 1988 (Anon,, 2001a).

The P/B (M=0.14 year^{-1}) and Q/B (1.80 year^{-1}) ratios used in the model were calculated in Fishbase (Froese and Pauly, 2000) for each species using an average temperature of 7.6^{o}C and aspect ratio of 1.63 and then prorated by their average biomass for 1974-1990. As there was no fishing for intermediate sharks in 1974, the

M was used as an estimate of P/B. Natural mortality for *C. squamosus* and *D. calceus* is given by Clarke, (2003) as 0.09 year^{-1} and 0.16 year^{-1} respectively. The average of these is similar to the natural mortality calculated from fishbase and prorated.

Diet:
For the Rockall Trough region the diets of all sharks in this group were reported by Mauchline and Gordon (1983a). In addition new research on the diet of *C. crepidater* and *D. calceus* has been undertaken as part of the wider DEEPFISH project (Howell, unpublished data).

Based on stomach dissection of 132 individuals, *C. coelolepis* was found to feed predominantly on fish and squid (Mauchline and Gordon, 1983a). Carrassón et al. (1992) studied the diet of this species from the western Mediterranean and found the diet to be almost exclusively based on cephalopods. Based on stomach dissection of 113 individuals, *C.crepidater* was reported to feed predominantly on squid and micronektonic fish including myctophids (Mauchline and Gordon, 1983a). The DEEPFISH project has undertaken dissection of 172 individuals from the Rockall Trough and also found the diet of this species to be dominated by squid and micronektonic fish (Howell, unpublished data). This new dissection data has been used to calculate the diet of this species for use in the Ecopath model. Regressed weights, based on beak dimensions, have been used to calculate squid weights. This will undoubtedly have led to the importance of cephalopods in the diet of this species being overemphasised.

Based on stomach dissection of 139 individuals, *D. calceus* were found to be principally fish eaters, supplementing their diet with crustaceans and squid (Mauchline and Gordon, 1983a). This project has undertaken dissection of 93 individuals from the Rockall Trough and found the diet of this species to be dominated by squid and fish (Howell, unpublished data). Both the present study and the previous study of Mauchline and Gordon (1983a) found both mesopelagic and demersal fish species to contribute to the diet. The new unpublished diet data have been used to calculate the diet of this species for use in the model. Regressed weights, based on beak dimensions, have been used to calculate ingested squid weights. This method will undoubtedly have led to the importance of cephalopods in the diet of this species being overemphasised.

Mauchline and Gordon (1983a) found *Apristurus* spp. consumed micronekton in the vicinity of the seabed.

The diets of these species were prorated by their biomass to give a total diet for this group of: 0.8% large demersals, 3.5% large Coryphaenoides, 5.1% blue whiting, 3.5% Baird's smoothhead, 4.3% mesopelagic fish, 9.6% benthopelagic fish, Chimaera 3.5%, 69% cephalopods, 0.06% prawns and shrimp and 0.01% large zooplankton. In addition, it is assumed that intermediate sharks cannibalise (0.0001%) feed on juvenile cetaceans (0.001%), skates and rays, small *Coryphaenoides*, monkfish, orange roughy, black scabbard fish, greater forkbeard, cardinalfish, Kaups arrowtooth eel, megrim and benthic fish (0.000001% respectively).

3.4. Deep sharks

Deep water sharks include the black dogfish, *Centroscyllium fabricii* and the great lanternshark, *Etmopterus princeps.* Their biomass was estimated from German trawl data at 1424t (0.019 t.km^{-2}) in 1974. Basson et al. (2002) calculated the virgin stock biomass for all deep-water sharks in sub area VI, VII and Division Vb to be around 50-70,000t and for biomass to be at around 20-30,000t in 1998, thus this figure falls well within that range. Deep water sharks have been recorded as caught by the demersal trawlers from 2000 onwards.

The natural mortality and Q/B ratios for both species were obtained from Fishbase (Froese and Pauly, 2000) using an average temperature of 4.5°C and aspect ratio of 1.63, and prorated by their average biomass between 1974-1990 to give a total M (0.17 year^{-1}) and Q/B (1.84 year^{-1}) ratios for the model.

Diet:
In the Rockall Trough *C. fabricii* are principally fish eaters while *E. princeps* exploit micronekton close to the seabed (Mauchline and Gordon, 1983a). The diet of *E. princeps* was reported by Mauchline and Gordon (1983a) to include mainly bony fish, with cephalopods and decapod crustaceans also being important in terms of % by number. This project has undertaken stomach dissection of 43 individuals and found the diet of this species to be dominated by decapod crustaceans and cephalopods, with fish as a minor component (Howell, unpublished data). The use of regressed weights based on beak dimensions to calculate squid weights will undoubtedly have led to the importance of cephalopods in the diet of this species being overemphasised. The diet of *C. fabricii* has been based on the published diet of this species from the waters around Iceland (Jakobsdottir, 2001). *C. fabricii* is distributed over a shallower depth range in Icelandic waters than in the waters of the Rockall Trough and this could have implications for the use of their diet from this region. However, Jakobsdottir's (2001) findings broadly concurred with the earlier findings of Mauchline and Gordon (1983a). Her data were reported as frequency of occurrence but were converted to proportion by weight using conversion factors developed by this project (Howell, unpublished data).

These two diets were prorated by their biomass to give a total diet for deep sharks of: cephalopods (14.4%), benthopelagic fish (8.9%), blue whiting (43.9%), orange roughy (3.2%), mesopelagic fish (1.8%), argentine (1.3%), prawns and shrimp (26.6%), large zooplankton (0.001%). In addition, it was assumed that deep sharks cannibalise, and consume skates and rays, small Coryphaenoides, Baird's smoothhead, Cardinal fish, Kaup's arrowtooth eels and Chimaera (0.00001%).

3.5. Large demersals

The large demersal group include the tusk, *Brosme brosme*, and the European hake, *Merluccius merluccius*. These species are poorly represented in the bottom trawl catches, and are mainly caught by longlines. The biomass estimated from the German surveys was 2,050 t (0.027 t.km^{-2}). The natural mortality rates for these species and Q/B ratios were estimated using an average temperature of 8°C and aspect ratio of 1.32, prorated by biomass to calculate the M (0.16 year^{-1}) and Q/B (2.01 year^{-1}) ratios.The hake fisheries of the outer shelf and slopes of the Rockall Trough were never as important as those to the west of Ireland, but by the 1980s there had been an increase in hake catches as a result of increased fishing effort

mainly by the Spanish fleet (Gordon, 1986). Tusk is caught by trawlers and longliners off the west coast of Scotland (Anon,, 2001c).

Diet:
Bergstad (1991b) estimated the diets for these two species in the Norwegian Deep. The diet of tusk include large quantities of blue whiting, *M. poutassou*, hagfish, *Myxine glutinosa*, with squat lobsters, *Munida* spp., also being important (Bergstad, 1991b). The blue whiting also dominated in the hake diet, with Norway pout, *Trisopterus esmarki*, and rockling, *Ciliata mustela*, also being important. Sánchez and Olaso (2004) examined the stomach content of 5000 hake from the Catabrian Sea and again found blue whiting to dominate the diet of large hake (>20cm). Horse mackerel, *Trachurus trachurus*, and small demersal fish were an important part of the diet of small hake (<20cm). Guichet (1995) examined the content of 8293 hake stomachs sampled quarterly. The diet was mainly composed of fish (96% by weight), with a predominance of horse mackerel (23%), anchovy, *Engraulis encrasicolus* (19%) and blue whiting (14%), and crustaceans and cephalopods (4%). There was a strong seasonal component to the diet with blue whiting dominating the diet in spring and summer, horse mackerel dominating in autumn and winter, and anchovy dominating in winter and spring. The diet of hake was calculated through combining published data from Sánchez and Olaso (2004) and Guichet (1995), while the diet of tusk was calculated from Bergstad (1991b).

These two diets were prorated by their biomass to give a total diet for large demersals of: blue whiting (74.1%), benthic fish (8%), benthopelagic fish (7.1%), prawns and shrimp (3.1%), other benthic invertebrates (3%), large demersals (2.1%), large zooplankton (1.3%), cephalopods (0.69%), mesopelagic fish (0.5%), argentine (0.03%), megrim (0.024%), Polychaeta (0.013%). In addition, it is assumed that large demersals will also sometimes feed on juvenile shallow sharks (0.0001%).

3.6. Skates and rays
Skates and rays in this system include blue skate, *Dipturus batis*, longnose skate, *D. oxyrinchus*; Norwegian skate*, D. nidarosiensis;* thornback ray, *Raja clavata;* cuckoo ray, *Leucoraja naevus;* sandy ray *Leucoraja circularis,* round ray, *Rajella fyllae;* deepwater ray, *Rajella bathyphila* blue ray, *Neoraja caerulea;* pale ray, *Bathyraja pallida;* Richardson's ray, *B. richardsonii;* and Bigelow's ray, *Rajella bigelowi* (Gordon and Duncan, 1989). However, no estimates of biomass were available for the last four species. The biomass estimated from the German survey in 1974 for this group was very low a 55t (0.0007 t.km^{-2}), while the 1975 biomass was two orders of magnitude higher (0.017 t.km^{-2}). Skates and rays are likely to have been discarded since the development of the trawl fishery in1988, and have been recorded as landed by the demersal fleet since 1999.

The natural mortality and Q/B ratios for these species were obtained from Fishbase (Froese and Pauly, 2000) assuming an aspect ratio of 1.63 and prorated by their average biomass between 1974 and 1990 to give annual P/B (0.14 year^{-1}) and Q/B (1.62 year^{-1}) ratios for this group.

Diet:
The diet of 4 species of rays and skates were given by Gordon and Duncan (1989), namely: *R. fyllae, R. bigelowi, R. bathyphila* and *R. nidarosiensis*. These authors

found the rays of the Rockall Trough to show a preference for benthic species, specifically crustaceans, polychaetes, and fish. Diet for each of the four species was calculated using the numbers of prey items detailed in Gordon and Duncan (1989). Numbers were converted to weights using average prey weights calculated from stomach dissection of 38 *Chimera monstrosa* undertaken as part of this project. Where no average prey weight data were available for *Chimera monstrosa* general conversion factors developed by this project were used (Howell, unpublished data).

The total diet of rays is calculated as the diet of *R. fyllae, R. bathyphila* and *R. nidarosiensis* prorated by their biomass. No biomass data were available for *R. bigelowi*, therefore this species could not be included in the calculation. The total diet for skates and rays is: Chimaera (86.7%), polychaeta (4.8%), other benthic invertebrates (4.3%), large zooplankton (4.2%), small zooplankton (0.034%). It was also assumed that cannibalism would play a minor part in the diet of this group (0.0001%).

3.7. Adult roundnose grenadier (>21.5cm)

Roundnose grenadier, *Coryphaenoides rupestris,* Gunnerus 1765, is, depending on trawl type, a dominant species by both number and weight over a wide depth range in the Rockall Trough (Gordon and Bergstad 1992). This species has a complex size distribution by depth and sex: large fish are found in the shallow part of the depth distribution of the species while a bimodal size distribution is found in the deeper waters, with both juveniles and adult fish observed at about 1000-1300m (Lorance et al., 2008).

The biology of the species is well described and its reproduction was the subject of several studies as well as its distribution and some aspects of its ecology (Gordon, 1979; Haedrich and Merrett, 1988; Bergstad, 1990; Atkinson, 1995; Kelly et al., 1996, 1997; Allain, 1999, 2001; Lorance et al., 2008). However the stocks and population identities are as yet unknown although some studies have detected genetic differentiation (protein electrophoresis) in at least parts of the species' range and indicated the presence of distinct populations within the species (cf. Logvinenko et al., 1983; Duschenko & Savvatimskiy 1988). The areas used as stock units for stock assessment purposes are based on hydrological hypothesis (Anon, 2000).

Since the onset of targeted fishing for this species in the Rockall Trough in1989, there has been a three fold increase in effort by the French fleet, mainly in ICES Division VI in 1990 which produced a 30% increase in catches (Kelly et al., 1996). French scientists carried out a pseudo cohort analysis in 1992 and predicted a MSY of 7000-9000 tonnes for the stock in the Rockall Trough (Kelly et al., 1996). There is evidence that the French fishing fleet has shifted effort from ICES division VI and VII to division V, prompted by a fall in catches.

Kelly (1997) carried out studies of age, growth, maturity and fecundity of roundnose grenadier from the Rockall Trough and Porcupine Seabight. Age estimations, using sectioned sagittal otoliths, were conducted and estimates of the parameters of the von Bertalanffy growth model were obtained with respect to pre-anus length and total weight. Size at maturity – from probit modelling – and age at maturity estimates were also obtained (Kelly, 1997). The annual periodicity of the annuli read on otoliths was validated for juveniles up to the age of 8 (Gordon and Swan, 1996). Although this

validation is only partial (Beamish and McFarlane, 1983) the growth rate of the juveniles in the range of the validated ages is consistent with that inferred from otolith reading of larger fish.

Females mature at 9-11 years (Kelly et al., 1996) and produce a small number of large eggs (Grigorev, 1972; Kelly et al., 1996.). The spawning is prolonged throughout the year (Bergstad, 1990; Gordon and Hunter, 1994b; Magnusson and Magnusson, 1995; Kelly et al., 1996; Allain, 2001), with possible peaks in spring and autumn (Connolly and Kelly, 1994; Kelly et al., 1996). The spawning season in the Rockall Trough extends from July to Nov and probably later. Maturation of oocytes may take more than 1 year and individual females may spawn several batches of eggs over the spawning period. Kelly et al. (1996) found that this species was a determinant spawner, though Allain (2001) considers fecundity to be indeterminate and that the number of batches produced each year is unknown. Alekseyev et al. (1992) state that 44% of the total egg production is made by females of length greater than the mode. As a result of the commercial fishery prosecuted in the Rockall Trough since 1989 the modal length of this species at 1000m (where fishing is most intense) has dropped from 80cm to 65cm (Kelly et al., 1997). Thus total egg production of this species in Rockall Trough may have decreased over the period.

In this model roundnose grenadier were divided into two categories, called adults and juveniles at 21.5 cm TL due to changes in their feeding. However age at first maturity is closer to 50cm (Gordon, 1979). Their depth distribution was reported in Gordon and Hunter (1994a) as 180-2200m but with an maximum abundance between 500-1500m, with their distribution in the SAMS surveys was between 458m and 1870m.

The biomass for adult *Coryphaenoides* in 1974 estimated from German trawl survey data for VIa was 19,839t (0.26 t.km^{-2}). Russian scientists have estimated total biomass of this species in the North Atlantic to be around 400,000-500,000 tonnes (Troyanovsky and Lisovsky, 1994). While Basson et al. (2002) estimated virgin stock biomass for sub-area VI and Division VIIb, c as 167,000t, which if pro-rated by the area between 400-2000m in each region provides an estimate of 48,758 tonnes in area VIa or 0.645 t.km^{-2}. This figure was used as the biomass for adults in preference to the figure calculated from German trawl data. By the end of 1998 the biomass of this species in sub-areas VI, VII and Division Vb was thought to be close to 20% of the virgin stock biomass (Basson et al., 2002). Their natural mortality is given by Clarke et al. (2003) as 0.08 for females and 0.09 from males. Using the relationship developed by Annala and Sullivan (1996), Basson et al. (2002) estimated natural mortality at 0.1 year^{-1}. Fishbase (Froese and Pauly, 2000) calculated a natural mortality of 0.15 year^{-1} using a temperature of 7.3°C - average between 495 and 1438m taken from Ellett and Martin (1973). Fishbase also estimated a Q/B ratio of 1.2 year^{-1} using an aspect ratio of 1.32 (Froese and Pauly, 2000). The w_{mat}/w_{inf} ratio was calculated from the SAMS survey data as 0.03 and estimates of K between 0.13 (male) and 0.1 (female) were obtained, with 0.1 being similar to that given in Fishbase and therefore used here. The age at 21.5cm TL was estimated at 2yrs (or 24 months) (Kelly et al., 1997).

Diet:
Mauchline and Gordon (1984b) examined the diet of adult and juvenile individuals from the Rockall Trough. They concluded this species feeds predominantly on copepods, decapods, and fish supplemented by mysids euphausiids, amphipods and cephalopods. The smallest fish feed predominantly on calanoid and cyclopoid copepods supplemented by a variety of other small organisms. Mysids, euphausiids, amphipods and decapods all become increasingly prominent in the diets of larger fish. Bergstad et al. (2003) also examined the diet of adult and juvenile specimens from the Skagerrak and concluded that pelagic and hyperbenthic crustaceans were the dominant prey of all size classes of this species. Of the identifiable gut contents, 96% was crustacean remains ranging from copepods to brachyurans. Fish remains occurred in very few stomachs while polychaetes, *Clione limacine*, nudibranchs and chaetognaths occurred in small amounts. Gartner et al. (1997) placed this species in a guild of "Macronekton Foragers" among other macronekton specialists primarily inhabiting upper and middle slope waters. It is possible this species feeds both demersally and pelagically. Specific species important to the diet included the pelagic euphausiid *Meganyctiphanes norvegica*, the shrimp *Pasiphaea multidentata* and *Pandalus borealis*, the amphipod *Parathemisto abyssorum*, the copepod *Pareuchaeta norvegica*, and decapod *Sabinea sarsi*.

The diet of adult *C. rupestris* is calculated using the prey numbers data from Mauchline and Gordon (1984b) converted to weight data using general conversion factors developed by this project (Howell, unpublished data). The total diet for adult roundnose grenadier (>21.5cm) is: prawns and shrimp (31%), mesopelagic fish (30.1%), *Synaphobranchus kaupi* (17.3%), cephalopods (11.8%), other benthic invertebrates (4.6%), polychaeta (1.9%), large zooplankton (1.4%), gelatinous zooplankton (1.2%), small zooplankton (0.74%).

3.8. Juvenile roundnose grenadier (<21.5cm)
Juvenile roundnose grenadier, *C. rupestris*, biomass was estimated by the SAMS data at 0.0005 t.km^{-2}, and a P/B ratio of 3.0 year^{-1} was assumed with an age at 21.5cm TL of 2 years (Kelly et al., 1997). They are not caught by any fishing gear.

Diet:
The main dietary components of juvenile *C. rupestris* in the Rockall Trough are calanoid and cyclopoid copepods, supplemented by a variety of other small organisms. In the Skagerrak their diet includes euphausiids, Calanidae, Amphipoda, Hyperiidae and shrimps (Bergstad et al., 2003). Pelagic juveniles feed mainly on copepods (Bergstad and Gordon, 1994), and demersal juveniles on small hyperbenthic crustaceans (Mauchline et al., 1994).

The diet of juvenile *C. rupestris* is calculated using the prey numbers data from (Mauchline and Gordon, 1984b) converted to weight data using general conversion factors developed by this project (Howell, unpublished data). The total diet for juvenile roundnose grenadier (<21.5cm) is: prawns and shrimp (42.3%), mesopelagic fish (23.9%), polychaeta (17.6%), small zooplankton (10.2%), large zooplankton (4.4%), other benthic invertebrates (1.7%).

3.9. Monkfish

In 1994, 11,850 tonnes of anglerfish, with a value of £29.1 million, were landed at Scottish ports by UK vessels and they were the third most important species of finfish landed by the Scottish fleet in terms of their contribution to the first sale value of the total catch (Afonso-Dias and Hislop, 1996). In the past, anglerfish were taken mainly as a by catch, however there is now a directed fishery for anglerfish on the grounds to the north and west of Scotland (Afonso-Dias and Hislop, 1996).

Monkfish or anglerfish, *Lophius piscatorius,* are mainly benthic and their bathymetric distribution extends from shoreline to 1,800m (Wheeler, 1969; Afonso-Dias and Hislop, 1996). The depth range of monkfish caught in the SAMS trawl surveys is 245-1,032m. This species is a determinant spawner but it is unlikely that females spawn more frequently than once a year. Anglerfish are very fecund; the ripe ovary contains well over one million eggs (Fulton, 1891; Armstrong et al., 1992). Afonso-Dias and Hislop (1996) suggests that in ICES area VIa *L. piscatorius* spawns mainly in winter and spring, with juveniles observed in surface waters in May - July. Female anglerfish do not reach sexual maturity until they have attained a considerable size (>70cm), with females attaining larger size than males (Afonso-Dias and Hislop, 1996). The findings that only medium/large females are capable of spawning and that all large anglerfish are female have important implications for fisheries management, in that they indicate this species may be very vulnerable to overfishing.There are indications that commercial catches of large anglerfish on traditional trawling grounds in depths of 200m off the North and West coast of Scotland are declining (Afonso-Dias and Hislop, 1996). More information is needed on the location of spawning grounds and the bathymetric distribution of the population (Afonso-Dias and Hislop, 1996).

The biomass of monkfish calculated from the German trawl survey data (in the model area) was 3106t (0.04 t.km^{-2}) and the natural mortality and Q/B ratio for this species was calculated by Fishbase at 0.11 year^{-1} and 1.3 year^{-1} (Froese and Pauly, 2000) using a temperature of 7.9°C – the average temperature between 200m and 1,190 m (Ellett and Martin, 1973). These values are less than the 0.38 year^{-1} and 1.9 year^{-1} respectively calculated by Sánchez and Olaso (2004) but their estimates also includes *L. budegassa*.

Diet:
Laurenson (2005) examined the diet of monkfish from the Shetland area and found that although monkfish can consume a wide range of prey types, their diet tends to be dominated by a small number of species, mainly Norway pout and sandeel. The geographical and seasonal differences in diet composition indicated that monkfish diet probably reflects the species that are most available in a particular place at a particular time. Diet data used in an Ecopath model of the Cantabrian Sea shelf ecosystem (Sánchez and Olaso, 2004) suggest blue whiting, horse mackerel and other demersal species are important components of the diet of *L. piscatorius* and *L. budegassa* in this region.

The diet of monkfish is modified from Sánchez and Olaso (2004). Their large hake, small hake and large demersal fish groups are combined as "large demersals" in this model, horse mackerel are combined with blue whiting under "blue whiting", while the benthic cephalopods and squid groups are combined into "cephalopods". The

total diet for monkfish is: blue whiting (73%), benthopelagic fish (16%), benthic fish (2.6%), Chimaera (2.5%), cephalopods (4%), large demersals (1%), prawns and shrimp (0.7%), other benthic invertebrates (0.2%). In addition, it is assumed that monkfish will also take juveniles speciemens of shallow sharks, intermediate sharks, skates and rays, coryphaenoides, blue ling, ling, greater forkbeard, Baird's smoothhead, cardinalfish, Kaups arrowtooth eel and megrim (0.0001%).

3.10. Orange roughy

In the eastern Atlantic orange roughy, *Hoplostethus atlanticus*, is widely distributed from Europe to South Africa (Woods and Sonoda, 1973). They are unevenly distributed on the slopes and banks to the west of the British Isles (Bridger, 1978; Ehrich, 1983). Bridger (1978) found at 58°N on the continental slope and on the slopes of Rosemary Bank, that it was most common between depths of 914-1,042 m, which was the maximum depth trawled on his cruises. Ehrich (1983) also found it was common on the slopes of Rosemary Bank and Porcupine Bank.

The orange roughy fishery in sub-area VI began in 1989 with landings peaking at 3,500 t in 1991, and 5,300 t removed from the stock by the end of 1993 (ICES, 2008b). Initially it was a French target fishery, centred on spawning aggregations around the Hebrides Terrace Seamount. However in 2001 Irish vessels began fishing there for two years but have now effectively abandoned it, fishing further south in sub-area VII. This stock is now severely depleted (ICES, 2006). Reported landings since 2003 are decreasing and are consistently below the TAC. Reported landings of orange roughy in VI in 2007 were10 tons compared to a TAC of 51t. A phased zero TAC for orange roughy has been put in place for area VI and a number of orange roughy protection zones have been introduced in area VII, from which EU vessels have no permission to land or retain any catches of this species.

The virgin stock biomass of orange roughy is estimated to be around 6,000 tonnes (0.025 t.km^{-2}) in area VI (95% confidence limits: 5,400-6,300 tonnes) (Basson et al., 2002), while the biomass estimated from the German trawl surveys for 1974 was 210,033 tonnes (2.78 t.km^{-2}). As orange roughy is an aggregating species, and the estimated virgin stock biomass is much lower than that calculated from German trawl survey, we allowed Ecopath to estimate the biomass. Population biomass in 1998 was estimated to be 27% of virgin biomass (Basson et al., 2002).

The length weight relationship of this species is given in Gordon and Duncan (1987a) as W(g) = 0.0415*SL(cm)$^{2.9541}$ and the M calculated from Fishbase (Froese and Pauly, 2000) using a temperature of 6.9°C, the average between 992 and 1,190m taken from Ellett and Martin (1973) was 0.05 year^{-1}, while Fishbase calculates the Q/B ratio at 2.9 year^{-1} using an aspect ratio of 1.9 year^{-1} (Froese and Pauly, 2000). This correlates well with the P/B of 0.048 year^{-1} estimated for this species by Morato and Pitcher (2002) and 0.042 year^{-1} from Bulman et al. (2002) for the Tasmanian seamounts.

Diet
The diet of orange roughy was described by Gordon and Duncan (1987a) from specimens sampled in the Rockall Trough and Porcupine Seabight. Decapods and mysids were the principle dietary components by numbers and fish, cephalopods and amphipods were of lesser importance (Gordon and Duncan, 1987a). Mauchline

and Gordon (1984c) found that some 80-90% by weight of the diet of orange roughy in Rockall Trough consisted of mysids and decapod crustaceans, especially *Ponthophilus norvegicus*. The diet of this species has also been described by Bulman and Koslow (1992) from examination of 7500 samples from south-eastern Australian waters. They found juveniles fed mainly on bentho- and meso-pelagic crustaceans, while mature fish consumed predominantly fish and squid.

The diet of this species is calculated through combining data from both Mauchline and Gordon (1984c) and Bulman and Koslow (1992). Prey numbers data from Mauchline and Gordon (1984c) has been converted to weight data using general conversion factors developed by this project (Howell, unpublished data). Data from Bulman and Koslow (1992) has been modified in the following manor: deep migratory small fish and non-migratory small fish have been combined into "mesopelagic fish", epibenthos and megabenthos have been combined into "other benthic invertebrates". Average values for each prey group from the two studies have then been calculated for use in the model. The total diet for orange roughy is: prawns and shrimp (38.9%), mesopelagic fish (33.4%), benthopelagic fish (11.7%), other benthic invertebrates (8.5%), cephalopods (6.6%), gelatinous zooplankton (0.5%), large zooplankton (0.4%), polychaeta (0.06%), small zooplankton (0.0011%).

3.11. Argentine

Argentine, *Argentina silus*, are a relatively slow growing bathydemersal species (Froese and Pauly, 2000). The depth range from Gordon and Hunter (1994a) was 155-700m but most shoals seem to occur between 200-500m and in the SAMS trawls of Rockall Trough they occur in 353-720m. Clarke et al. (2003) and Ronan et al. (1993) carried out studies of age and growth from the Rockall Trough and Porcupine Seabight. Age estimations, using whole otoliths, were conducted and estimates of the parameters of the von Bertalanffy growth model were derived. *A silus* produce a small numbers of large eggs (Ronan et al., 1993; Clarke et al., 2003) and spawning proceeds throughout the year (Magnusson, 1988; Ronan et al., 1993) though there may be seasonal peaks in spawning intensity (Anon, 1999). Argentine are assumed to have been discarded by the bottom trawl fleet off the west coast of Scotland since its development in 1988 (Anon,, 2001a), it is recorded as caught by pelagic trawlers since 1978.

The biomass of argentine estimated from German trawl surveys (253 t) was very low as argentine is not efficiently caught by demersal gear. The biomass of this species was estimated by Ecopath. Fishbase calculates a natural mortality of 0.21 year^{-1} (Froese and Pauly, 2000) using a temp of 9.77°C for the average depth between 200-500m (Ellett and Martin, 1973) and an annual Q/B of 10.17 year^{-1} (Ellett and Martin, 1973). However, in the Bay of Biscay, Ainsworth et al. (2001) estimated a higher P/B of 0.282 year^{-1} and a Q/B of 5.584 year^{-1}, nearly half that calculated by Fishbase (Froese and Pauly, 2000). Clarke et al. (2003) estimated life history parameters for Rockall Trough and the Porcupine Seabight from samples taken in 1993-1995 and found M of 0.13 year^{-1} for females.

Diet:
Bergstad et al. (2003) examined 397 stomachs of this species of which 207 were empty. 94% by weight of stomach contents in the two most sampled size classes could not be identified and the stomachs of small individuals contained a higher

proportion of identifiable remains primarily crustaceans. Pelagic and benthopelagic crustaceans dominated the identifiable stomach contents and included euphausiids, hyperid amphipods, mysids, and a large copepod *Pareuchaeta norvegica*. However the small % by weight suggests they may not be of great significance in the diet of this species. Fish remains were also present. Bergstad et al. (2003) concluded that due to high proportion of unidentifiable remains in the stomach content of this species we cannot be confident about the importance of crustaceans in the diet. The lack of dentition, the big eyes, the fusiform body and forked tail and the virtual absence of benthic prey in the stomach led Bergstad et al. (2003) to conclude that this species is a visual pelagic predator belonging to a guild of pelagic specialists comprising species feeding on gelatinous plankton such as hydromedusae, ctenophores or salps. The morphology of this species is similar to *Alepocephalus bairdii,* known to feed on gelatinous zooplankton.

Other studies have also recorded large proportions of unidentifiable stomach content for this species (Borodulina, 1964; Keysler, 1968; Mauchline and Gordon, 1983b). In some areas small mesopelagic fishes such as *Cyclothone* spp. and *Chauliodus* spp. may be important (Keysler, 1968; Westhaus, 1982) but to larger individuals. Chaetognaths and gelatinous prey have been reported by many investigators, and Mauchline and Gordon (1983b) found that 47.6% of the stomachs with identifiable remains contained salps or ctenophores. The diet of this species has been calculated by averaging the proportion of each major prey group by weight using data from both Mauchline and Gordon (1983b) and Bergstad et al. (2003). The prey numbers data from Mauchline and Gordon (1983b) has been converted to weight data using conversion factors developed by this project. The total diet for argentine is: gelatinous zooplankton (38.9%), mesopelagic fish (26.7%), large zooplankton (25.9%), other benthic invertebrates (7.1%), polychaeta (1%), prawns and shrimp (0.38%), small zooplankton (0.032%).

3.12. Blue whiting

Blue whiting, *Micromesistius poutassou*, is a gadoid that occurs in the Rockall Trough primarily as a migrant passing through the region, with peak abundance in March to April (Bailey, 1982). The biomass of blue whiting in the model area as estimated from German trawl survey data was 232 t. This species is mainly pelagic and therefore not well sampled by demersal trawls. Their biomass was therefore estimated by Ecopath. It has been assumed that blue whiting has been discarded by the bottom trawl fleet off the west coast of Scotland since its development. It has been recorded as caught by the pelagic fleet since 1974 (Anon,, 2001a).

Their depth distribution given from Fishbase is 150-3000m but more common at 300-400m (Froese and Pauly, 2000). Bailey (1982) describes adults as living pelagically at depths of 300-500m with a mean depth of occurrence at 420m in the Rockall Trough. Their natural mortality (0.3 year^{-1}) and Q/B ratios (9.06 year^{-1}) were calculated in Fishbase (Froese and Pauly, 2000) using a temperature of 9.8°C (Ellett and Martin, 1973). This is similar to the P/B and Q/B ratios calculated for the Faroe Islands (Zeller and Reinert, 2004) and the Cantabrian sea (Sánchez and Olaso, 2004), but lower than that for the Bay of Biscay (Ainsworth et al., 2001).

Diet:
The diet of blue whiting off the Portuguese coast is composed mainly of crustaceans (Cabral and Murta, 2002). Seasonal changes in the principle prey species are apparent. The decapod *Pasiphaea sivado* is the most important prey in summer and autumn, being replaced by the euphausid *Meganyctiphanes norvegica* in winter. Differences in diet with size were also observed. Small blue whiting consumed decapod larvae, copepods, euphausids and mysids. Larger blue whiting consumed *P. sivado*, myctophids and *M. norvegica*. The main prey species of blue whiting in the Norwegian deep, in terms of numbers, was *Meganyctihanes norvegica* (Bergstad, 1991b). By weight their diet changes from mostly euphausiids at younger ages (<30cm) to approximately 10% crustaceans, 30% euphausiids, 35% caridae and 15% teleosts at lengths of 40cm and larger (Bergstad, 1991b).

The stomachs of a few individuals were examined by Mauchline and Gordon (1984a) and found to contain euphausiids, *Meganyctiphanes norvegica* predominating, and fragments of other pelagic crustaceans and cephalopods (see also Gordon (1977), MacPherson (1978; 1981), Sorbe (1980) and Zilanov (1968)). In general this species exploits the pelagic and benthopelagic resources at depths shallower than 750m. This species may contribute to the diet of deeper living demersal scavenging species. It was found in the stomachs of *Synaphobranchus kaupi*, *Antimora rostrata*, Apristurus, *Centroscymnus coelolepis*, *Aphanopus carbo* and others at depth of 750-2900m but generally only in March and April when the large migratory shoals pass through. Mauchline and Gordon (1984a) speculated that the spawning migration of this species provides a seasonal contribution to the diets of scavenger species and that some degree of mortality of this species occurs during March/April in the Rockall Trough. The diet of this species has been taken from Cabral and Murta (2002). The total diet for blue whiting is: large zooplankton (57%), prawns and shrimp (34%), mesopelagic fish (5%), blue whiting (2%), cephalopods (1%), small zooplankton (1%).

3.13. Black scabbard fish
Swan et al. (2003) found that black scabbard fish, *Aphanopus carbo*, is widely distributed in throughout the NE Atlantic at depths of between about 200-1600m (Nakamura and Parin, 1993). In the SAMS trawls they were caught over the depth range of 500 – 1250 m, but were most common at 750m (Mauchline and Gordon, 1984c). Exploratory deep-water trawling surveys in Rockall Trough and Porcupine Seabight in the 1970s and early 1980s showed that this species was one of the dominant species at depths of around 600-1000m (Bridger, 1978; Ehrich, 1983). Gordon and Hunter (1994a) reported the best catches in the MAFF survey (Bridger, 1978; Ehrich, 1983) at depths of 550-825m, while the best catches occurred between 200-1500m in the German trawl surveys and from 484m to 1282m in SAMS surveys, but peak abundance and biomass appears to be at 750-1000m.

Egg and larval stages of this species are unknown and juvenile fish are seldom caught (Swan et al., 2003). Mature fish are caught at Madeira where spawning occurs from November to December (Morales-Nin and Sena-Carvalho, 1996) while only spent fish have been found off mainland Portugal. In the Rockall Trough fish are generally smaller than off Portugal (80-110cm TL) and are immature although mature fish have been reported (Ehrich, 1983). Recent Spanish landings from Hatton Bank had a length range from 80-120cm (Anon, 2000). Earlier Russian data from the

same general area reported spawning fish from November to April (Zilanov and Shepel, 1975). On the Icelandic slope and the Reykjanes Ridge the majority of females were 90-110cm in length and males were 85-105cm (Magnusson et al., 2000). Most fish were immature, although some spawning and newly spent fish were found between January and September. Un-validated age estimates based on whole otoliths suggest that this species has rapid growth rate and longevity of about 8 years (Morales-Nin and Sena-Carvalho, 1996). Studies using sectioned otoliths suggest older ages (Morales-Nin et al., 2002)

ICES currently arbitrarily divide the stock into a northern and southern component for assessment purposes (Anon,, 2001b). The northern stock comprises the trawl fisheries in subareas V, VI, VII, XII, while the southern stock comprises the longline fishery in sub area IX. The stock in the northern area is considered to be outside safe biological limits, with a steady decline in CPUE. In the southern area total catches appear to be declining. The N/S split is questionable as data from the BASBLACK Study (Santos, 2000) suggest there is a single stock with spawning grounds at the southern range of its distribution, unknown nursery grounds and feeding grounds in northern regions (Santos, 2000; Swan et al., 2003), although results from otolith microchemistry were inconclusive.

The virgin stock biomass in areas VI, VII, XII and Vb was estimated to be around 22,000 tonnes (Basson et al., 2002) and the biomass in area VIa estimated from the German trawl survey was 40,213 tonnes (0.532 t.km^{-2}). The German estimate is significantly higher than that of Basson et al. (2002). We have used the higher estimate and thus our biomass may be unacceptably high. The stock in 1998 was estimated to be between 19 and 24% of virgin biomass (Basson et al., 2002).

Clarke et al. (2003) estimated life history parameters for Rockall Trough and Porcupine Seabight from samples taken in 1993-1995 and estimated a M of 0.14 year^{-1}, while using Pauly's empiric formula relating M with growth parameters and mean ambient temperatures, Martins et al. (1994) estimated M at 0.17 year^{-1}. Fishbase calculates a natural mortality using a temperature of 7.7°C at an average depth between 693 and 1190m (Ellett and Martin, 1973) at 0.27 year^{-1} and the Q/B at 2.2 year^{-1} (Froese and Pauly, 2000). By comparison Ainsworth et al. (2001) estimate the Q/B from Portuguese samples at 4.431 year^{-1} for the Bay of Biscay. We used the natural mortality estimate of 0.17 year^{-1} from Martins et al. (1994).

Diet:
This species appears to feed mainly on pelagic and semi-pelagic species such as mackerel and blue whiting (Mauchline and Gordon, 1984c). However, new data from this project suggest squid may also be an important dietary component (Howell, unpublished data). The diet figures used in the model have been calculated by combining the prey numbers used in Mauchline and Gordon (1984c) with new stomach dissection data. Mauchline and Gordon (1984c) recorded only fish in the diet of this species, while the present study recorded squid as accounting for 99% of the diet by weight. In order to represent the diet adequately prey numbers (fish numbers) from Mauchline and Gordon (1984c) have been converted to weights using conversion factors developed by this project (Howell, unpublished data). These data have then been used to represent 50% of the diet. The other 50% of the diet is represented by the new diet data obtained as part of the wider project. The total diet

for black scabbard fish is: cephalopods (49.7%), blue whiting (44%), benthopelagic fish (6.1%), prawns and shrimp (0.2%). In addition, we assumed that black scabbardfish would also predate on Baird's smoothhead, cardinalfish and Kaup's arrowtooth eel (0.0001%).

3.14. Blue ling

Blue ling is caught by both trawling (Anon,, 2001c) and longlining (Bergstad and Hareide, 1996) in the model area. The biomass estimated for blue ling (*Molva dypterigia*) from the German trawl survey was 4,484t (0.059 t.km^{-2}) while their minimum virgin stock biomass was estimated at 45,000t for sub-area VI and Division VII b, c (Basson et al., 2002). By the end of 1998 the biomass of blue ling in sub areas VI, VII and Division Vb was considred to be below 20% of virgin stock biomass (Basson et al., 2002). The depth distribution is reported in Gordon and Hunter (1994b) as occurring from 300-1,300m and at 484-1,470m in the Rockall Trough, but the species is most abundant between 750-1,000m.

Natural mortality for blue ling was estimated to be around 0.15 year^{-1}, using the relationship developed by Annala and Sullivan (1996), while Fishbase (Froese and Pauly, 2000) estimated a natural mortality and Q/B of 0.16 year^{-1} and 1.6 year^{-1} using a temperature of 8.4°C for the average depth between 693 and 992m (Ellett and Martin, 1973). These natural mortality and Q/B ratios are substantially lower than the P/B (0.513 year^{-1}) and Q/B (4.4 year^{-1}) estimated for the Bay of Biscay (Ainsworth et al., 2001), but those were estimated using using area specific length-weight relationships for France, UK, North Sea, Portugal and the Western Atlantic. The fishery for blue ling started before 1974 and therefore the P/B ratio used here should include a fishing mortality, and should therefore be higher than 0.15 year^{-1}.

Diet:
Blue ling is primarily a piscivore but it also predates upon some epibenthic organisms, especially when young (Andriyashev, 1954). It is frequently found with an everted stomach, therefore dietary studies are difficult for this species. Mauchline and Gordon (1984c) examined the stomach content of a few individuals and concluded the species consumes fish, squid and amphipods. The diet of blue ling in the Norwegian deep > 300 m was found to consist mainly of argentine (49%), blue whiting (32%) and roundnose grenadier (12.5%) (Bergstad, 1991b). The dietary values used in this model are principally taken from Bergstad (1991a), but have been modified to incorporate cephalopods and large zooplankton as dietary elements, based on the description of diet given by Mauchline and Gordon (1984c). The total diet for blue ling is: argentine (46.6%), blue whiting (30.7%), adult *Coryphaenoides rupestris* (6%), small *C. rupestris* (6%), benthopelagic fish (5.6%), cephalopods (4.8%), prawns and shrimp (0.38%), large zooplankton (0.0095%). In addition, it was also assumed that blue ling would take juvenile shallow sharks, intermediate sharks, monkfish, orange roughy, blue ling, greater forkbeard, Baird's smoothhead, cardinalfish, Kaup's arrowtooth eel, megrim and Chimaera (0.0001%).

3.15. Ling

Both the longline and demersal fisheries target ling (*Molva molva*, Linnaeus, 1758). It occurs mainly above 400m depth and therefore the biomass estimated by the German trawls is very small (0.0000001 t.km^{-2}). Their natural mortality and Q/B ratios were estimated by Fishbase (Froese and Pauly 2000) at 0.22 year^{-1} and 1.8 year^{-1}

respectively using a temperature of 9.78°C average between 100 and 396m (Ellett & Martin, 1973). This is much lower than the ratios obtained from Ainsworth et al. (2001) (0.515 year^{-1} and 3.53 year^{-1} respectively). However as ling was already fished heavily in 1974, the natural mortality should be increased to include fishing mortality.

Diet:
This gadoid is primarily a fish eater but their diet is supplemented by cephalopods, crustaceans and echinoderms (Rae and Shalton, 1982; Svetovidov, 1986). It is frequently found with an everted stomach, therefore dietary studies are difficult for this species.

The diet for ling was therefore assumed to be similar to that of blue ling: argentine (46.5%), blue whiting (30.7%), adult *Coryphaenoides rupestris* (6%), small *C. rupestris* (6%), benthopelagic fish (5.6%), cephalopods (4.8%), prawns and shrimp (0.38%), large zooplankton (0.0095%). In addition, we assume that ling also feed on juvenile shallow sharks, intermediate sharks, large demersals, skates and rays, monkfish, blue ling, greater forkbeard, megrim and Chimaera (0.00001%).

3.16. Greater forkbeard
In the SAMS survey the greater forkbeard, *Physis blennoides,* occurred between 245 and 1054m, but were most abundant in 500-750m depths bands (Mauchline and Gordon, 1984a). Clarke et al. (2003) and Kelly (1997) carried out studies of age and growth from the Rockall Trough and Porcupine Seabight. Age estimations, using sectioned sagittal otoliths, were conducted but estimates of the parameters of the von Bertalanffy growth model were not given in Clarke et al. (2003).

The biomass of greater forkbeard, calculated from the German trawl survey data, was estimated at 738t (0.01 t.km^{-2}). This species is primarily caught by longlines in the Azores, suggesting that the catchability of the species by demersal trawls is not very good. We have therefore assumed that the biomass estimate is too low. The natural mortality (0.23 year^{-1}) and Q/B ratio (2.1 year^{-1}) of this species was calculated in Fishbase (Froese and Pauly, 2000) using a temperature of 9.4°C (average between 495 and 792m taken from Ellett and Martin (1973)). This Q/B ratio was much lower than the 5.99 year^{-1} estimated by Ainsworth et al. (2001). This species has been caught by trawlers in the study area since 1974 (Anon,, 2001c).

Diet:
This species feeds on epibenthic and other organisms closely associated with the surface of the sediment. Mauchline and Gordon (1984a) examined 83 individuals for stomach content. The diet consisted of a variety of organisms dominated by crustaceans. The great majority of the decapods found were larval or early juvenile stages and all other prey organisms were also small in size, the squid and fish being in the 20-40mm length range. The dietary values used in the present study are based on the prey numbers from Mauchline and Gordon (1984a) converted to weight data using conversion factors developed by this project. The total diet for greater forkbeard is: prawns and shrimp (66.7%), other benthic invertebrates (23.9%), cephalopods (6.8%), benthopelagic fish (1.8%), polychaeta (0.55%), large zooplankton (0.25%).

3.17. Baird's smooth-head

Baird's smooth-head, *Alopecephalus bairdii*, were trawled mainly between the 750m and 1500 m bathymetric zones (Mauchline and Gordon, 1983b). Gordon and Hunter (1994a) found them between 650 and 1700m and in the SAMS surveys they occurred from 450-2,200m but were most abundant at 750-1500m (Mauchline and Gordon, 1983b). The biomass estimated from German trawl data was 208,809t (2.76 t.km^{-2}). This species is one of the principal species discarded by the trawl fishery, discarding has been assumed to have been taking place since the development of the trawl fishery in 1988.

Fishbase estimates a natural mortality of 0.13 year^{-1} using a temperature of 7°C (average between 693 and 1438m taken from Ellett and Martin (1973)) and an annual Q/B ratio of 1.8 (Froese and Pauly, 2000).

Diet:
This species is thought to feed primarily on gelatinous zooplankton (Golovan and Pakhorukov, 1975). They occur about 5-8 m off the bottom where in the Rockall Trough they feed on coelenterates, *Pyrosoma*, tunicates and bathypelagic fishes (Gordon and Mauchline, 1990). Coelenterates (ctenophores, jellyfish of order Coronata) were found to account for 79% of the diet abundance from stomach content analysis (Gordon and Mauchline, 1990) and these authors further suggest that most of the unidentified part of their diet consisted of coelenterates, salps and ctenophores. The dietary values used in the present study are based on the prey numbers from Mauchline and Gordon (1983b) converted to weight data using conversion factors developed by this project. Unidentified material has not been taken into account therefore the contribution of gelatinous zooplankton to the diet may be under-represented. The total diet for Baird's smooth-head is: benthopelagic fish (38%), gelatinous zooplankton (32.5%), prawns and shrimp (9.6%), other benthic invertebrates (7%), polychaeta (8.5%), echinoderms (1.4%), cephalopods (1.2%), large zooplankton (1.7%), small zooplankton (0.15%).

3.18. Deep water cardinal fish

The depth distribution of deep water cardinal fish, *Epigonus telescopus*, is reported in Gordon and Hunter (1994a) from the SAMS surveys as 450-1000m, but they are most abundant at 735m. Their biomass in 1974, calculated from the German trawl survey data was 286t (0.004 t.km^{-2}). They are poorly sampled as they tend to aggregate over topographic features such as seamounts. Fishbase calculates a natural mortality of 0.07 year^{-1} using a temp of 9.17°C for the depth of 693-792m (Ellett and Martin, 1973) and a Q/B ratio of 2.4 year^{-1} (Froese and Pauly, 2000).

The largest catches of deepwater cardinal fish came from sub-areas VI and VII and showed an increasing trend from 1993 until 2003. Landings have decreased in recent years possibly as a result of a general reduction of effort resulting from management measures aimed at other species (ICES 2008b). Discarding of this species has been assumed to have been taking place since the development of the trawl fishery in 1988.

Diet:
Mauchline and Gordon (1984c) suggest a diet of benthopelagic crustaceans with a significant contribution of fish. The dietary values used in the present study are based on the prey numbers from Mauchline and Gordon (1984c) converted to weight data using conversion factors developed by this project. The total diet for *Epigonus telescopus* is: prawns and shrimp (64.9%), mesopelagic fish (31.6%), other benthic invertebrates (1.8%), large zooplankton (0.7%), cephalopods (0.63%), gelatinous zooplankton (0.18%), polychaeta (0.13%), small zooplankton (0.047%), echinoderms (0.029%).

3.19. Kaup's arrowtooth eel
Kaup's arrowtooth eel, *Synaphobranchus kaupi,* has a wide depth distribution in Rockall Trough from about 500 to 2,500 m (Gordon and Duncan, 1987b). This species is widely distributed on the continental slopes of the North Atlantic (Haedrich and Merrett, 1988). There is some size – depth distribution patterns with larger individuals being found deeper (Merrett and Domanski, 1985; Gordon and Mauchline, 1996). Their male:female ratio was 0.62:1 with females attaining a slightly larger size than males. The estimated fecundity of 2 female fish of size 56.5 and 60.2cm SL was 119,467 and 111,507 respectively (Gordon and Mauchline, 1996). Gordon and Maucline (1996) gave a length-weight relationship of weight(g)=0.000075.SL$^{3.6443}$cm with a r of 0.992.

Biomass estimates from the earlier bottom trawl surveys were underestimated, but single warp OTSB trawls showed that they are the most abundant species on the slopes of the Rockall Trawl (Gordon and Mauchline, 1996). Although this species is quite abundant, its biomass is not that high (Merrett et al., 1991). The biomass estimated by the OTSB was substantial in the lower half of its range, while their abundance was great in all of its range (Merrett et al., 1991). Their biomass was always higher when estimated by single warp OTSB, followed by paired warp OTSB, long bridled Granton trawls and then short bridled Granton trawls (Gordon and Mauchline, 1996). The biomass estimate from German trawl survey data of 5,601t (0.074 t.km^{-2}) was assumed to be too low as this species is clearly not well sampled by the gear used. Fishbase calculates a natural mortality and Q/B ratio of 0.57 year^{-1} and 1.7 year^{-1} respectively using an average temperature of 4.4°C. Discarding of this species has been assumed to have been taking place since the development of the trawl fishery in 1988.

Diet:
Gordon and Mauchline (1996) examined 1350 stomachs and found fish, cephalopods and decapod crustaceans to be the primary dietary components for this species, with fish being dominant. Larger fish were reported to feed more heavily on squid and fish, and less heavily on crustaceans than the smaller fish. Most of the prey organisms were swallowed whole. Heads of fish and squid, abdomens or heads of decapods and the stomachs and intestines of fish occurred. These occurrences along with parts of blue whiting suggest a role as a scavenger, with an opportunistic diet. Plots of cumulative numbers of prey species suggest the diet of this species in the RT is well described. Submersible observations showed that most individuals hover at ~1m off bottom while swimming into the weak current (Gordon and Mauchline, 1996). Sedberry and Musick (1978), while not ruling out scavenging, consider that the mesopelagic fauna, when it approaches the bottom, provides a

major source of food for this species. The diet of this species has been calculated using the prey numbers from Gordon and Mauchline (1996) converted to weight data using conversion factors developed by this project. The total diet for Kaup's arrowtooth eel is: blue whiting (77.2%), prawns and shrimp (10%), cephalopods (5.7%), mesopelagic fish (5.4%), other benthic invertebrates (1.6%), large zooplankton (0.09%) and polychaeta (0.03%).

3.20. Megrim and witch

Megrim is frequently caught in the anglerfish fishery and there are problems with misreporting of landings (see 2.3.1.). They have been recorded as landed by demersal trawlers since 1989, and it has been assumed that this species has been discarded since the development of the trawl fishery in 1988. Biomass of Megrim, *Lepidorhombus whiffiagonis*, as estimated from German trawl data was very low at 1.2t (0.00002 t.km^{-2}). Their natural mortality and Q/B ratio were estimated by Fishbase (Froese and Pauly, 2000) at 0.21 year^{-1} and 2.8 year^{-1} respectively using an average temperature of 9°C for their depth range of between 100-693m (Ellett and Martin, 1973). This is much lower than the P/B and Q/B ratios estimated for the Bay of Biscay (0.46 year^{-1} and 5.3 year^{-1} respectively) (Ainsworth et al., 2001).

Diet:
The diet values used in the present study are taken directly from Sánchez and Olaso (2004). Their data represent the diet of two species, *L. whiffiagonis* and *L. boscii*. They indicate that horse mackerel, prawns and shrimp, and benthic invertebrates are important components of the diet of this species. In this study Sánchez and Olaso's (2004) "Squid" and "benthic cephalopods" groups have been combined into "cephalopods"; "other invertebrates" and "benthic invertebrates" have been combined in "other benthic invertebrates"; "horse mackerel" has been included in the "blue whiting" group. The total diet for megrim is: benthopelagic fish (26.6%), prawns and shrimp (25.2%), other benthic invertebrates (19.7%), blue whiting (11.3%), benthic fish (4.9%), Chimaera (4.9%), large zooplankton (5.6%), polychaeta (1.4%), cephalopods (0.28%), megrim (0.14%).

3.21. Mesopelagics

The mesopelagics include garrick, *Cyclothone braueri*; veiled anglemouth, *Cyclothone microdon*; pearlsides, *Maurolicus muelleri*; half-naked hatchetfish, *Argyropelecus hemigymnus*; goiter blacksmelt, *Bathylagus euryops*; glacier lanternfish, *Benthosema glaciale*; and rakery beaconlamp, *Lampanyctus madonaldi*; while there were 37 additional species that were rarely caught (Mauchline, 1983). In addition the group also includes the silvery pout, *Gadiculus argenteus thori*, the only species for which we have catch or biomass estimates. Biomass estimates calculated from demersal trawl data are of little use since these are pelagic species. The natural mortality (0.97 year^{-1}) and Q/B ratio (6 year^{-1}) for this group was taken from *G. argenteus thori* as estimated by Fishbase (Froese and Pauly, 2000). Discarding of this group has been assumed to have been taking place since the development of the trawl fishery in 1988.

Diet:
There are two main groups of mesopelagics in the Rockall Trough: one group contains *C. graueri, C. microdon, B.glaciale* and *Protomyctophum arcticum* whose diet is dominated by copepods, while the second group include *Argyropelecus* spp.,

Xenodermichthys copei, B. euryops, L. macdonaldi and *Scopelogadus beanii* who have a more varied diet and include a greater proportion of fish (Mauchline, 1983). The last group also mainly undertake ontogenetic migrations. *M. muelleri* and the two *Arygropelecus* spp. have their centres of population higher in the water column than the other species (Mauchline, 1983). The silvery pout, also included in this group, feeds on benthopelagic organisms but to some extent on pelagic euphausiids. Its diet is dominated by pelagic crustaceans and supplemented by chaetognaths and micronektonic fish (Mauchline and Gordon, 1984a). Other authors have found the diet of this species to be dominated by euphausiids and supplemented by decapods and micronektonic fish (MacPherson, 1978, 1981), while Mattson (1981) examined approximately 470 fish and found a diet restricted almost exclusively to crustaceans: *Meganyctiphanes norvegica* was dominant but supplemented by copepods and epibenthic mysids *Boreomysis megalops* and *Lophogaster typicus*. The diet of the mesopelagic group is dominated by copepods and large zooplankton with a smaller fish component. The values used in the present study are based on the diet of the silvery pout described in Mauchline and Gordon (1984a). The prey numbers from their study have been converted to weight data using conversion factors developed by this project. The values calculated for the silvery pout do not reflect well the importance of small and large zooplankton in the diets of the other species within this group. The total diet for mesopelagic fish is: mesopelagic fish (72.8%), large zooplankton (25.8%), small zooplankton (1.3%).

3.22. Benthopelagic fish
This group include the blackbelly rosefish, *Helicolenus dactylopterus*; Mediterranean grenadier, *Chalinura mediterranea*; hollowsnout grenadier, *Coelorhynchus coelorhynchus*; *Coelorhynchus labiatus*; Günther's grenadier (previously *C occa*), *Coryphaenoides guentheri*; slender codling, *Halargyreus johnsonii*; North Atlantic codling, *Lepidion eques*; common mora, *Mora moro*; common Atlantic grenadier, *Nezumia aequalis*; roughnose grenadier, *Trachyrhynchus murrayi;* and all *Sebastes* spp.

Ross & Gordon (1978) record the depth range for north Atlantic codling, *L. eques*, off the west of Scotland as 450-1250m (although didn't sample shallower than 450m) and their depth range reported in Fishbase (Froese and Pauly, 2000) is 127 – 1850m, but most abundant between 500-1,300m (Templeman, 1970). In the Rockall Trough Mauchline and Gordon (1980) suggests that *L. eques* is a slope-dwelling species recorded from 330-1850 m but is most abundant between 500 and 1300m. The natural mortality of this species was calculated by Fishbase using a temperature of 6.9°C (Ellett and Martin, 1973) as 0.15 year^{-1} and the Q/B ratio as 3.0 year^{-1} using an aspect ratio of 1.32 (Froese and Pauly, 2000).

The depth distribution of the common mora, *Mora moro,* is reported in Gordon and Hunter (1994a) from SAMS surveys as 530-1025m, but they are most common between 820-1350m and the Fishbase depth range is reported as 450 – 2,500m (Froese and Pauly, 2000). Fishbase also calculates their natural mortality at 0.21 year^{-1} using a temperature of 6.93°C (Ellett and Martin, 1973) and their Q/B at 1.9 year^{-1} (Froese and Pauly, 2000). Natural mortality and Q/B of the common Atlantic grenadier, *N. aequalis*, were calculated by Fishbase as 0.21 year^{-1} and 1.9 year^{-1} respectively, using a temperature of 6.9°C (Ellett and Martin, 1973) and an aspect ratio of 1.32 (Froese and Pauly, 2000). Clarke et al. (2003) give the natural mortality

for male *Helicolenus dactylopterus* at 0.11 year^{-1} and females at 0.12 year^{-1}. The natural mortality (M) calculated by Fishbase using a temperature of 7.97°C (Ellett and Martin, 1973) was 0.15 year^{-1} and the Q/B ratio estimated by Fishbase was 3.3 year^{-1}, using an aspect ratio of 1.32 (Froese and Pauly, 2000). The natural mortality (0.19 year^{-1}) and Q/B (2.0 year^{-1}) ratios of the Mediterranean grenadier, *C. mediterranea*, were obtained from Fishbase using a temperature of 6.5°C and an aspect ratio of 1.32 (Froese and Pauly, 2000). For *C. labiatus*, the M calculated by Fishbase using the average temperature of 6.3°C (Ellett and Martin, 1973) for their depth range of 460-220m was 0.29 year^{-1}, while their Q/B ratio was estimated at 2.5 year^{-1}, using an aspect ratio of 1.32 (Froese and Pauly, 2000). The M for Günther's grenadier, *C. guentheri,* calculated from Fishbase using a temp of 6°C (Ellett and Martin, 1973) was 0.28 year^{-1} and the Q/B ratio was 2.5 year^{-1}, using an aspect ratio of 1.32 (Froese and Pauly, 2000). The M (0.33 year^{-1}) and Q/B (2.8 year^{-1}) ratio of roughnose grenadier, *T. murrayi,* were calculated by Fishbase using an aspect ratio of 1.32 (Froese and Pauly, 2000) and an average temperature of 4.8°C at 1438m (Ellett and Martin, 1973). For slender codling, *H. johnsonii*, the natural mortality calculated by Fishbase was 0.27 year^{-1} using a temperature of 6.39°C averaged (Ellett and Martin, 1973) for their depth range of 450-3000m and the Q/B was calculated at 2.6 year^{-1} using an aspect ratio of 1.9 (Froese and Pauly, 2000). Finally, there are no estimates of M for *C.coelorhynchus* as there is no L_{inf} available for this species, but their Q/B ratio was estimated in Fishbase at 7.5 year^{-1} using an aspect ratio of 1.32 and an average temperature of 6.5°C (Froese and Pauly, 2000).

All of the M and Q/B values were prorated by the average biomass in the SAMS and German trawl series, to get an average P/B and Q/B ratio for this group of 0.27 year^{-1} and 3.53 year^{-1} respectively. The biomass for benthopelagic fish in 1974 estimated from German trawl survey data was 1,884t (0.025 t.km^{-2}). Of these species, some were more readily caught by one type of trawl than others. For example *L. eques* was caught equally well by all trawls including slower speed Agassiz trawl and faster Granton trawls, while *H. johnsonii* were mostly caught by the Granton trawl and not by the Agassiz trawl (Gordon and Duncan, 1985b), thus the estimated biomass is likely to be too low.

There have been some landings of *H. dactylopterus* since 1989, but this species is primarily discarded (Connolly and Kelly 1996). The early fishery landings of *Mora moro* was included with *Phycis* and for some countries this practice continues (ICES, 2008b). *Mora moro* are caught infrequently by trawlers off the west coast of Scotland (Anon,, 2001c). *H. dactylopterus* are caught more frequently (Anon,, 2001c).The *C.mediterranea* and *C.guentheri* present at the depth of the commercial fishery are mainly juveniles, thus they are not really included in the catch. *C. coelorhynchus, C.occa* (spearsnout grenadier), *L. eques, N. aequalis* and *T. murrayi* are discarded species (Anon,, 2001a).

Diet:
The diets of all members of this group in the Rockall Trough are given in a series of papers (Mauchline and Gordon, 1980, 1984b) except that of the common mora *Mora moro*. Roughnose grenadier, *Trachyrhynchus murrayi*, feeds predominantly on polychaetes and forages on the sediment surface. The diet of Atlantic grenadier *Nezumia aequalis*, is dominated by amphipods; the hollowsnout grenadier *Coelorhynchus coelorhynchus* diet contains large numbers of small amphipods, with

polychaetes, isopods, copepods and mysids also important; *Coelorhynchus labiatus* (formally *C. occa*) diet is dominated by copepods supplemented by polychaetes, amphipods, mysids and small quantities of unidentifyable soft tissues; Mediterranean grenadiers *Chalinura mediterranea*, feed mainly on copepods, amphipods and mysids; and Günther's grenadier, *Coryphaenoides guentheri,* is primarily a benthopelagic feeder, consuming mainly copepods, amphipods and mysids (Mauchline and Gordon, 1984b). Dietary studies of *Chalinura mediterranea, Coelorhynchus labiatus* and *Coryphaenoides guentheri* from the western Mediterranean (Carrassón and Matallanas, 2002) broadly supported these findings although some differences in diet between Atlantic and Mediterranean populations were apparent.

The principle dietary components of North Atlantic codling *Lepidion eques* in the Rockall Trough are epibenthic and hyperbenthic decapod crustaceans. Amphipods and cephalopods are also important constituents but are of irregular occurrence in the diet. The diet of this species shows little overlap with the co-occurring, similar sized slender codling *Halargyreus johnsonii*. The slender codling is a benthopelgic feeder that preys primarily on crustaceans, although a few fragments of chaetognaths and fish were observed in its stomach content (Mauchline and Gordon, 1984a). This species tends to evert its stomach on capture and thus obtaining dietary data is difficult. Ontogenetic differences in the diet are evident (Mauchline and Gordon, 1984a). Smaller fish consume marked numbers of aetideid calanoid copepods and small mysids and decapods in the size range 15-25mm. Large fish have a diet dominated by *Euchaeta norvegica* (Copepoda). Decapod shrimps have also been observed in the stomachs of this species (*Sergestes arctcus* and *Pasiphaea tarda*) (Templeman, 1968; Mauchline and Gordon, 1984a).

The diet of the blue mouth red fish *Helicolenus dactylopterus* from the Rockall Trough is relatively diverse containing small crustaceans and polychaetes (Mauchline and Gordon, 1985). Studies of the diet of this species off the northwest coast of Africa found that cephalopods, echinoderms, and pelagic and demersal fish species are eaten by large individuals (McPherson, 1985) and diet can be highly selective (Merrett and Marshall, 1981).

The common mora is frequently found to have an everted stomach on capture making dietary studies difficult. Dietary analysis of three stomachs from the western Mediterranean found this species has a diet based on benthic prey, chiefly epibenthic and suprabenthic prey (crustaceans, fishes and cephalopods) (Carrassón et al., 1997).

The diet for this group has been calculated using the prey numbers data from Mauchline and Gordon (1980), Mauchline and Gordon (1984a) and Mauchline and Gordon (1985) converted to weight data using conversion factors developed by this project. As a result of the conversion factors used for fish the contribution of *Synaphobranchus kaupii* to the diet of this group may be over estimated. The total diet for benthopelagic fish is: prawns and shrimp (35.7%), other benthic invertebrates (33%), *Synaphobranchus kaupii* (12.9%), benthopelagic fish (6.5%), polychaeta (4.9%), large zooplankton (4.3%), echinoderms (1.1%), cephalopods (0.9%), small zooplankton (0.7%).

3.23. Benthic teleosts

Benthic fish species include the Bonapart's spiny eel, *Notacanthus bonapartei*; smallmouth spiny eel, *Polyacanthonotus rissoanus*; and blue antimora, *Antimora rostrata*. Bonapart's spiney eel, and smallmouth spiny eel range in depth from 450 – 1,200m, 487-2,000m, 500-2,800m respectively (Froese and Pauly, 2000). The blue antimora depth distribution was reported in Gordon and Hunter (1994a) as 402-2,904m, while in the SAMS surveys they occurred from 450-2,200 but were most abundant at 2000m.

The biomass estimate of this group obtained from the German trawl survey data was 984t or 0.013 t.km^{-2}. These species are not well sampled by trawls and their biomass is likely to be too low. The L_{inf} for smallmouth spiny eels was not known, therefore no M could be estimated for this species, while their Q/B ratio was estimated as 6.9 year^{-1} by Fishbase using aspect ratios of 1.32 (Froese and Pauly, 2000). Blue antimora natural mortality (0.34 year^{-1}) and Q/B ratios (1.9 year^{-1}) were calculated in Fishbase using a temperature of 4°C from Rice et al. (1991) and an aspect ratio of 1.32 (Froese and Pauly, 2000). The natural mortality (0.47 year^{-1}) and Q/B ratios (5.7 year^{-1}) of Bonapart's spiney eel were estimated from Fishbase using a temperature of 6.88°C (Ellett and Martin, 1973) and an aspect ratio of 1.32 (Froese and Pauly, 2000). The natural mortality and Q/B ratios were pro-rated by their biomass to give a P/B and Q/B ratio of 0.31 year^{-1} and 4.08 year^{-1} respectively.

No landings of blue antimora were available for ICES VI as only juveniles are encountered at depth of the commercial fishery. However, they make up a propotion of the fishery discards and have been assumned to have been discarded since the development of the trawl fishery in 1988.

Diet:
Diet data for the blue antimora is difficult to obtain as larger individuals of this species frequently have everted stomachs when recovered to the surface (Sedberry and Musick, 1978; Mauchline and Gordon, 1984a). 17 stomachs were examined by Mauchline and Gordon (1984a) who found the diet to be dominated by fish and supplemented with squid and crustaceans. Unidentifiable soft tissue occurred in 13 of the stomachs and some may have been derived from squid. Other studies have reported decapod crustaceans (*Nematocarcinus ensifer*, *Plesiopenaeus armatus*, other penaeids), brachyuran crabs, amphipods, squid and octopus, and foraminifera as dietary components (Koefoed, 1927; Sedberry and Musick, 1978).

Prey composition of the diet of Bonapart's spiny eel *Notacanthus bonapartei*, and the smallmouth spiny eel *Polyacanthonotus rissoanus* differ greatly although both are dependant on benthic macrofauna (Coggan et al., 1998). *N. bonapartei* feeds primarily on benthic ophiuroids and sedentary cnidarians, while *P. rissoanus* feeds primarily on errant arthropods and polychaetes. Studies of the diet of *P. rissoanus* from the western Mediterranean (Carrassón and Matallanas, 2002) broadly supported the findings of Coggan et al. (1998).

The diet of this group has been calculated using the prey numbers from Mauchline and Gordon (1983a; 1984a) and Coggan et al. (1998) converted to weight data using conversion factors developed by this project. The total diet for benthic teleosts is: blue whiting (58%), echinoderms (11.4%), cephalopods (10%), other benthic

invertebrates (9%), polychaeta (6%), benthopelagic fish (4%), large zooplankton (1%), prawns and shrimp (0.06%), gelatinous zooplankton (0.5%), small zooplankton (0.03%).

3.24. Chimaeras

This group includes the rabbit fish, *Chimaera monstrosa* and the large-eyed rabbitfish, *Hydrolagus mirabilis*. The rabbit fish has been trawled between 500-1,250 m in the Rockall Trough (Mauchline and Gordon, 1983a), while large-eyed rabbitfish range in depth globally from 450 – 1,200m (Froese and Pauly, 2000). The biomass of chimaeras estimated from German trawl data was 8,184t or 0.108 t.km^{-2}. The L_{inf} for rabbitfish were not known, therefore no M could be estimated for these species, while their Q/B ratios was estimated as 3.7 year^{-1} respectively by Fishbase using aspect ratios of 1.32 (Froese and Pauly, 2000). An annual P/B ratio of 0.22 year^{-1} for rabbitfish was obtained from the Bay of Biscay model (Ainsworth et al., 2001).

There are no reliable landings data for rabbitfish or large-eyed rabbitfish as it has been only occasionally landed by the French fleet since 1994. This group contributes significantly to the species discarded by the fishery, and has been assumed to have been discarded since the development of the trawl fishery in 1988.

Diet:
The diets of all members of this group in the Rockall Trough are given in a series of papers (Mauchline and Gordon, 1983a, 1984a; Coggan et al., 1998). The rabbit fish feeds primarily on anemones and their tubes but decapods and spatangoids are also important. There are marked differences in the diets of smaller and larger fish with smaller individuals consuming errant polychaetes and small amphipods preferentially. Although the distribution of rabbitfish overlaps with that of the large-eyed rabbitfish their diets differ in that the diet of large-eyed rabbitfish is more restricted and dominated by polychaetes, small benthic crustaceans and spatangoids. Dietary studies of rabbitfish from the Norwegian Deep found large crustaceans such as caridean shrimps and anomurans to be significant prey of larger individuals with polychaetes and bivalves also important (Bergstad et al., 2003).

The total diet for chimaeras is: other benthic invertebrates (86%), *Synaphobranchus kaupii* (8.6%), prawns and shrimp (2.7%), polychaeta (1.2%), echinoderms (1.2%), large zooplankton (0.3%), small zooplankton (0.00000913%).

3.25. Cephalopods

The biomass of cephalopods in the modelled area was calculated from published figures of megafaunal biomass on the Goban Spur (Lavaleye et al., 2002), sampled using an Agassiz trawl and the Porcupine Sea Bight, sampled using an epibenthic sledge (Lampitt et al., 1986). The Goban Spur lies on the continental slope to the south west of Ireland, and forms part of the Porcupine Seabight. Both lie to the south of the Rockall Trough. We have assumed that the invertebrate biomass in the Porcupine Seabight is broadly comparable to that of the Rockall Trough.

The average cephalopod biomass on the Goban Spur has been calculated from the first five depth bands given in Lavaleye et al. (2002) as 35 g.1000m^{-2} or (0.035 t.km^{-2}). This figure represents 1.6% of the total recorded megafaunal biomass in that

study. Lampitt et al. (1986) record the total megafaunal biomass in the Porcupine Seabight as 5.28g.m^{-2} (or t.km^{-2}) at 1000m, thus giving a total biomass for this group of 0.084 t.km^{-2}. This figure is likely to be a gross underestimate for this group as many cephalopods (squid) are fast swimming pelagic species that are not adequately sampled with benthic sampling gear. It is substantially lower than the 2.3 and 1.8 t.km^{-2} estimated for the Bay of Biscay by Ainsworth et al. (2001) and the 0.386 t.km^{-2} estimated for the Scottish shelf by Haggan and Pitcher (2005). We have therefore allowed Ecopath to estimate the biomass of this group.

The annual P/B and Q/B ratios used for the Bay of Biscay (Ainsworth et al., 2001) and the Scottish shelf (Haggan and Pitcher, 2005) were 2.5-3 and 8-10 respectively, with the lower values being for the Bay of Biscay. We used a value of 2.5 year^{-1} and 9 year^{-1} respectively.

Diet:
The diet data were modified from Ainsworth et al. (2001) and Zeller and Reinert (2004). The diet include 12% mesopelagic fish, 5% cephalopods, 9% prawns and shrimp, 9% gelatinous plankton, 39% large zooplankton, 8% small zooplankton, 9% polychaetes and 9% other benthic invertebrates.

3.26. Prawns and shrimps
The biomass of this group in the modelled area was calculated from published figures of megafaunal biomass on the Goban Spur (Lavaleye et al., 2002), sampled using an Agassiz trawl and the Porcupine Seabight, sampled using an epibenthic sledge (Lampitt et al., 1986). The Goban Spur and the Porcupine Seabight both lie to the south of the Rockall Trough. We have assumed that the invertebrate biomass in the Porcupine Seabight is broadly comparable to that of the Rockall Trough. The average biomass of *Caridia* on the Goban Spur has been calculated from the first five depth bands given in Lavaleye et al. (2002) as 12.2 g.1000m^{-2} or (0.0122 t.km^{-2}). This figure represents 0.56% of the total recorded megafaunal biomass in that study. Lampitt et al. (1986) record the total megafaunal biomass in the Porcupine Seabight as 5.28 g.m^{-2} (or t.km^{-2}) at 1000m, which gives a total biomass for this group of 0.03 t.km^{-2}. This figure is likely to be an under estimate for this group as many members of this group are fast swimming and/or pelagic species that are not adequately sampled with benthic sampling gear. The biomass for the Cantabrian Sea was 8.442 t.km^{-2} (Sánchez and Olaso, 2004), while the Barents Sea biomass was 0.138 t.km^{-2} (Blanchard et al., 2002), the Norwegian Sea and Barents Sea combined was 3 t.km^{-2} (Dommasnes et al., 2001), the western north Atlantic shelf was 7.6 t.km^{-2} (Okey and Pugliese, 2001) and the Scottish Shelf was 16.3 t.km^{-2} (Haggan and Pitcher, 2005).

The P/B and Q/B ratios for the Barents Sea (Blanchard et al., 2002), western north Atlantic (Okey and Pugliese, 2001), the Cantabrian Sea (Sánchez and Olaso, 2004) and the Scottish shelf (Haggan and Pitcher, 2005) ranged between 1.25-4.2 year^{-1} and 5-12 year^{-1} respectively. Values for P/B and Q/B of 2.5 year^{-1} and 8 year^{-1} were used in this model.

Diet:
The diet composition of shrimps/prawns is based on that used by Ainsworth et al. (2001) in their model of the Bay of Biscay. Their diet data is based on the diet of the brown shrimp (*Crangon crangon,* Pihl, 1985) and diets for herbivorous and predatory

shrimps (Venier and Pauly, 1997). The most important food item for these animals is phytoplankton followed by detritus. Other benthic invertebrates are also important and this group includes small benthic crustaceans, meiofauna, crabs and molluscs. The total diet for prawns and shrimp is: phytoplankton (47.9%), detritus (30.4%), other benthic invertebrates (14.7%), polychaeta (6%), prawns and shrimp (1%).

3.27. Gelatinous zooplankton

According to Gordon and Mauchline (1990), Hargreaves et al. (1984) sampled macro-and microplankton in the Rockall Trough and found there were large concentrations of salps and other gelatinous zooplankton, with a peak of medusae between 500-600 m and even more at 900-1,500 m. They found that siphonophores showed a similar pattern but that ctenophores were not abundant in the Rockall Trough (Gordon and Mauchline, 1990). They are mostly preyed upon by the alepocephalid fishes such as *Alepocephalus bairdii* (Gordon and Mauchline, 1990). No estimate of gelatinous zooplankton biomass was obtained for the deep ocean, thus Ecopath estimated the biomass using an EE of 0.95 year^{-1}. The P/B (2.858 year^{-1}) and P/Q (0.45) ratios of jellyfish in the North Sea were used here.

Diet:
The diet was assumed to consist of 20% cannibalism, 40% large zooplankton, 20% small zooplankton and 20% phytoplankton.

3.28. Large zooplankton

The large zooplankton group consist of mysids, amphipods and euphausiids. No biomass estimates were available for zooplankton, thus Ecopath estimated the biomass using an EE of 0.95 year^{-1}.

The P/B of large zooplankton was 2.5 year^{-1} in the North Sea (Mackinson and Daskalov, 2007), 4.0 year^{-1} in the northwest Atlantic (Morissette et al., 2003), 5.0 year^{-1} in the Bay of Biscay (Ainsworth et al., 2001) and 10.0 year^{-1} on the west coast of Scotland (Haggan and Pitcher, 2005). A value of 2.97 year^{-1} was used for this model.

The Q/B of large zooplankton on the west coast of Scotland was 35.0 year^{-1} (Haggan and Pitcher, 2005) and 28.4 year^{-1} for the Bay of Biscay (Ainsworth et al., 2001), while the North Sea Q/B was estimated by using a P/Q ratio of 0.3. We also estimated the Q/B ratio (8.333 year^{-1}) by using a P/Q of 0.3.

Diet:
The diet data was modified from Ainsworth et al. (2001) and Zeller and Reinert (2004) and based on euphausiids, isopods and herbivorous/detritivorous amphipods. The diet consists of 3.8% cannibalism, 60.1% small zooplankton, 24% phytoplankton and 12% detritus.

3.29. Small zooplankton

Small zooplankton includes ostracods, calanoid and cyclopoid copepods. No estimate of small zooplankton biomass was available, so Ecopath estimated the biomass using an EE of 0.95 year^{-1}. A P/B ratio of 18 year^{-1} was used for small zooplankton of west coast of Scotland (Haggan and Pitcher, 2005) and for the Bay of Biscay (Ainsworth et al., 2001), while the North Sea P/B ratio (Mackinson and

Daskalov, 2007) was 9.2 year^{-1} which is what we used in this model. Q/B ratios of 72 year^{-1} and 60 year^{-1} were used for the west coast of Scotland (Haggan and Pitcher, 2005) and for the Bay of Biscay (Ainsworth et al., 2001) respectively, while we used the value of 30 year^{-1} estimated for in the North Sea (Mackinson and Daskalov, 2007).

Diet:
The diet data was modified from (Ainsworth et al., 2001) and Zeller and Reinert (2004) and include 100% phytoplankton.

3.30. Polychaeta
Hughes and Gage (2004) record the percentage biomass of polychaetes at 1,100m in the Rockall-Hatton Basin and 1,920m on the northern Feni Ridge (northern Rockall Trough) as 56.9% and 78.8% respectively; the average of which is 68%. The biomass of macrofauna in the model area (VIa, 400-2,000m) ranges between 0.5 and 3 g.0.1m^{-1} (Bett, 2001). We have assumed an average biomass of 1.5 g.0.1m^{-1} (15 t.km^{-2}) which gives a polycheate biomass for the modelled area of 10.2 t.km^{-2}. This estimate is similar to that of the Cantabrian Sea (11.9 t.km^{-2}) obtained from (Sánchez and Olaso, 2004), the Bay of Biscay (Ainsworth et al., 2001) and the Scottish shelf (Haggan and Pitcher, 2005). The P/B ratios for the Cantabrian Sea and Scottish Shelf were estimated around 5 year^{-1} while that of the Bay of Biscay was 2.28 year^{-1} which is what we used. Similarly, Q/B ratios of 12-16 year^{-1} were used for the Cantabrian Sea and Scottish Shelf, while the Bay of Biscay value was 22.2 year^{-1}. However, we estimated a Q/B (11.4 year^{-1}) by using a P/Q ratio of 0.2.

Diet:
The diet data was modified from Ainsworth et al. (2001) and include 1.1% small zooplankton, 1.6% cannibalism, 1.1% other benthic invertebrates, and 96.2% detritus.

3.31. Echinoderms
The biomass of this group in the modelled area was calculated from published figures of megafaunal biomass on the Goban Spur (Lavaleye et al., 2002), sampled using an Agassiz trawl and the Porcupine Seabight, sampled using an epibenthic sledge (Lampitt et al., 1986). Both lie to the south of the Rockall Trough. We have assumed that the invertebrate biomass in the Porcupine Seabight is broadly comparable to that of the Rockall Trough. The average biomass of Echinoderms on the Goban Spur has been calculated from the first five depth bands given in Lavaleye et al. (2002) as 1281 g.1000m^{-2} (1.281 t.km^{-2}). This figure represents 59% of the total recorded megafaunal biomass in that study. Lampitt et al. (1986) recorded echinoderm abundance at 1,000m in the Porcupine Sea Bight as 33% of the total megafaunal abundance. The total megafaunal biomass in the Porcupine Seabight is 5.28 g.m^{-2} (or t.km^{-2}) at 1,000m (Lampitt et al., 1986) which gives a total biomass figure for this group of 3.12 t.km^{-2}. Echinoderms are adequately sampled by both Agassiz trawl and epibenthic sledge and so this figure is likely to be a reasonable estimate of echinoderm biomass. This estimate is similar to that obtained for the Scottish shelf (3.945 t.km^{-2}) by Haggan and Pitcher (2005), and much less than the 22 t.km^{-2} obtained for the Bay of Biscay (Ainsworth et al., 2001).

The P/B and Q/B ratios for the Scottish Shelf and Bay of Biscay ranged between 0.649-4 year^{-1} and 4.7-16 year^{-1}, with the Bay of Biscay values being lower. In this model we used values of 2 year^{-1} and 8 year^{-1}.

Diet:
The diet of this group was adapted from Ainsworth et al. (2001) and includes 20% small zooplankton, 20% other benthic invertebrates, 60% detritus.

3.32. Other benthic inverts
The biomass of this group in the modelled area was calculated from published figures of megafaunal biomass on the Goban Spur (Lavaleye et al., 2002) and the Porcupine Sea Bight (Lampitt et al., 1986) and macrofaunal biomass from the Rockall Trough (Bett, 2001).

The average biomass of other benthic invertebrates on the Goban Spur has been calculated from the first five depth bands given in Lavaleye et al. (2002) as 854.6 g.1000m^{-2} (0.8546 t.km^{-2}). This figure represents 39% of the total recorded megafaunal biomass in that study. Lampitt et al. (1986) record 'other invertebrate phyla' (not echinoderm or crustacea) abundance at 1000m in the Porcupine Sea Bight as 35% of the total megafaunal abundance. The total megafaunal biomass in the Porcupine Sea Bight is 5.28 g.m^{-2} (or t.km^{-2}) at 1000m (Lampitt et al., 1986) giving a total biomass for megafaunal invertebrates of 2.06 t.km^{-2}, but the macrofaunal biomass must also be considered. The biomass of macrofauna in the model area (VIa, 400-2000m) ranges between 0.5 and 3 g.0.1m^{-1} (Bett, 2001). We have assumed an average macrofaunal biomass of 1.5 g.0.1m^{-1} (15 t.km^{-2}), 10.2 t.km^{-2} of which is attributed to polychates leaving 4.8 t.km^{-2} to add to the megafaunal biomass figure of 2.06 t.km^{-2}. This gives a total other benthic invertebrate biomass of 6.86 t.km^{-2}. This value is quite similar to the 8.7 t.km^{-2} estimated by Ecopath for the Faeroese model (Zeller and Reinert, 2004), the 6.9 t.km^{-2} estimated for the Cantabrian Sea (Sánchez and Olaso, 2004), and the 7.6 t.km^{-2} estimated for the Scottish Shelf (Haggan and Pitcher, 2005).

The P/B and Q/B ratios for benthic invertebrates range from 2.6-6 year^{-1} and from 10-24 year^{-1} respectively for the Faeroese (Zeller and Reinert, 2004), Cantabrian sea (Sánchez and Olaso, 2004) and Scottish (Haggan and Pitcher, 2005) systems. We use values of 3 year^{-1} and 10 year^{-1} for the P/B and Q/B ratios in this system.

Diet:
Diet data was taken from Zeller and Reinert (2004) and modified to reflect deep-sea: It includes 20% small zooplankton, 20% other benthic invertebrates and 60% detritus.

3.33. Phytoplankton
Sir Alister Hardy Foundation for Ocean Science (SAHFOS) provided the mean Phytoplankton Color Index (PCI) value for the area bounded by 54°30'-60° N, and 8°-12°W for 1974. PCI value was converted to Chl-a in mg.m^{-3} using conversion factors published by Raitsos et al. (2005). The biomass of Chl-a was converted to carbon biomass using C:Chl-a ratio of 29, the average of values given by Morales et al. (1991) for the NE Atlantic for 56° and 60°N (27 and 31 respectively). Carbon biomass (mg.m^{-3}) was converted to wet weight biomass using the conversion factor

of 9 (Pauly and Christensen 1995) giving 417.6 mg.m^{-3}. The total biomass of phytoplankton in tonnes in the top 100m of the water column (Kennington and Johns, 2006) has then been calculated, and this figure divided by the total area of the model in km^2 to give a phytoplankton biomass of 41.76 t.km^{-2} in the model area in 1974. This is nearly half of the biomass obtained by Haggan and Pitcher (2005) for the Scottish Shelf, where the primary productivity (70 year^{-1}) was assumed to be similar to the North Sea (Mackinson, 2001).

3.34. Detritus

No estimate of biomass was available for the Rockall Trough, and therefore an arbitrary biomass of 50 t.km^{-2} was used, which is similar to the value used for the North Sea by Mackinson and Daskalov (2007) and to the value use for the Bay of Biscay by Ainsworth et al. (2001).

4. Balancing and fitting each group

Here the changes required to model input parameters, in order to balance and fit the model, are described for each group. However there are some general comments that can be made concerning changes to species / group diet data. The diet data used to describe the trophic links within the model have been taken from studies where an analysis of stomach content as been undertaken. Analysis of stomach content provides data on the diet of a species at a specific point in its life cycle at a specific time of year. Some studies are more detailed and provide data on seasonal changes in a species diet. Few provide data on ontogenetic changes in diet. For these reasons the diet matrix on which the model is built can be regarded as an indication of the dietary interactions between species. Thus minor modifications made to the diet of a species / group are in general justified on the basis of uncertainty in the diet of a species over its life cycle.

The model was unbalanced for large demersals (EE=3.863), large Coryphaenoides (EE=1.712), blue ling (EE=24.894), ling (EE=6972159), Kaups arrowtooth eel (EE=2.359), megrim (EE=3.595), mesopelagics (EE=2689), benthopelagic fish (EE=324), benthic fish (EE=1.413), Chimaera (EE=2.667), cephalopods (EE=13.4), prawns and shrimp (400) and other benthic invertebrates (EE=1.142). The high EE values for ling, mesopelagics and benthopelagics were due to the low catchability for these species in the German trawls, and the biomass of ling and benthopelagic fish were therefore estimated by Ecopath by assuming an EE of 0.95. Mesopelagics diet consisted of 79% cannibalism, thus we were unable to estimate their biomass this way. The input data therefore had to be adapted to fit the model. The changes made are described below. Balanced-fitted model data and diet matrix are provided in Appendix 4.

4.1. Cetaceans

No data were available on predation of cetaceans. Since all model compartments must have some level of predation it was assumed that cetaceans (juveniles) are preyed on by intermediate sharks (0.001%). The 14.1% benthopelagic fish in their diet was reduced to 1% to fit that group and the rest was added to benthic invertebrates.

4.2. Shallow sharks

The biomass in the model area for 1974 calculated from German trawl data was 0.002 t.km^{-2}. This biomass was too small to support the landings and discards of these species over time, therefore biomass was increased to 0.013 t.km^{-2} as it was assumed these species are not well sampled by the Granton trawl. The P/B of 0.26 year^{-1} was increased to 0.3 year^{-1} to fit the model, this figure however is higher than the P/B of either species and thus may be too high.

4.3. Intermediate sharks

The biomass in the model area for 1974 calculated from German trawl data was 0.97 t.km^{-2}. However, previous estimates of virgin stock biomass of intermediate sharks (Basson et al., 2002) suggested a biomass of approximately 0.132 t.km-2. The latter figure was too low to support the catch (landings + discards) in this system, so an intermediate figure of 0.7 t.km^{-2} was used in order to fit the catch data. The consumption of benthic fish by this group was too high to allow the model to balance. Given the apparent importance of mesopelagic species to the diet of this group, it

was assumed that the contribution of mesopelagic fish to the diet as calculated in the raw diet matrix was too low. Therefore the contribution of benthopelagic fish in their diet was reduced from 9.6% to 1% and mesopelagics increased from 4.3% to 15.4%.

4.4. Deep sharks

The contribution of blue whiting to the diet of this group as calculated from stomach content data (43.9%) were considered unlikely, and reflective of the time of year of sampling, thus the contribution by this species wasreduced to 1%, and the contribution of mesopelagics in their diet increased from 1.8 to 44.6%. This may over-emphasize the importance of mesopelagics in the diet of this group.

4.5. Large demersals

The biomass for this group in the model area for 1974 calculated from German trawl data was 0.027 t.km^{-2}. However, neither of these species is considered adequately sampled by demersal trawls. Therefore in order to fit the catches the figure was increased to 0.15 t.km^{-2}.The P/B ratio was increased from 0.16 year^{-1} to 0.19 year^{-1}, as the main catch of this group was for tusk, which has a P/B of 0.19 year^{-1}.

4.6. Skates and rays

The biomass for this group in the model area for 1974 calculated from German trawl data was 0.0007 t.km^{-2}. It was assumed that this group is not effectively caught by the trawls as this biomass was too low to support the catch data. Therefore the biomass of this group was increased to 0.013 t.km^{-2} to fit the catches. Similarly, the P/B ratio was increased from 0.14 year^{-1} to 0.2 year^{-1} to fit the model as the main species caught has a higher P/B ratio. The predation of intermediate and deep sharks on skates and rays were assumed as no data were available on predation on this group. The predation of skates and rays on benthopelagic fish was reduced from 7.1% to 1%, and the contribution of Chimaera reduced from 86.7% to 5%, as it was felt the contribution of these groups to the diet of skates and rays was too high and not reflective of our understanding of the diet and feeding mode of these species. The remainder was added to polychaetes (1%) and other benthic invertebrates (55.1%) reflecting the known importance of these groups in the diet of the skates and rays.

4.7. Large Coryphaenoides

The virgin stock biomass for Coryphaenoides was estimated as 48,758 tonnes for the area of the model (or 0.646 t.km-2) (Basson et al., 2002), which was significantly higher than the biomass estimated from German trawl data (0.26 t.km^{-2}). However, both were too low to fit the known catches of this species, and a biomass of 1.3 t.km^{-}^{2} was needed. To fit the model the P/B of adult Coryphaenoides was also increased from 0.1 year^{-1} to 0.15 year^{-1}. However, this figure may be unacceptably high. The predation by intermediate sharks was reduced from 3.5% to 0.5% and 3% added to Baird's smooth head. Predation by both blue ling and ling on adult *Coryphaenoides* was reduced from 6% to 1% and added to argentine to allow the model to balance.

4.8. Small Coryphaenoides

It was assumed that small Coryphaenoides were preyed on by shallow, intermediate and deep sharks, ling and blue ling. However the assumed figure of a 6% contribution to the diets of blue ling and ling was too high to allow the model to balance. The contribution of small Coryphaenoides was therefore reduced to 0.5%

and the remainer added to argentine. There are no discards of small Coryphaenoides in the model, as it was felt that juveniles would not (or rarely) be retained in the net.

4.9. Monkfish

The biomass for this group in the model area for 1974 calculated from German trawl data was 0.04 t.km^{-2}. This figure was too low to support the catch data for the region and thus the biomass was increased to 0.2 t.km^{-2} to fit the model. Similarly the P/B ratio of this species was increased from the 0.11 year^{-1} (natural mortality (M) calculated from fishbase) to 0.3 year^{-1} (a value more similar to that calculated by Sánchez and Olaso (2004)) to fit the catch estimates. In addition, the vulnerability of blue whiting and benthopelagic fish to monkfish predation had to be reduced to 1.1 (bottom up forcing) to fit the model.

No data were available on predators of monkfish, therefore it was assumed that a small degree of canabalism occurs in this species (0.1%). The calculated diet included a large blue whiting proportion, which was decreased from 73% to 5.4%, with 25.7% assumed being imported into the model. The contribution of benthopelagic fish to the diet of this species was also reduced from 55.7% to 16% to fit benthopelagics (see 4.22). This species was assumed to predate shallow and intermediate sharks, small Coryphaenoides, orange roughy, blue ling, ling, greater forkbeard, Baird's smoothhead, Kaup's arrowtooth eel and megrim (0.001%).

4.10. Orange roughy

The biomass for orange roughy in the model area for 1974 calculated from German trawl data was 2.8 t.km^{-2}. However, virgin stock biomass was estimated at 6000t (95% confidence limits: 5400-6300t) (0.025 t.km^{-2}) for the whole of area VI (Basson et al., 2002). As the two figures were vastly different (most likely as a result of the aggregating behavior of this species) we allowed the model to estimate the biomass of this group providing a biomass of 0.1 t.km^{-2}. In addition, the 1974 biomass figure was removed from the time series data as it was felt that a spawning aggregation was encountered that year producing a significantly higher estimate of biomass than was attained from any of the other years from which data were available. The 11.7% contribution of benthopelagics to the diet of orange roughy was reduced to 5% and 6.7% added to other benthic invertebrates to fit the benthopelagics.

4.11. Argentine

The biomass for argentine in the model area for 1974 calculated from German trawl data was 0.003 t.km^{-2}. Argentine is not well sampled by demersal trawls therefore the biomass was left to be estimated by Ecopath using an EE of 0.95. Similarly, the P/B ratio was increased from 0.19 year^{-1} to 0.28 year^{-1}, a figure similar to that used by an Ecopath model constructed for the Bay of Biscay. The calculated diet of argentine included 7.1% other benthic invertebrates, which was reduced to 0.1% and 7% added to Polychaetes to balance invertebrates.

4.12. Blue whiting

The biomass for blue whiting in the model area for 1974 calculated from German trawl data was 0.003 t.km^{-2}. Blue whiting is not well sampled by Granton trawls and so this figure was increased to 7 t.km^{-2} to support the calculated catch for this species. The P/B ratio used in the first instance of the model was 0.3 year^{-1}, which

was similar to that used in an Ecopath model of the Faroes EEZ (Zeller and Reinert, 2004). Other P/B values used in models developed for neighbouring areas were 0.48 year^{-1} for the Cantabrian Sea (Sánchez and Olaso, 2004) and 0.432 year^{-1} for the Bay of Biscay (Ainsworth et al., 2001). In order to balance and fit the model we used a P/B ratio of 0.45 year^{-1}. The Q/B ratio was calculated by using a P/Q ratio of 0.1.

Changes to the diet of blue whiting were required in order to balance the model. The diet data used in the model were taken from Cabral and Murta (2002). These authors investigated the diet for his species from Portuguese coastal waters. Thus the diet data used for this species are not entirely appropriate for this model. To get a realistic biomass estimate of blue whiting and to fit the model we assumed that 50% of their diet was obtained outside the system as blue whiting are known to undertake significant seasonal migrations. Their input diet was then halved to give: 1% cannibalism, 2.5% mesopelagics, 0.5% cephalopods; 17% shrimp and prawns, 28.5% large zooplankton and 0.5% small zooplankton. The proportion of blue whiting in the diet of Kaup's arrowtooth eel, was reduced to 1% to fit and balance this group (see 4.19).

The landings estimates available for blue whiting included landings for all depths of ICES area VIa. It was therefore necessary to prorate the catch to only include those taken from the model area (400-2000m). It was assumed that 15% of the catch was taken from pelagic trawls deeper than 400m.

4.13. Black scabbard fish
The biomass for black scabbard fish in the model area for 1974 calculated from German trawl data was 0.532 t.km^{-2}, while estimates of virgin stock biomass for VIa were approximately 0.029 t.km^{-2} (Basson et al., 2002). In order to fit the catches the biomass had to be increased marginally to 0.6 t.km^{-2}. This figure may be unacceptably high. The P/B ratio of 0.14 year^{-1} (M given in Clarke et al. (2003)) was increased to 0.17 year^{-1} (M calculated by Basson et al. (2002)). In order to balance the black cardinal fish biomass it was assumed that black scabbard fish took a very small proportion of this group (0.01%) as part of its diet. Similarly, to fit the benthopelagic fish the 6.1% of benthopelagic fish in the diet of black scabbardfish was reduced to 1% and the remainder added to cephalopods.

4.14. Blue ling
The biomass for blue ling in the model area for 1974 calculated from German trawl data was 0.059 t.km^{-2}, while the catch for that year was 0.22 t.km^{-2}, highlighting the fact that the estimated biomass was much too low. The virgin stock biomass has been estimated at 0.174 t.km^{-2} (Basson et al., 2002), which is still lower than the catch from that year. Thus the biomass for this group was estimated using an EE of 0.95. The P/B ratio of 0.15 year^{-1} used in the model was the figure for natural mortality for this species calculated from fishbase. However, as this species was being fished in 1974 this figure was increased to 0.2 year^{-1}, which is less than that used in the Bay of Biscay model (0.5 year^{-1}) (Ainsworth et al., 2001). This provided a biomass estimate of 1.1 t.km^{-2}, which is substantially higher than all previous estimates.

The diet data for blue ling used in the model was adapted from Bergstad (1991b) who examined the diet of this species from the Norwegian Deep, thus the diet data

are not entirely appropriate for this model. In addition this species is frequently found with an everted stomach, therefore dietary studies are difficult. For these reasons the diet of blue ling has been adapted to help balance the model. The contribution of adult and juvenile Coryphaenoides to the diet was reduced from 6% to 1% and 6% to 0.5% to balance the model and the remainder was added to argentine. The contribution of benthopelagic fish to the diet of blue ling was reduced from 5.6% to 1% in order to reduce the biomass estimated for benthopelagics (which was unacceptably high). The contribution of large zooplankton to the diet of this species was increased from 0.0095 to 4.7% to compensate for the reductions.

4.15. Ling
The biomass of ling as estimated from German trawl data (0.0000001 t.km^{-2}) was too low to support the catch data, thus Ecopath was allowed to estimate biomass with an EE of 0.95. The P/B ratio used (0.22 year^{-1}) was the figure for natural mortality, however as ling were being fished in 1974 this figure should be higher. It was therefore increased to 0.25 year^{-1}. This is lower than the figure used for this species in the model constructed by Ainsworth et al. (2001) for the Bay of Biscay (0.515 year^{-1}). The diet of ling was not well known, and was based on the diet of blue ling. The high estimates of blue whiting and argentine in the diet were felt to be unrealistic as these species do not generally live in the same depth range. Therefore the diet was altered as follows: The contribution of small Coryphaenoides to their diet was reduced from 6% to 0.5% and the balance added to other benthic invertebrates. The contributions of benthopelagic fish (20%), prawns and shrimp (28.1%), echinoderms (15.5%), polychaetes (15%) and other benthic invertebrates (10%) were all increased, with appropriate decreases in the contribution of blue whiting and argentine.

4.16. Greater forkbeard
The biomass for greater forkbeard in the model area for 1974 calculated from German trawl data was 0.012 t.km^{-2}. This species is not effectively caught in the Granton trawls used for estimating the German biomass. The biomass of this species was therefore increased to 0.1 t.km^{-2} in order to balance the model.

4.17. Baird's smoothhead
The biomass of this group was estimated by the German trawl survey at 208,809t (2.76 t.km^{-2}) in 1974 and 14,749t (0.2 t.km^{-2}) in 1975, thus the estimate is not considered very robust. An intermediate biomass of 1.2 t.km^{-2} was used in order to fit the model (benthopelagic fish). The diet of this species also required modification in order to balance the model. The dietary values used in the present study were based on the prey numbers from Mauchline and Gordon (1983b) converted to weight data using conversion factors developed by this project. Unidentified material, likely to represent part of the contribution of gelatinous zooplankton to the diet, was not taken into account. For these reasons the contribution of benthopelagic fish to the diet of this species was reduced from 38% to 0.5% while the contribution of gelatinous zooplankton was increased from 32% to 69.9% in line with our current understanding of the diet of this species.

4.18. Black cardinal fish
The biomass of black cardinal fish in the model area for 1974 calculated from German trawl data (0.004 t.km^{-2}). This species is known to aggregate on seamounts.

The calculated biomass for this species was therefore thought to be an underestimate as seamounts were not effectively sampled by the German dataset. No data were available on the predators of black cardinal fish. It was therefore assumed that this species is preyed on by large piscivores such as the shallow, intermediate and deep sharks (0.1%), black scabbard fish (0.01%) and blue ling (0.001%).

4.19. Kaup's arrowtooth eel
The biomass (0.07 t.km^{-2}) in the model area for 1974 calculated from German trawl data for Kaup's arrowtooth eel, was too low to balance the model. This species is not well sampled by Granton trawls, we therefore allowed the model to estimate the biomass of this species giving a figure of 1.8 t.km^{-2}. The proportion of blue whiting in their diet was reduced from 77.2% to 1% and the remaining 76.2% added to detritus as this species is a well known scavenger.

4.20. Megrim
The biomass for megrim in the model area for 1974 calculated from German trawl data was 0.00002 t.km^{-2}. This species is not thought to be well sampled by Granton trawl therefore the biomass of this species was increased to 0.0003 t.km^{-2} to fit the model. However, this was not sufficient to fit the catches, and a further increase to a biomass of 0.012 t.km^{-2} was required.

4.21. Mesopelagic fish
No data were available on the biomass of mesopelagic fish in the Rockall Trough and this group is not well sampled by demersal trawls. Ecopath was therefore allowed to estimate the biomass of this group, proving a figure of 18.3 t.km^{-2}. The diet of the mesopelagic fish group was based on the diet of the silvery pout (*Gadiculus argenteus thori*) described in Mauchline and Gordon (1984a). This included 72.8% cannibalism. Based on available text on the diet of other members of this group it was felt the calculated diet did not well reflect the diet of this group. Therefore the cannibalism figure was reduced to 5% and the proportion of large and small zooplankton in the diet of this group increased to 70% and 25% respectively.

4.22. Benthopelagic fish
The benthopelagic fish biomass in the model area for 1974 calculated from German trawl data was 0.025 t.km^{-2}. This figure was suspected to be too low due to issues concerning the catchability of some members of this group and it was therefore estimated by Ecopath (1.51 t.km^{-2}) using an EE of 0.95. In addition the diet of their predators had to be changed. In order to fit / balance the model the proportion of benthopelagic fish in the diet of intermediate sharks, skates and rays, orange roughy, ling, blue ling, black scabbardfish and Baird's smoothhead was reduced (see above for justification). This then resulted in a new estimated biomass of 0.32 t.km^{-2}.

The diet of this group was calculated using the prey numbers data from Mauchline and Gordon (1980), Mauchline and Gordon (1984a) and Mauchline and Gordon (1985) converted to weight data using conversion factors developed by this project. As a result of the conversion factors used for unidentified fish it is likely that the contribution of benthopelagic fish to the diet of this group has been over estimated. The cannibalism within this group was therefore reduced from 6.4% to 1% to balance

the model. The contribution of small zooplankton to the diet of this group was increased to 6.2% to compensate.

4.23. Benthic teleost fish
The benthic teleost biomass in the model area for 1974 calculated from German trawl data was 0.013 t.km^{-2}. This group was not believed to be well sampled by the German trawl and thus ecopath was allowed to estimate the biomass, giving a figure of 0.061 t.km^{-2}. The contribution of benthopelagic fish to the diet of this group was reduced from 4% to 1% to fit that group, and the extra 3% was added to other benthic invertebrates.

4.24. Chimaera
The biomass of Chimaera in the German trawl data was 0.108 t.km^{-2}. This figure was too high to fit the model after the proportion of Chimaera in the diet of intermediate sharks and skates and rays were reduced from 3.5% to 1% and from 86.7% to 10% respectively. Ecopath was therefore allowed to estimate the biomass, giving a figure of 0.098 t.km^{-2} for this species. This figure is only marginally different from the trawl estimated biomass and thus was felt to be acceptable.

4.25. Cephalopods
The biomass of cephalopods from the Porcupine Seabight was estimated at 0.08 t.km^{-2}. This figure was suspected to be a gross under estimate for this group (see 3.25 for explanation) and was in fact too low to allow the model to balance. Ecopath estimated a biomass for this group of 1.2 t.km^{-2}. The contribution of cephalopods to the diet of intermediate sharks was increased to compensate for a necessary decrease in the contribution of large demersals to the diet of intermediate sharks (see 4.3 for explanation). However, the contribution of cephalopods to the diet of intermediate sharks was already likely to be an over estimate and thus this increase may be unacceptable. Cephalopods were reduced more than 50% in importance in the diet of blue whiting to 0.1% and the rest added to imports to reduce the estimated biomass of cephalopods to a more realistic figure.

4.26. Prawns and shrimp
The biomass of prawns and shrimp from the Porcupine Seabight was estimated at 0.03 t.km^{-2}. This figure was thought to be a gross underestimate (see 3.26 for explanation), therefore Ecopath was allowed to estimate the biomass of this group providing a figure of 4.2 t.km^{-2} to balance the model. This figure is more in line with the figures used in Ecopath models constructed for neighbouring sea areas (see 3.26). The diet of prawns and shrimp was based on the diet of shallow water benthic species and therefore was not entirely appropriate for deep-water benthic and pelagic species. The contribution of benthic invertebrates to the diet of this group was reduced from 14.7% to 5% to balance the model, while the contribution of large zooplankton was increased from 0 to 9.7% to compensate and reflect the likely importance of zooplankton in the diet of this group. The proportion of prawns and shrimps in the diet of blue whiting was increased to compensate for changes in the proportion of cephalopods (see 4.12).

4.27. Gelatinous plankton
The proportion of gelatinous zooplankton in the diet of Baird's smoothhead was increased from 32% to 69.5% (see 4.17 for explanation).

4.28. Large zooplankton

The biomass of large zooplankton estimated by the model was significantly higher than that used in models of neighbouring areas (Ainsworth et al., 2001; Haggan and Pitcher, 2005). In order to reduce the estimated biomass for this group to a more realistic level the cannibalism of large zooplankton was reduced from 3.8% to 1% and the difference (2.8%) added to small zooplankton. In addition the large zooplankton in the diet of blue whiting was reduced from 57% to 28.5%, with the difference added to shrimp and prawns, again to reduce the estimated biomass of large zooplankton. The contribution of large zooplankton to the diets of blue ling, mesopelagics and prawns and shrimp was increased from 0.001% to 4.7% (see 4.14 for explanation), 25.8% to 70% (see 4.21 for explanation), and 0 to 9.7% (see 4.26 for explanation) respectivly.

4.29. Small zooplankton

The contribution of small zooplankton to the diet of mesopelagics and benthopelagics was increased from 13% to 25% (see 4.21 for explanation) and from 0.7% to 6.2% (see 4.22 for explanation) respectively.

4.30. Polychaetes

The contribution of polychaetes to the diet of argentine and benthic invertebrates was increased from 1% to 8% (see 4.11 for explanation) and from 0 to 10% (see 4.32 for explanation) respectively, while they were added to the diet of ling (15%).

4.31. Echinoderms

Echinoderms were added to the diet of ling (15.5%) to fit the model (see 4.15 for explanation).

4.32. Other benthic invertebrates

Other bentic invertebrates had to be added to the ling diet as no definitive diet for this species was available (10%) (see 4.15 for explanation). In addition, the contribution of 'other benthic invertebrates' to the diet of argentine was reduced from 7.1% to 0.1% with the difference (7%) added to polychaetes. Similarly, the contribution of 'other benthic invertebrates' to the diet of prawns and shrimp was reduced from 14.7% to 5% with the difference added to large zooplankton, and the cannibalism of 20% was reduced to 5% with the difference added to polychaetes (10%) and detritus (5%).

4.33. Phytoplankton

No changes were made to this group.

4.34. Detritus

Detritus was added to the diet of Kaup's arrowtooth eel as they are thought to be largely scavengers (see 4.19 for explanation). The contribution of detritus to the diet of benthic invertebrates was increased from 60% to 65% (see 4.32 for explanation).

5. Fitted model

An additional step in fitting the model to the time series data involved finding the 20 predator-prey interactions that were the most sensitive to the data and estimating vulnerability parameters. Fitting the model in this way, by changing the predator prey interactions reduced the SS from 265 to 209. The search was only executed in fitting the model to the German and FRS data trends but not the SAMS biomass trends. See vulnerabilities in Table 4.

Table 4: Changes in predator-prey interactions implemented to fit the model to the data (vulnerability parameters, v = 2 = default; v >>2 = top down control; v = 1 = bottom up control). All other predator prey interactions were assumed to be at default.

Prey	Argentine	Blue whiting	Blue ling	Ling	Black cardinal fish	Megrim	Prawns/shrimp	Echinoderms
Argentine			1					
Blue whiting		2	5			2		
Megrim			2	1		2		
Mesopelagic fish	1.1	2		2	2			
Benthopelagic fish			2	1		1		
Benthic teleosts						1		
Chimaera			2	2		1		
Prawns and shrimp	2	>>100	2	7.3	1	>>100	2	
Large zooplankton	2	1.1	2	2	2	1	2	
Echinoderms				>>100	2			2
Other benthic invertebrates	2			2	2	>>100	2	>>100
Phytoplankton							1	
Detritus							>>100	2

Acknowledgements

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Appendices
1. Maps of sample distribution
2. Discard estimates used in the model
3. Fitted model data
4. Balanced fitted diet matrix

Appendix 1: Maps of sample distribution
The following maps show the distribution of trawl hauls by year from which biomass estimates were calculated using the swept area method.

Bathymetry © GEBCO Digital Atlas, British Oceanographic Data Centre on behalf of IOC and IHO 1994 & 1997.

Map 1: 1974
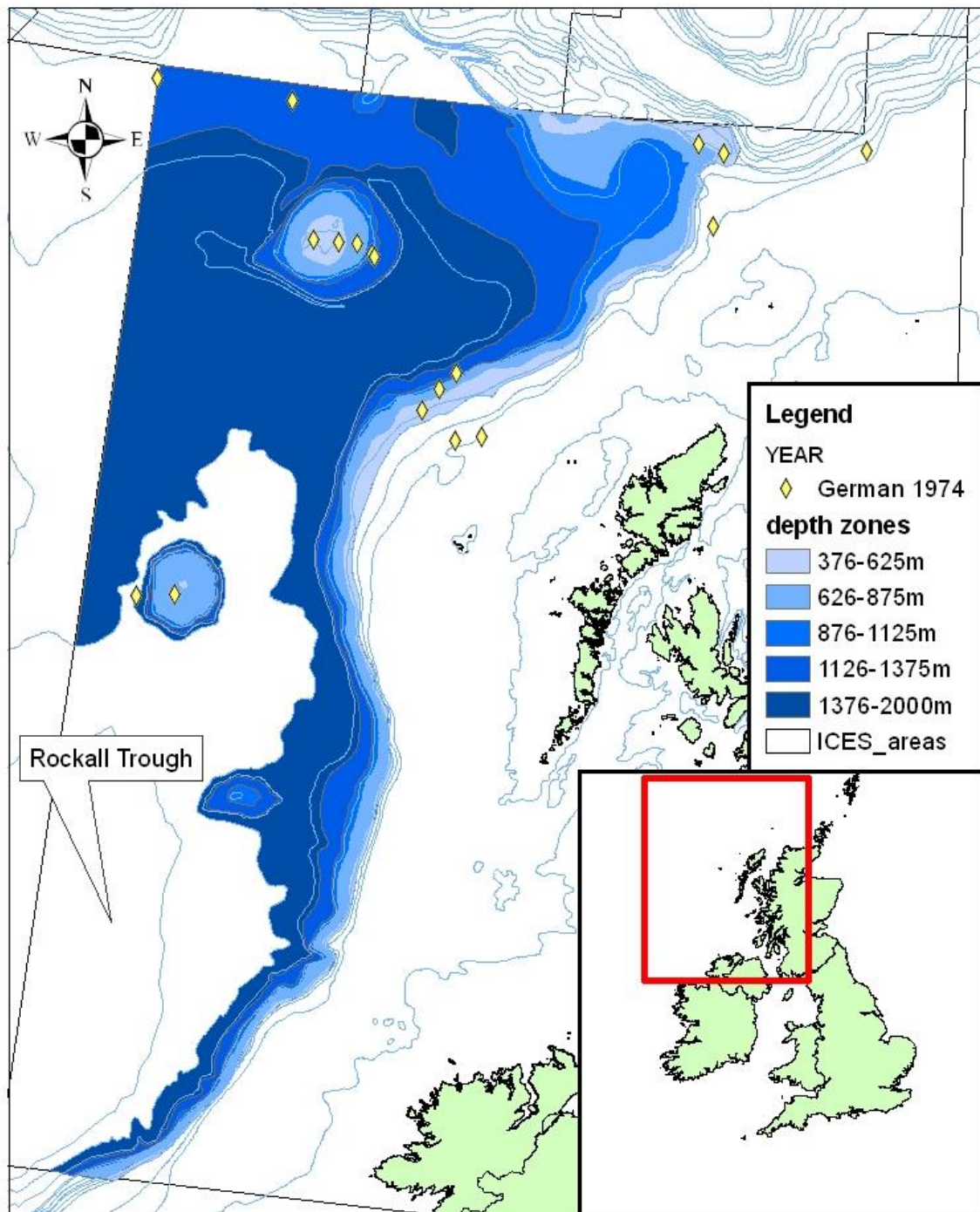
Map 2: 1975
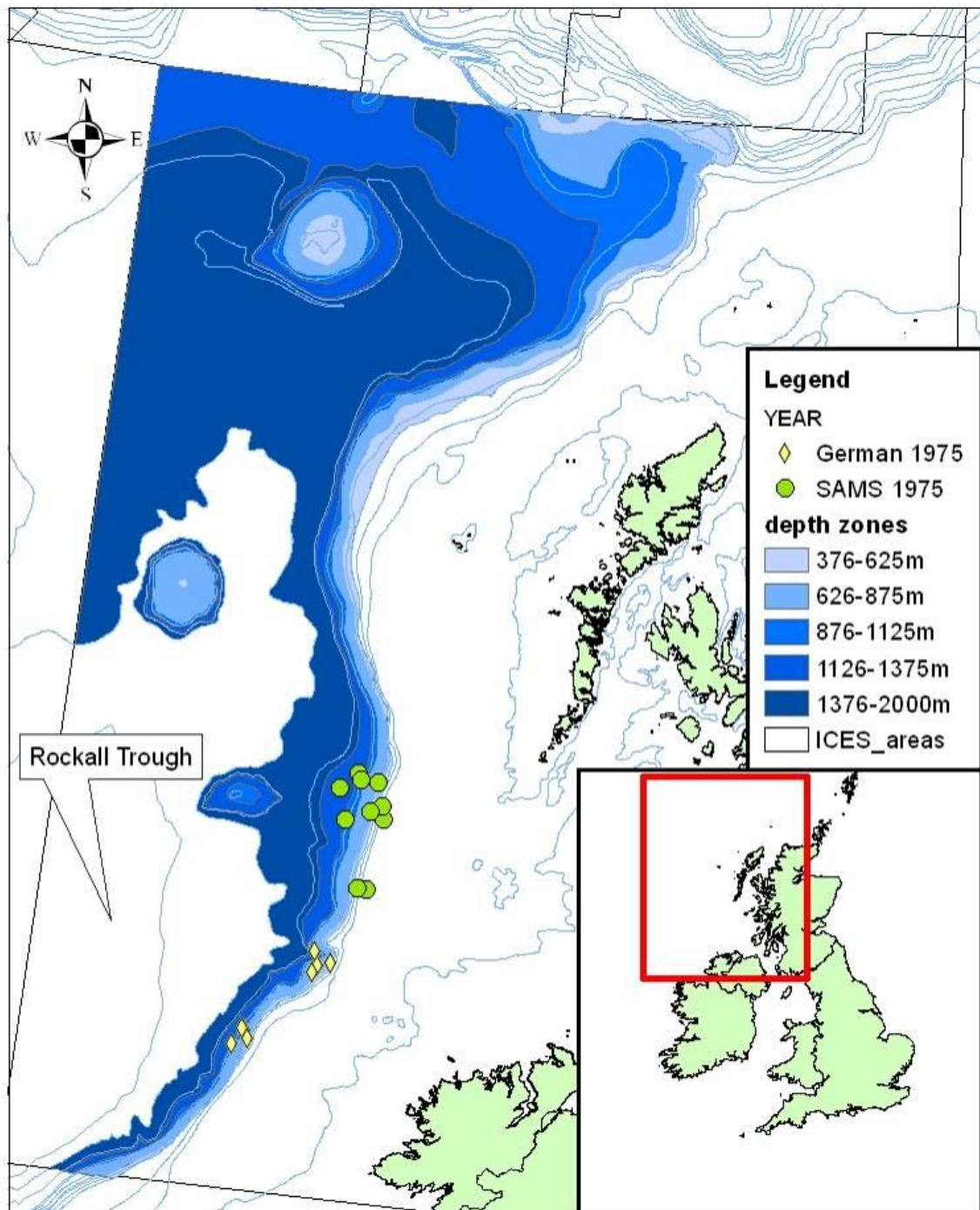
Map 3: 1976
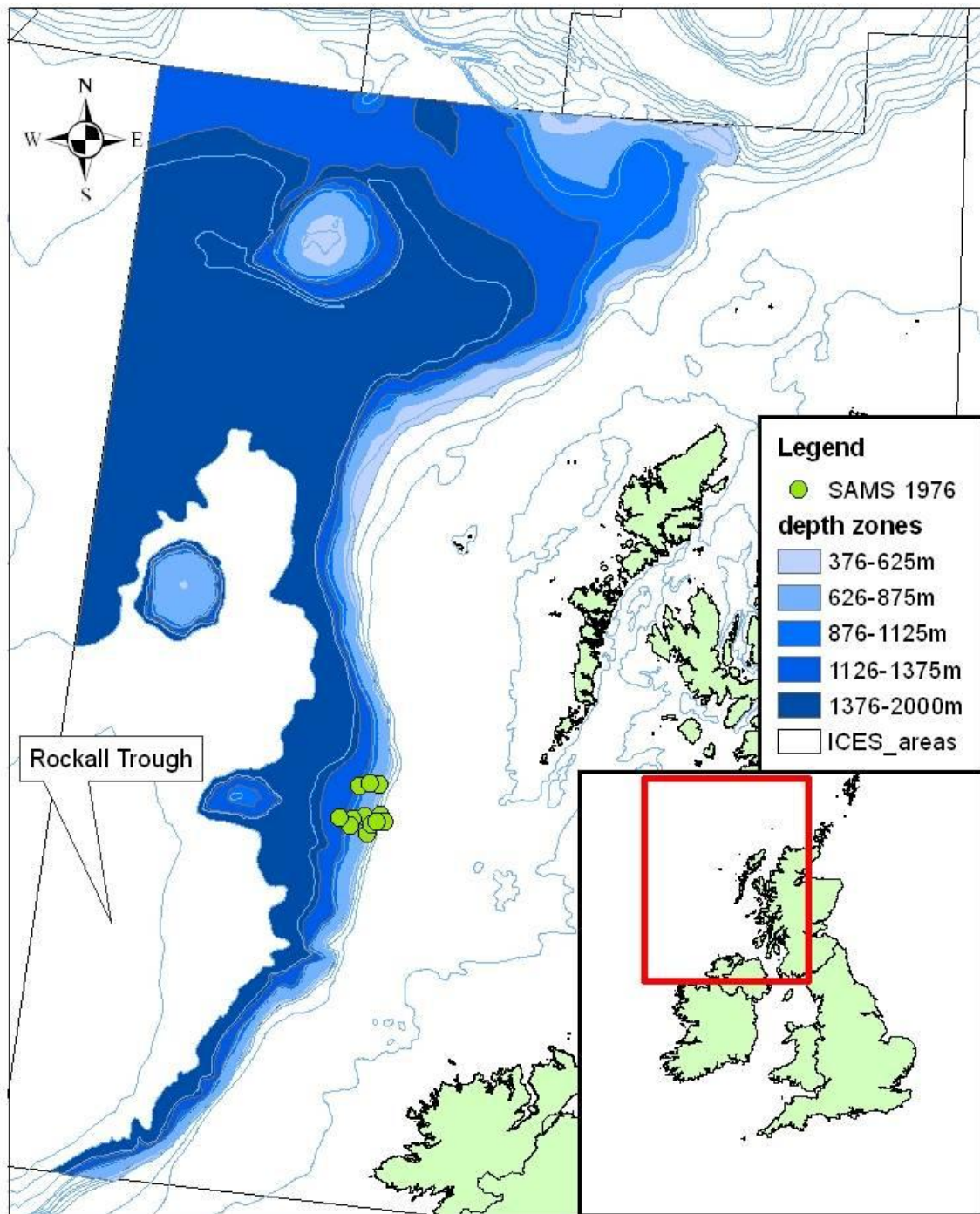
Map 4: 1977
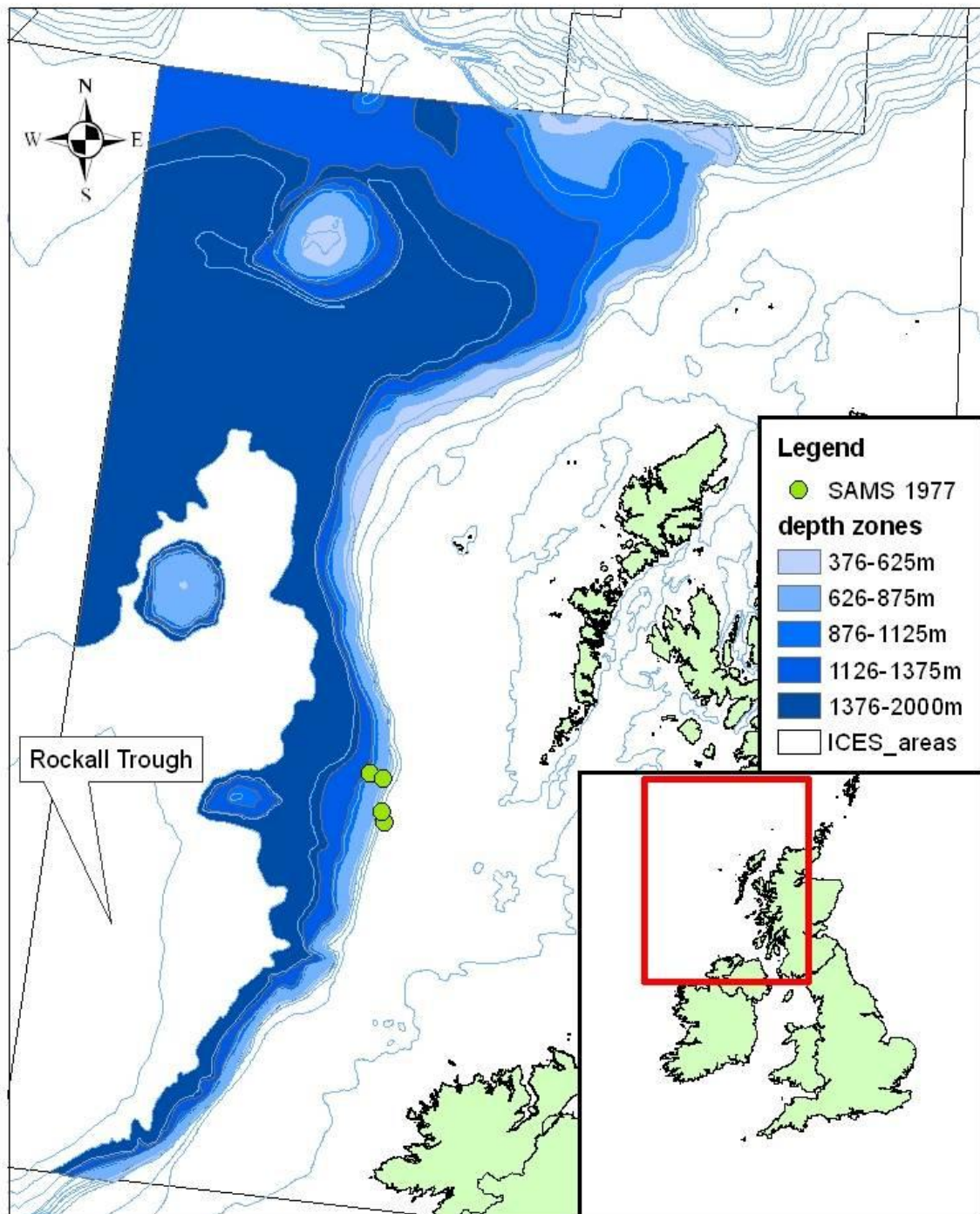
Map 5: 1978
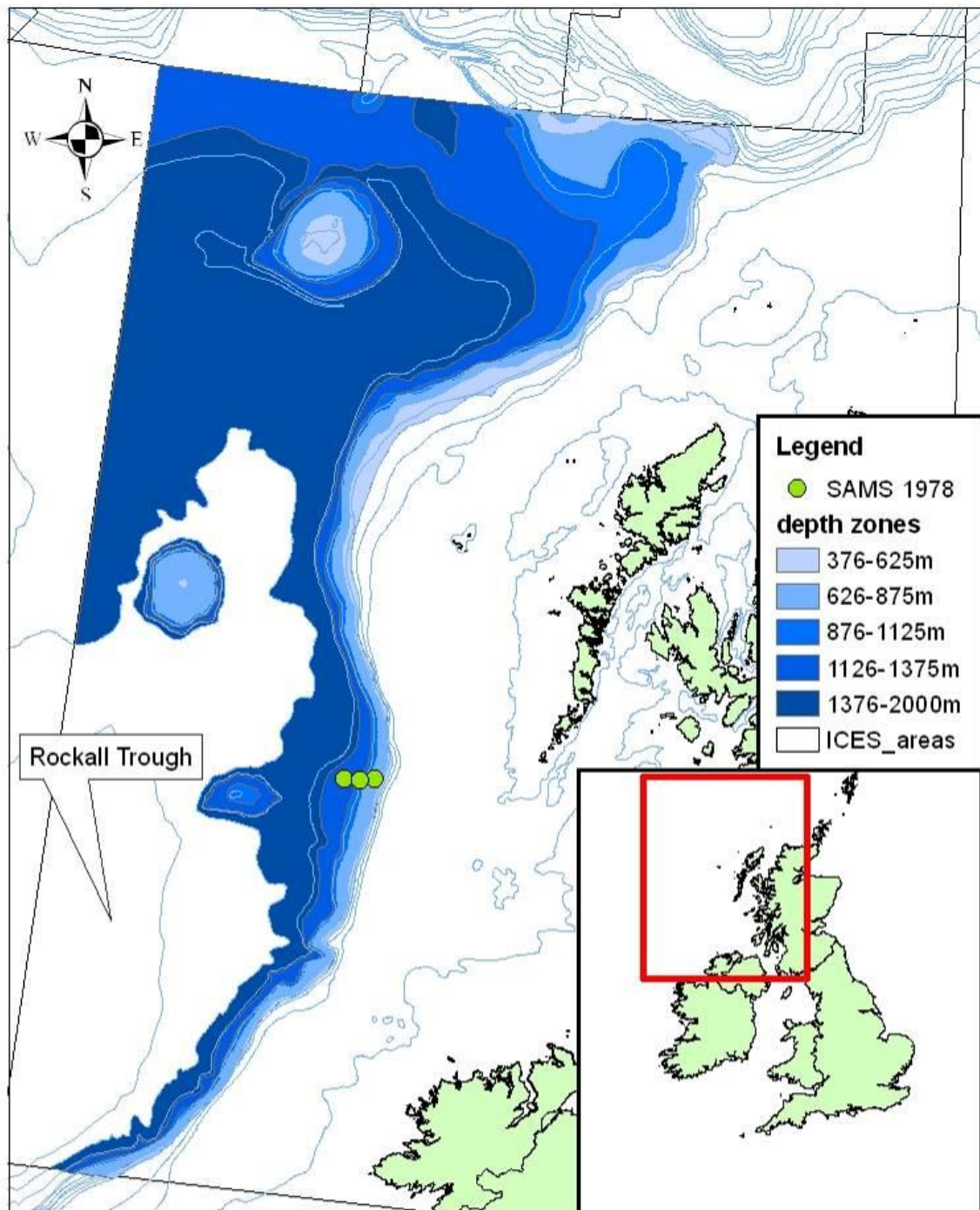
Map 6: 1979
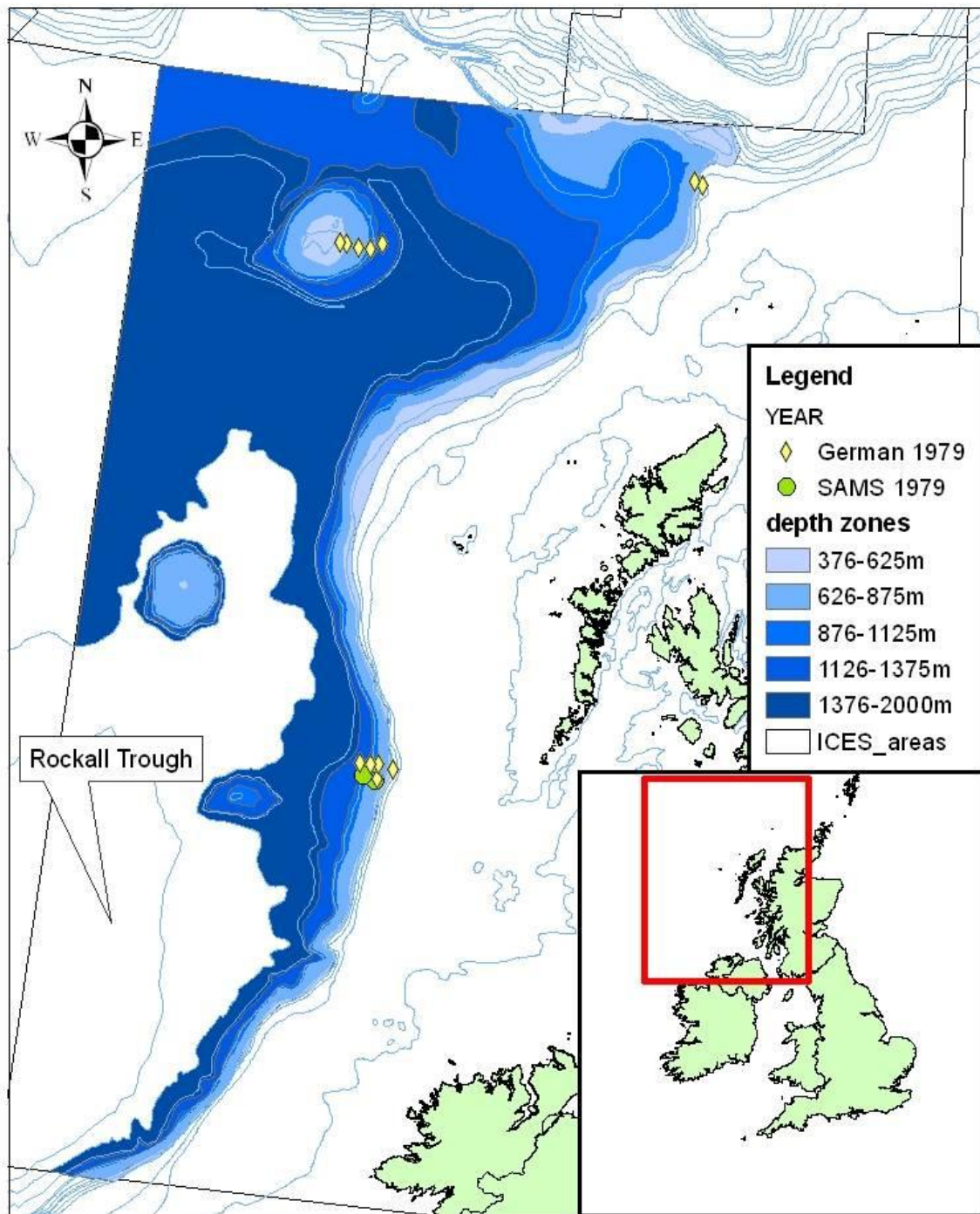
Map 7: 1980
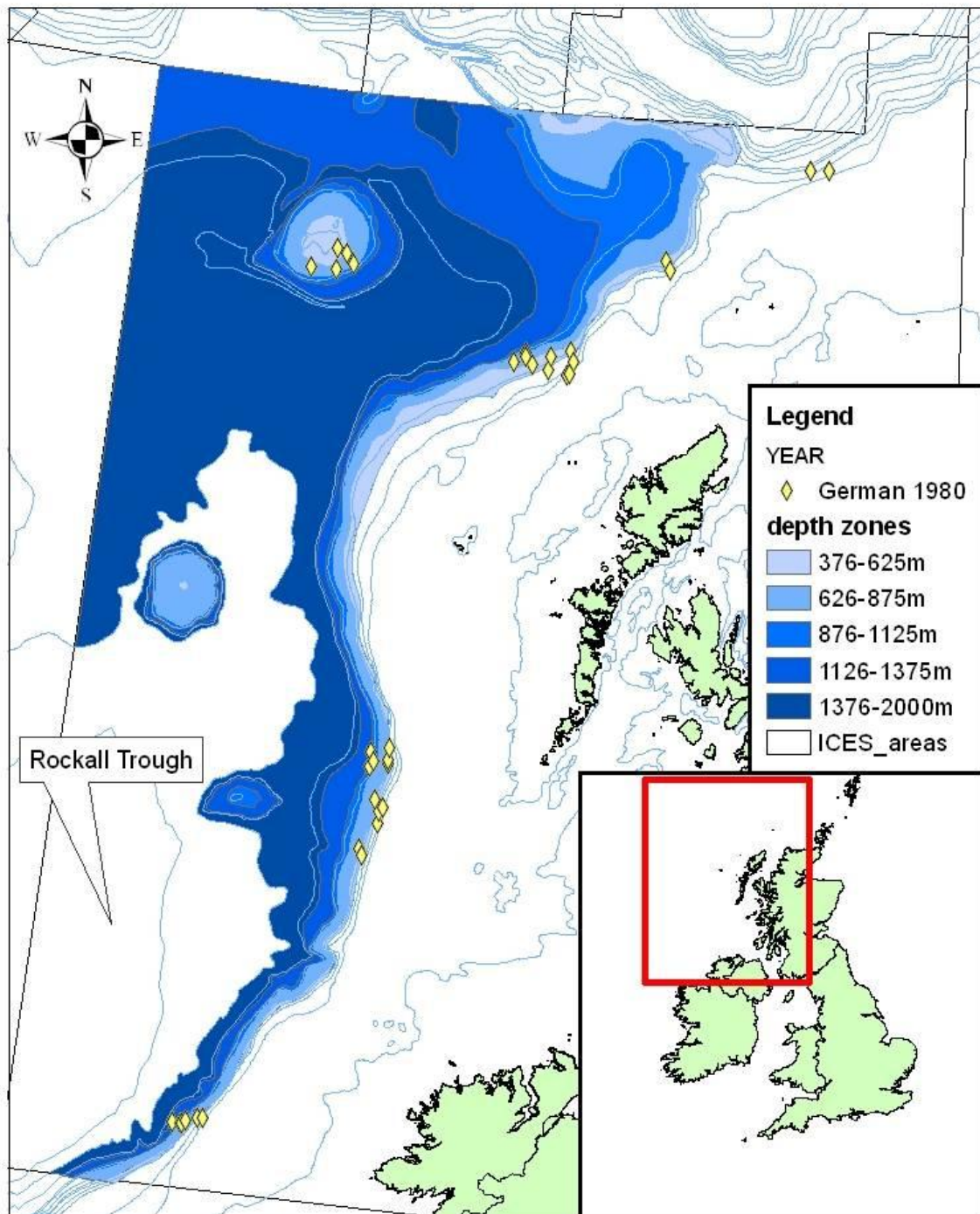
Map 8: 1981
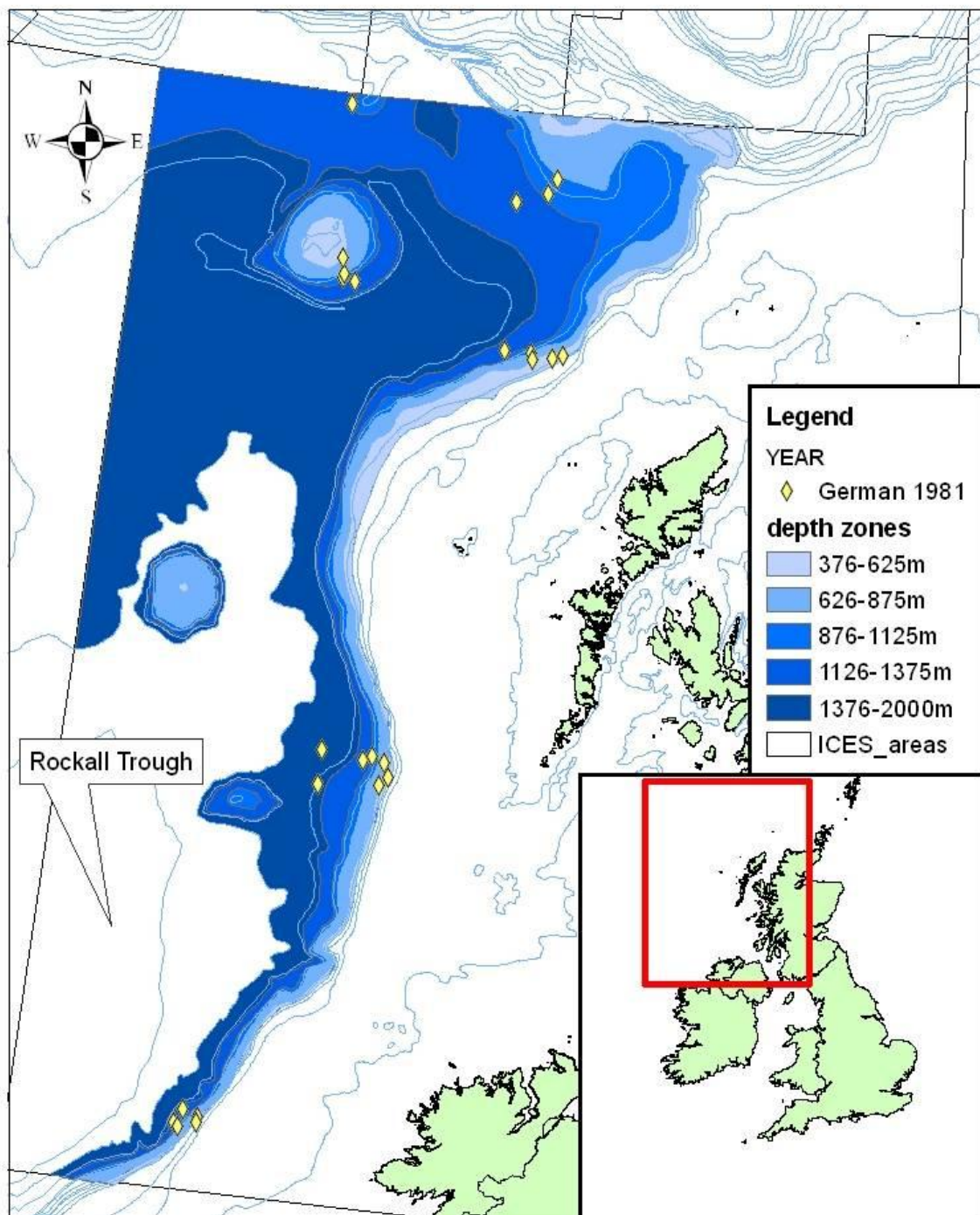
Map 9: 1982
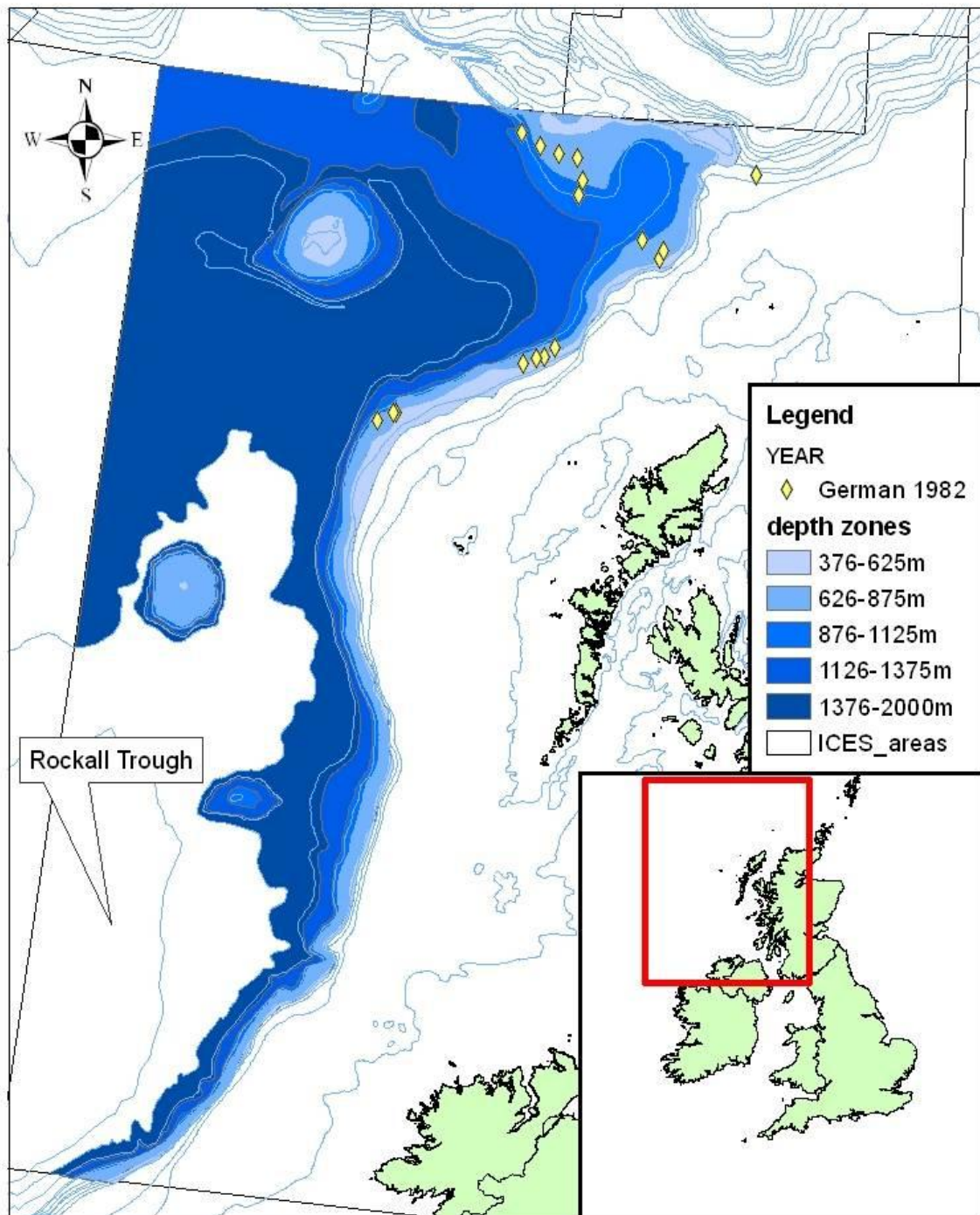
Map 10: 1983
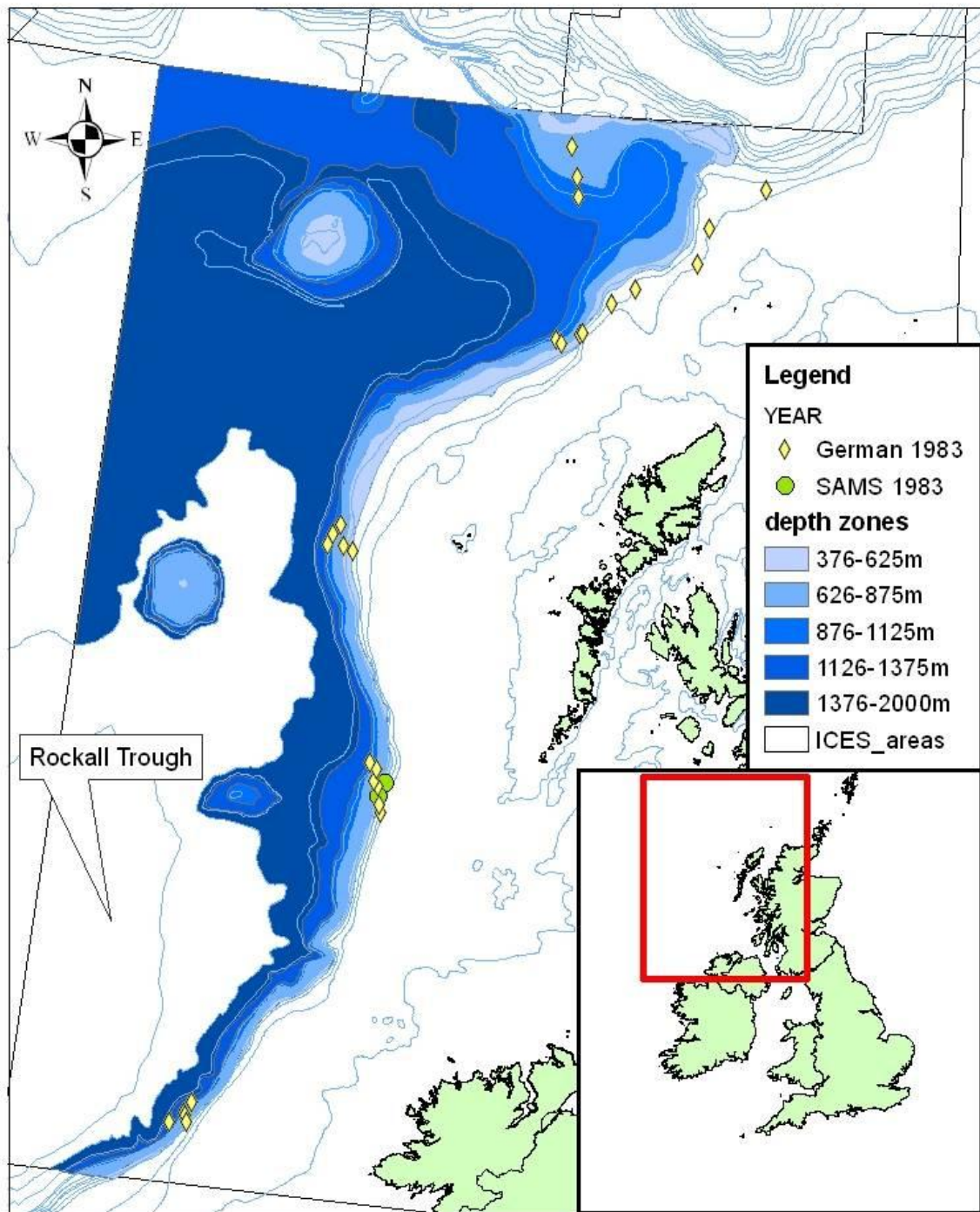
Map 11: 1984
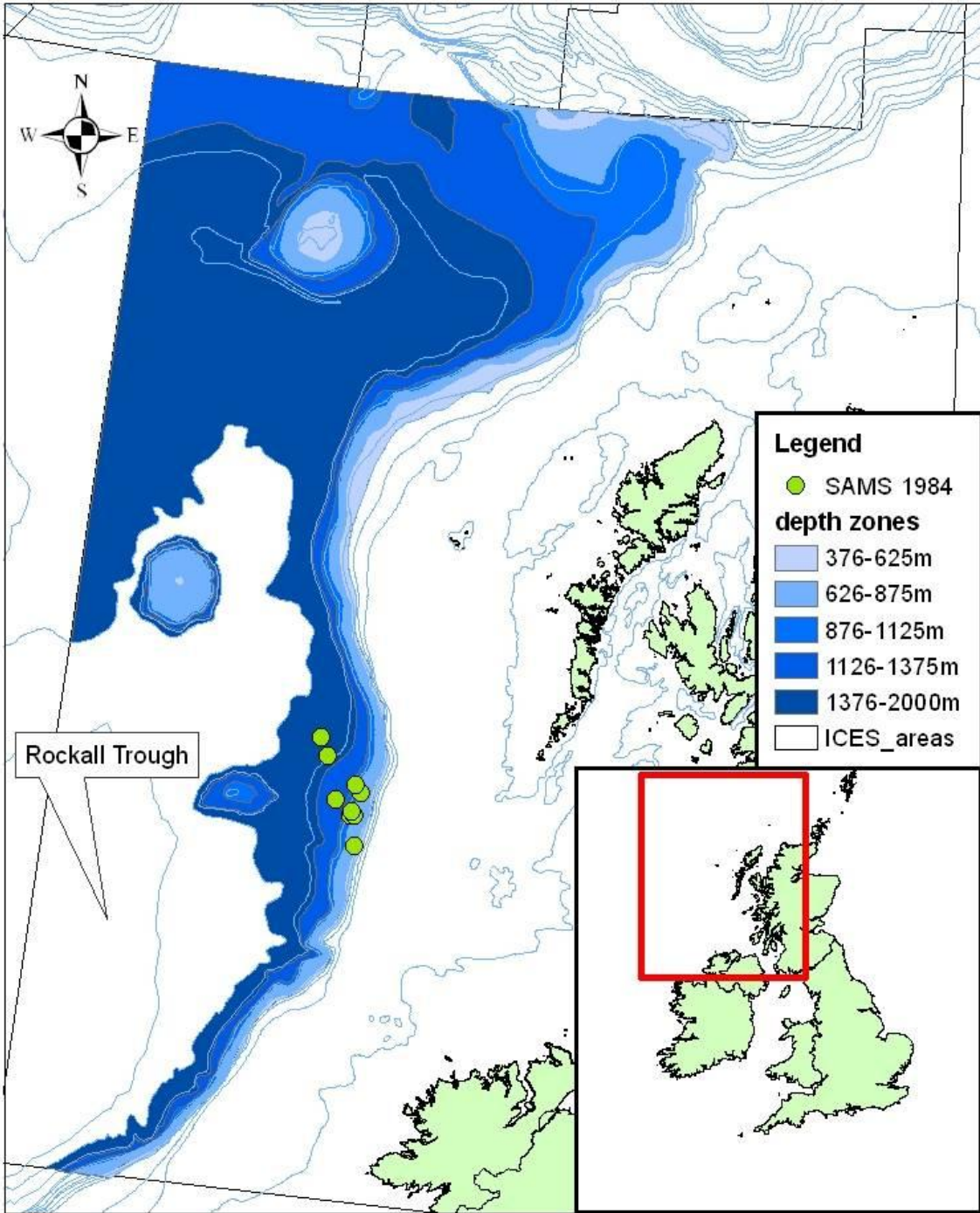
Map 12: 1985
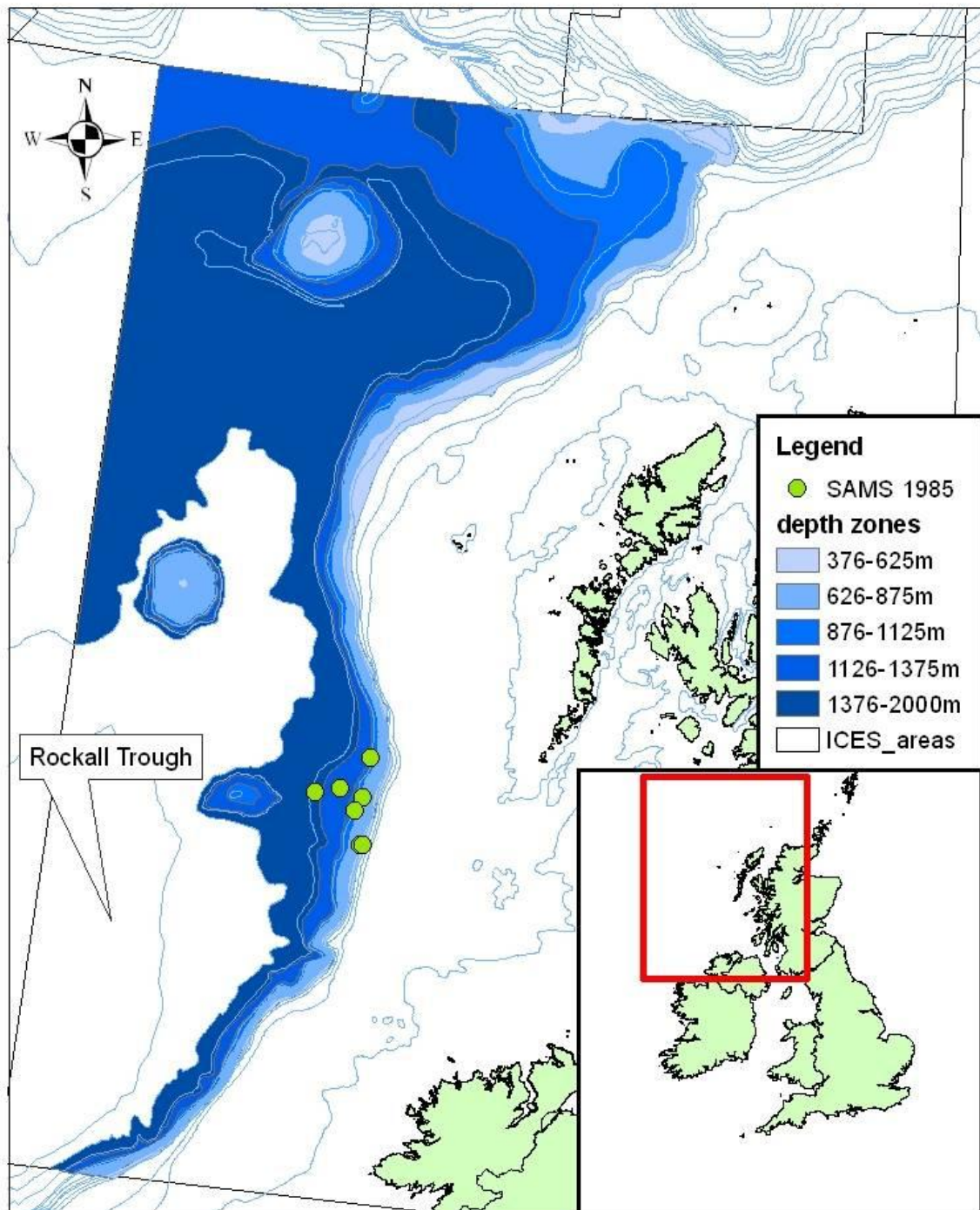
Map 13: 1987
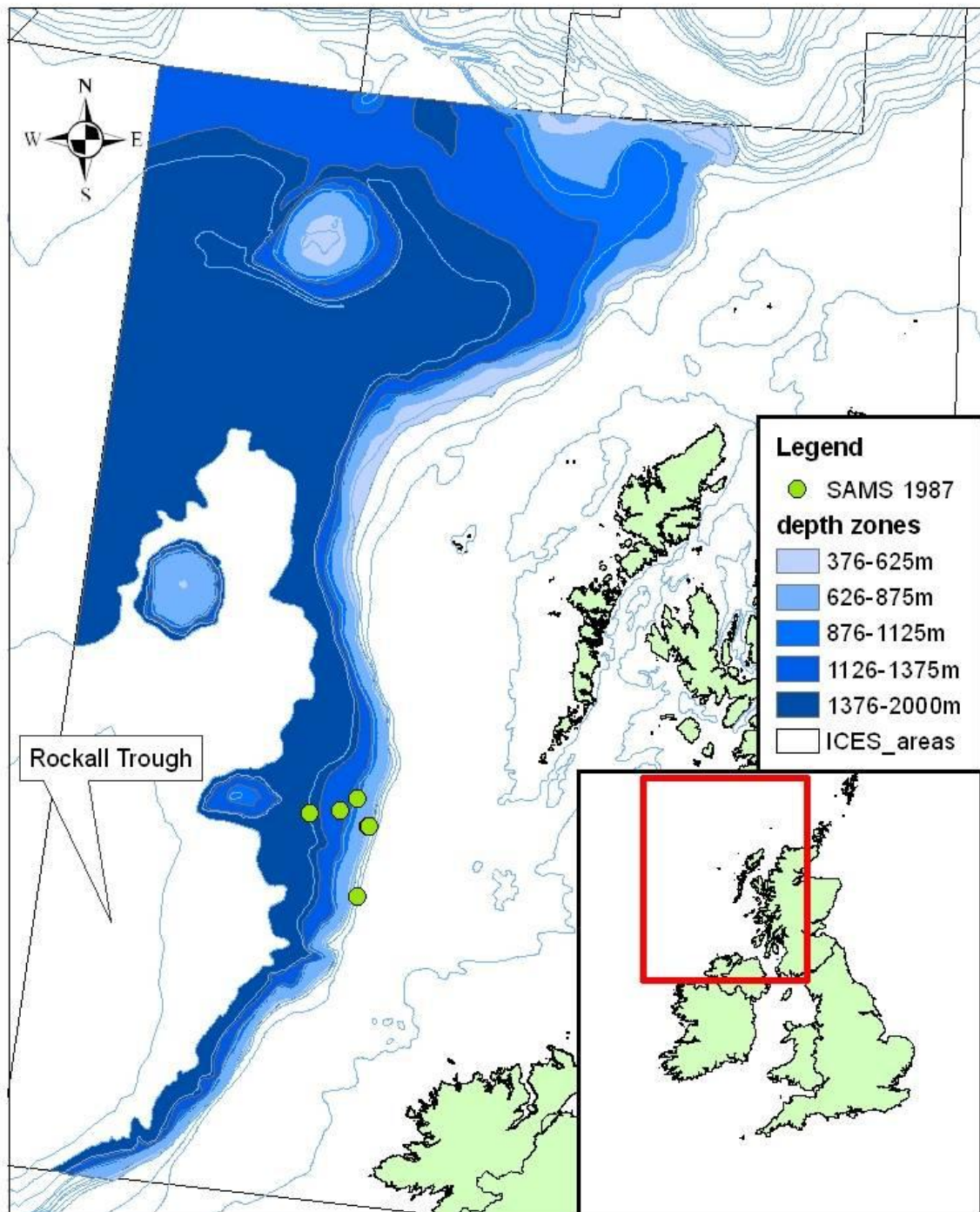
Map 14: 1990
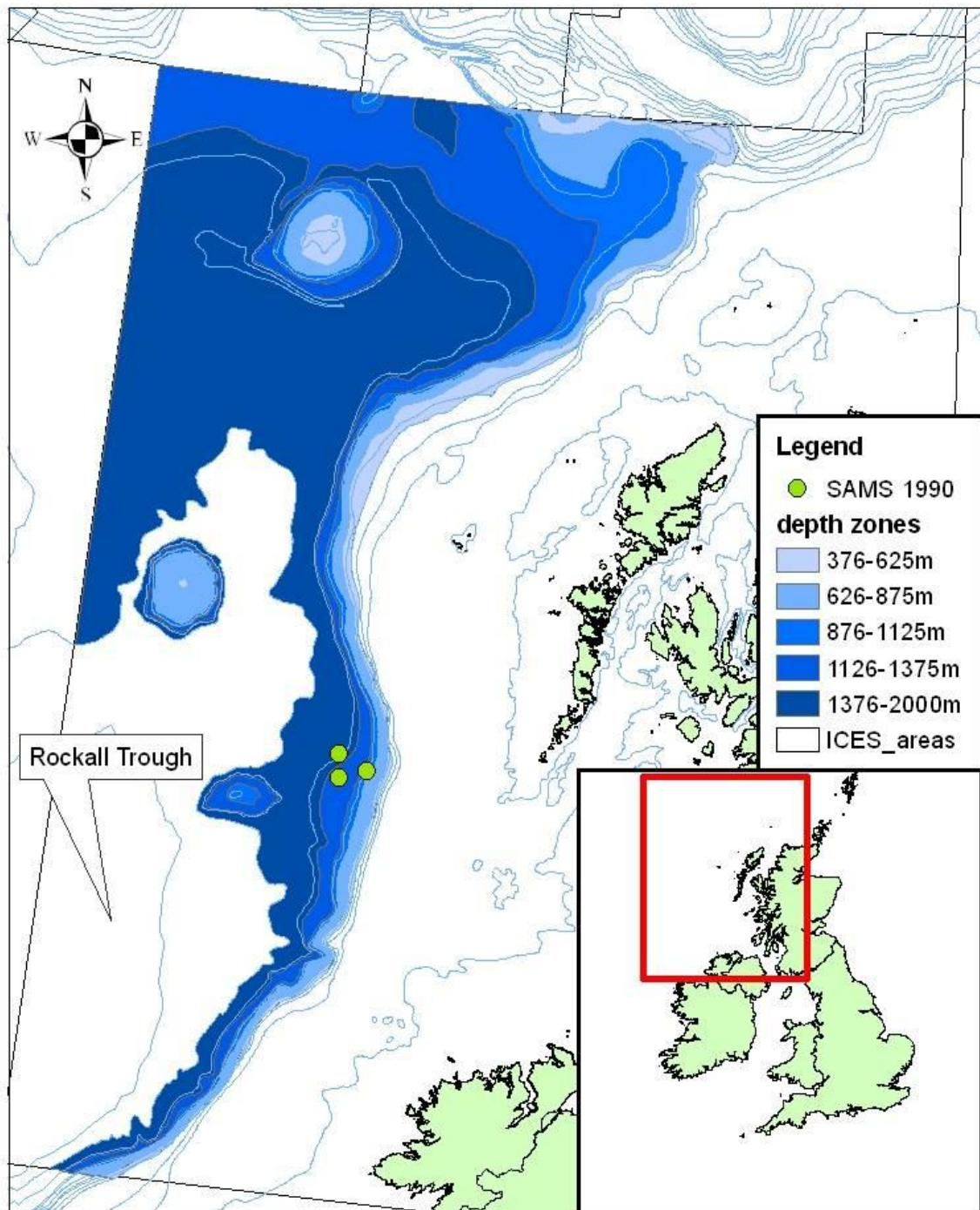
Map 15: 2002
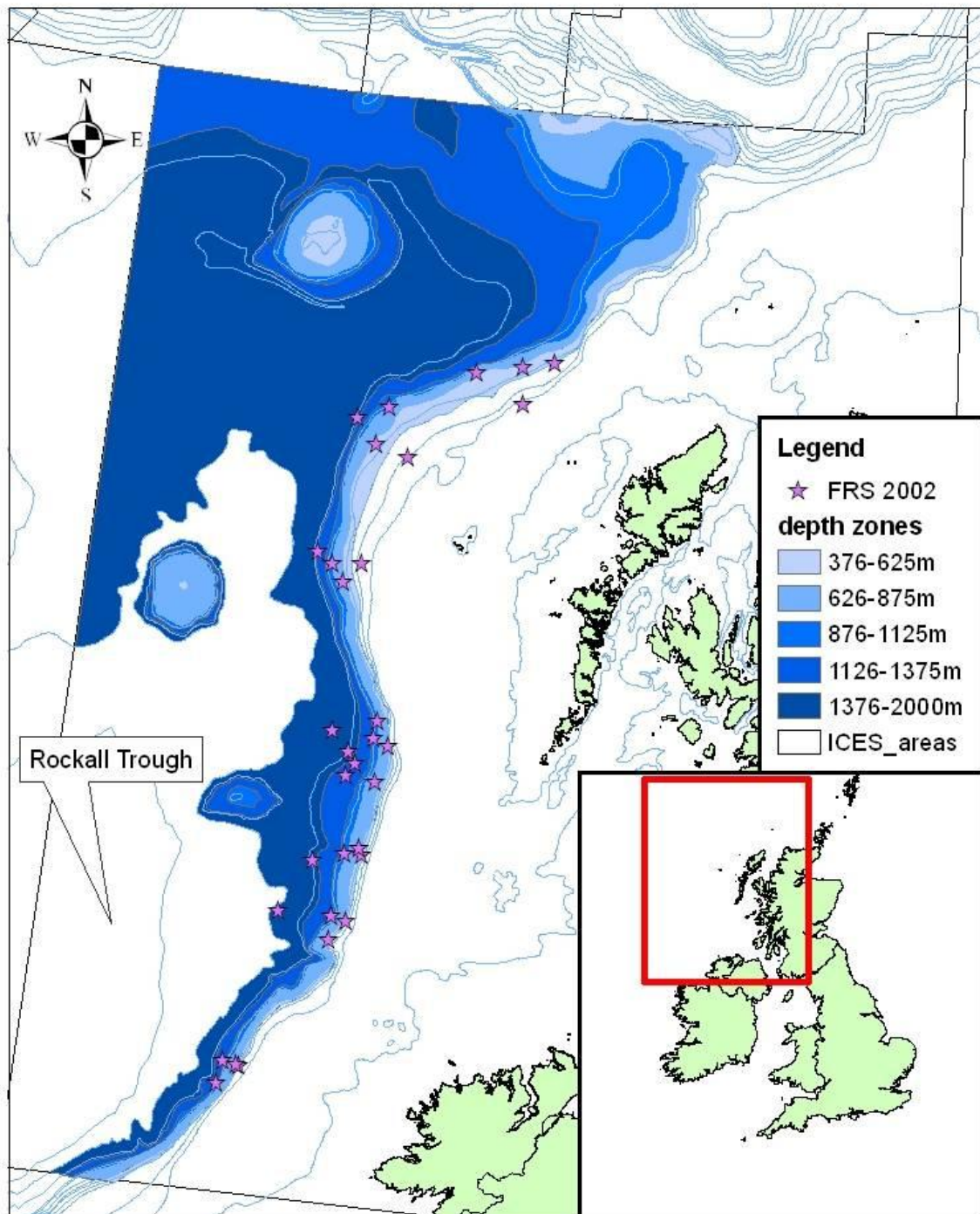
Map 16: 2004
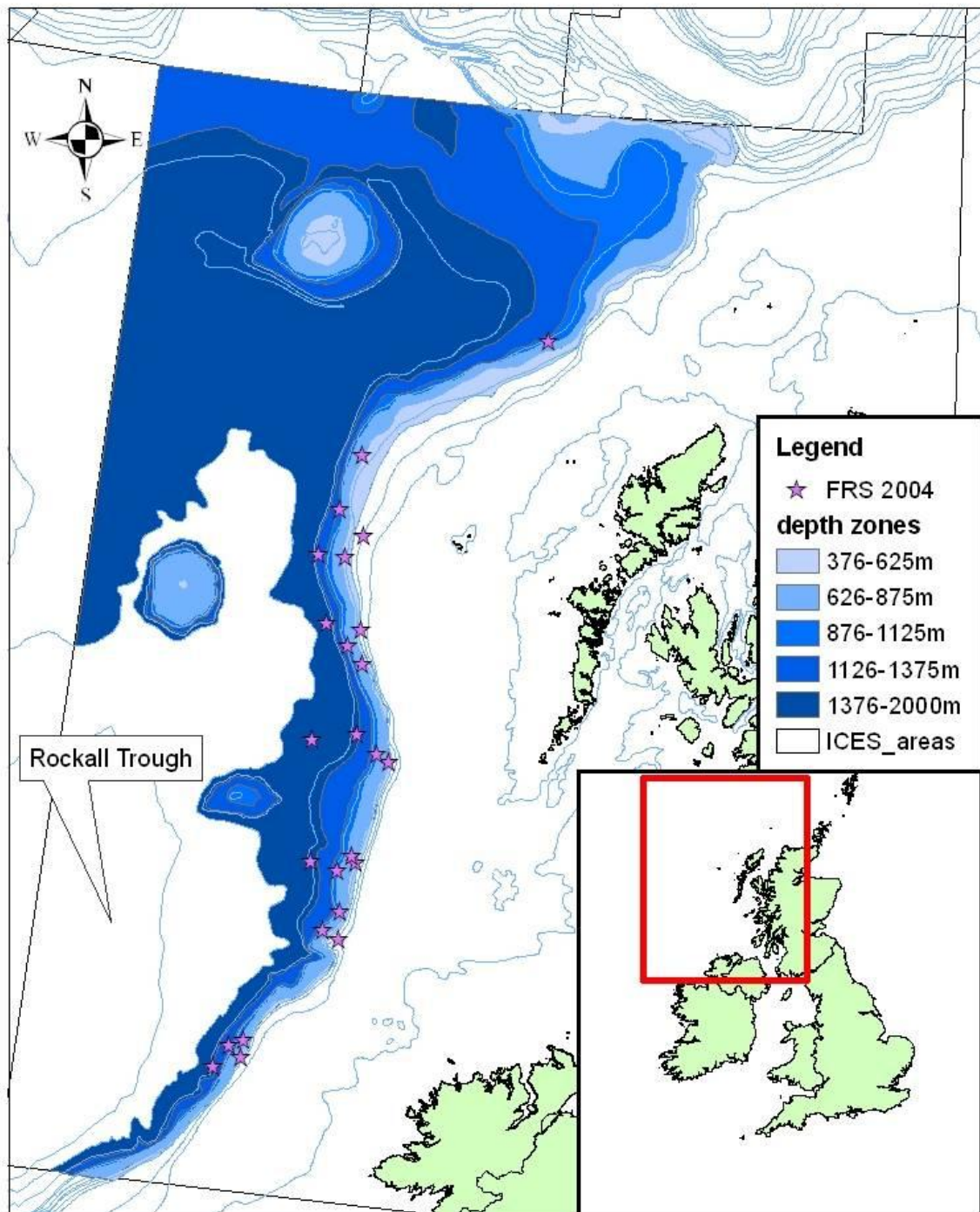
Map 17: 2005
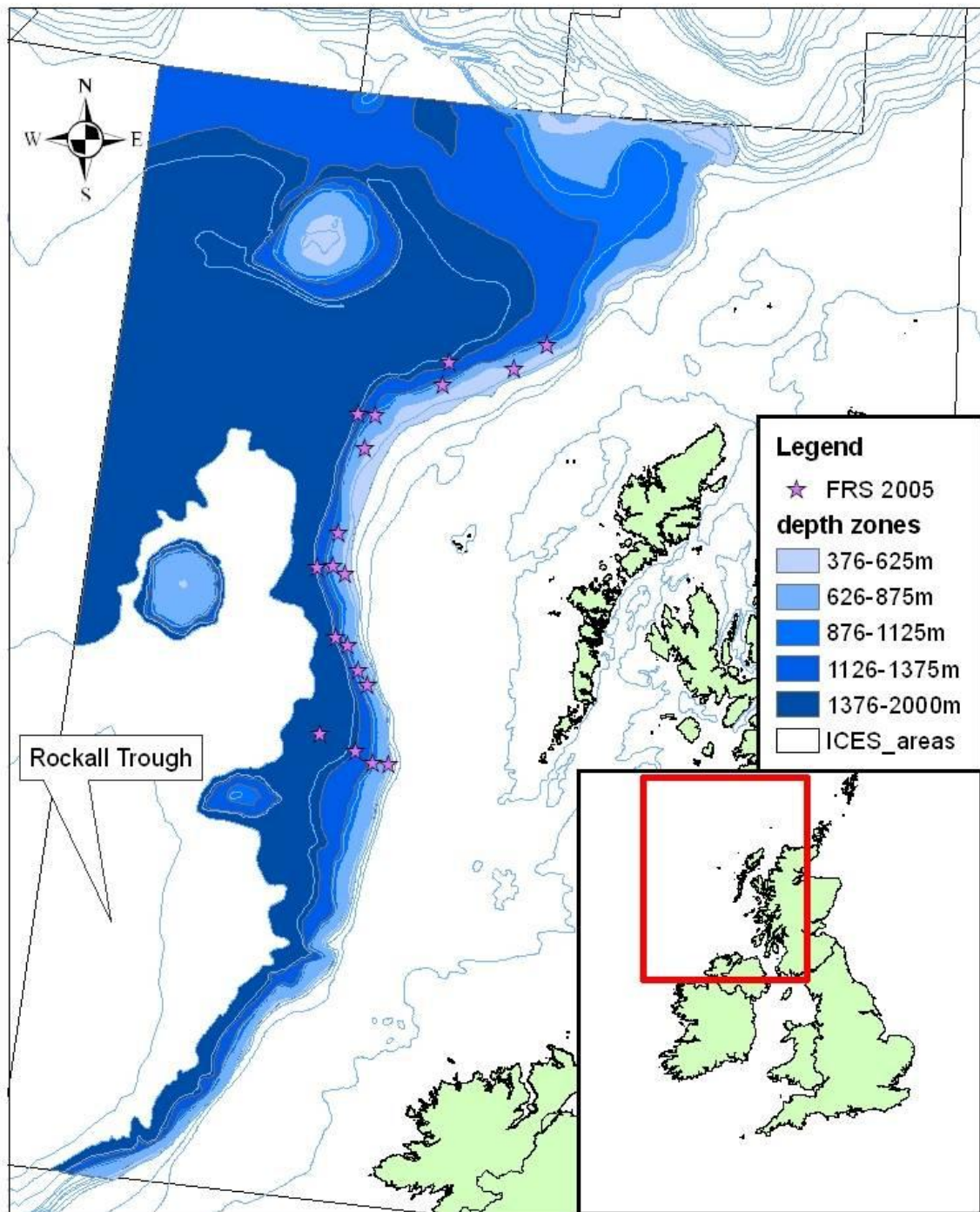
Map 18: 2006
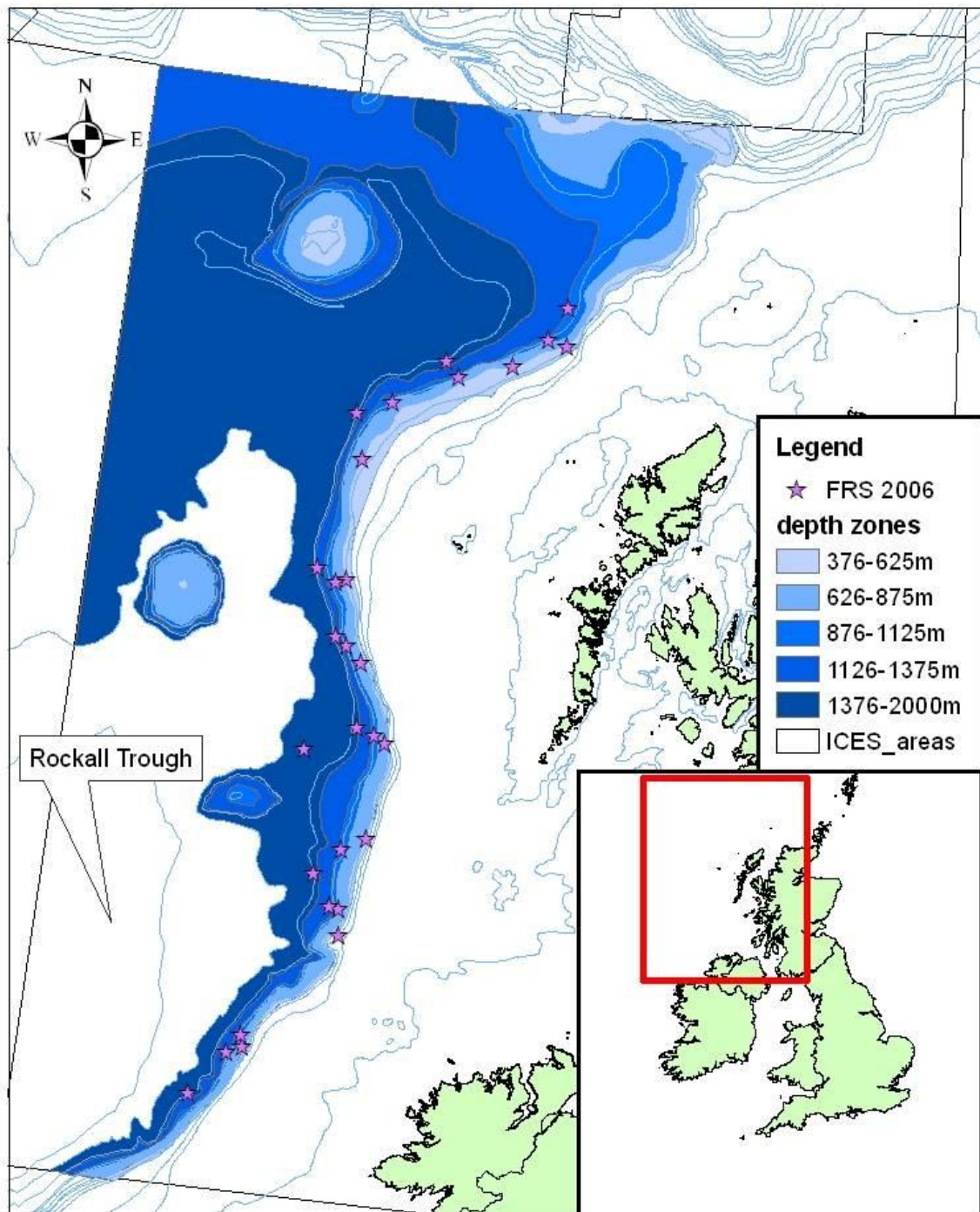
Map 19: 2007
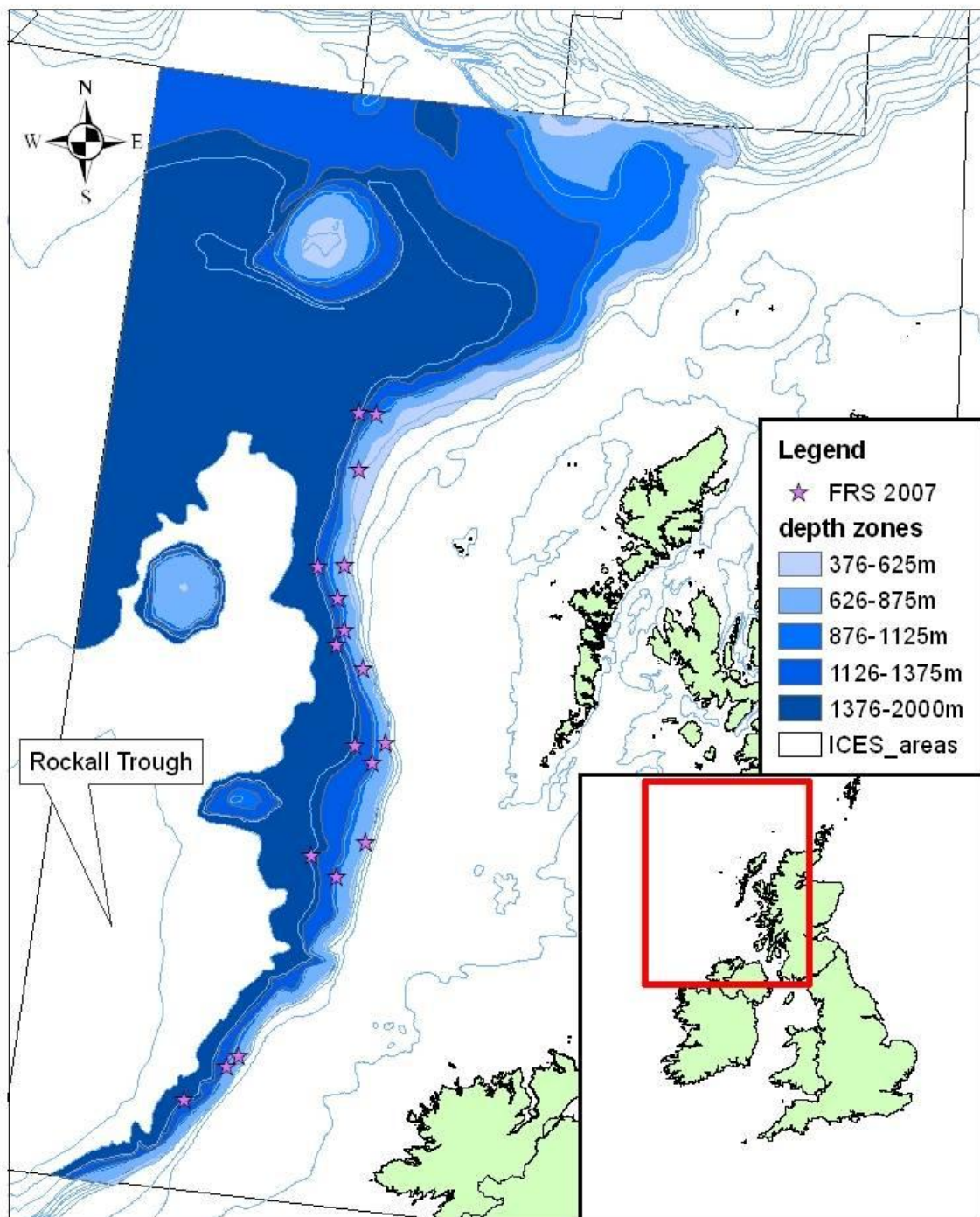
Appendix 2: Discard estimates used in the model (t/km^2).

Species	Alepocephalus bairdii	Aphanopus carbo	Argentina silus	Shallow Sharks	Shallow Sharks	Shallow Sharks	Intermediate sharks	Intermediate sharks
Gear	demersal trawl / total	demersal trawl / total	demersal trawl / total	Longline	demersal trawl	total	Longline	demersal trawl
Year								
1974	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0
1988	6.183900388	0.0027164	0.415937391	58.14948	0.004714264	58.15419426	361.6614	1.111517646
1989	2748.078335	1.207147312	184.8394154	63.004413	2.094982982	65.09939598	391.856715	493.9499942
1990	6726.74419	2.954854331	452.4497893	61.879824	5.128097851	67.00792185	384.86232	1209.090444
1991	8569.694919	3.764406588	576.4091142	42.322947	6.533061591	48.85600859	263.228085	1540.349379
1992	8139.571254	3.575466331	547.4784226	46.135578	6.20515909	52.34073709	286.94079	1463.037324
1993	7947.801082	3.491227522	534.579705	33.545667	6.058964114	39.60463111	208.637685	1428.567828
1994	7298.11185	3.205838783	490.8807404	34.615398	5.563676965	40.17907496	215.29089	1311.790228
1995	7929.881376	3.483355939	533.3744017	39.360615	6.045303121	45.40591812	244.803825	1425.346872
1996	7248.797718	3.184176583	487.5638061	38.153739	5.526082597	43.6798216	237.297645	1302.92632
1997	7329.814234	3.219764677	493.0130851	34.587969	5.587845109	40.17581411	215.120295	1317.488535
1998	6394.153001	2.808757128	430.0792622	35.136549	4.874548718	40.01109772	218.532195	1149.309246
1999	6916.363972	3.038148539	465.2038688	14.784231	5.272653489	20.05688449	91.950705	1243.173421
2000	9607.651097	4.220349199	646.2234317	55.159719	7.324341993	62.48406099	343.066545	1726.915548
2001	8402.637839	3.691023489	565.1726322	48.467043	6.40570651	54.87274951	301.441365	1510.321907
2002	6960.896836	3.057710473	468.1992087	30.830196	5.306602882	36.13679888	191.74878	1251.177926
2003	4301.805198	1.889652314	289.3451573	31.296489	3.279458438	34.57594744	194.648895	773.2227374
2004	3817.553235	1.67693514	256.7737241	20.379747	2.910291515	23.29003852	126.752085	686.1814579
2005	2952.987811	1.297157819	198.6219001	28.389015	2.251194637	30.64020964	176.565825	530.7811984
2006	2412.957931	1.059939102	162.2987699	29.458746	1.839505715	31.29825172	183.21903	433.7141853

Species	Intermediate sharks	DeepSharks	BenthicFish	Chimaera	Chimaera	Chimaera	BenthopelagicFish	*Coryphanoides rupestris*
Gear	total	total	demersal trawl / total	Demersal trawl	Longline	total	demersal trawl / total	demersal trawl / total
Year								
1974	0	0	0	0	0	0	0	0
1975	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0
1986	0	0	0	0	0	0	0	0
1987	0	0	0	0	0	0	0	0
1988	362.7729176	0.025689959	0.000847035	0.259835584	46.0941	46.35393558	1.149973745	1.519377569
1989	885.8067092	11.41642249	0.376415759	115.4689589	49.9425225	165.4114814	511.0395927	675.1998444
1990	1593.952764	27.94511083	0.921390226	282.6448353	49.05108	331.6959153	1250.922351	1652.753698
1991	1803.577464	35.60133514	1.173826879	360.0820755	33.5486775	393.630753	1593.642126	2105.564679
1992	1749.978114	33.81445978	1.114911045	342.0091075	36.570885	378.5799925	1513.655242	1999.883764
1993	1637.205513	33.01778332	1.088643484	333.9512942	26.5910775	360.5423717	1477.993177	1952.766042
1994	1527.081118	30.31876028	0.999652839	306.6526039	27.439035	334.0916389	1357.175325	1793.138108
1995	1670.150697	32.94333896	1.086188947	333.1983426	31.2004875	364.3988301	1474.660783	1948.36319
1996	1540.223965	30.11389313	0.992898076	304.5805191	30.2438175	334.8243366	1348.004744	1781.021679
1997	1532.60883	30.45046242	1.003995247	307.984677	27.4172925	335.4019695	1363.07078	1800.927349
1998	1367.841441	26.5634175	0.875833823	268.6699941	27.8521425	296.5221366	1189.072853	1571.036406
1999	1335.124126	28.73285386	0.947363239	290.6122933	11.7192075	302.3315008	1286.184525	1699.343071
2000	2069.982093	39.91334696	1.316000068	403.694995	43.7241675	447.4191625	1786.66308	2360.589377
2001	1811.763272	34.90732501	1.150944373	353.0626587	38.4189975	391.4816562	1562.575769	2064.518937
2002	1442.926706	28.91785804	0.953463091	292.4834785	24.43857	316.9220485	1294.465969	1710.284747
2003	967.8716324	17.8711156	0.589236212	180.7535693	24.8081925	205.5617618	799.9745671	1056.948837
2004	812.9335429	15.85937346	0.522906199	160.4062344	16.1546775	176.5609119	709.9218481	937.9686588
2005	707.3470234	12.26768394	0.404483065	124.0788604	22.5034875	146.5823479	549.1450767	725.5458787
2006	616.9332153	10.02422196	0.330512918	101.387845	23.351445	124.73929	448.7197555	592.8611274

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Species	Epigonus telescopus	Micromesistius poutassou	Molva dypterygia	Hoplostethus atlanticus	Phycis blennoides	Skates and Rays	Mesopelagics
Gear	demersal trawl / total	pelagic trawl / total	demersal trawl / total	orange roughy trawl	demersal trawl / total	demersal trawl / total	demersal trawl / total
Year							
1974	0	167.988	0		0	0	0
1975	0	319.224	0		0	0	0
1976	0	507.816	0		0	0	0
1977	0	482.496	0		0	0	0
1978	0	905.832	0		0	0	0
1979	0	1456.848	0		0	0	0
1980	0	1181.508	0		0	0	0
1981	0	1068.372	0		0	0	0
1982	0	1747.416	0		0	0	0
1983	0	2059.536	0		0	0	0
1984	0	2737.668	0		0	0	0
1985	0	2312.04	0		0	0	0
1986	0	3198.912	0		0	0	0
1987	0	1642.356	0		0	0	0
1988	0.0002936	1270.092	0.010055604		0.011381877	0.005632413	0.000153846
1989	0.1304734	1663.86	4.468633939		5.05801952	2.503001703	0.068368062
1990	0.319372695	1583.724	10.93831897		12.38101658	6.126845786	0.167351292
1991	0.406872402	881.124	13.93513026		15.77308901	7.805440153	0.213201138
1992	0.386450969	1377.576	13.23570871		14.98141802	7.413675387	0.202500308
1993	0.377346095	1529.004	12.92387237		14.62845236	7.239007489	0.197729354
1994	0.346500117	1703.916	11.86741655		13.43265646	6.647258253	0.181566062
1995	0.376495302	1805.532	12.89473324		14.59546996	7.222685881	0.197283538
1996	0.344158779	2019.996	11.78722713		13.34189055	6.602342009	0.1803392
1997	0.348005285	2847.684	11.91896761		13.49100679	6.676133383	0.182354769
1998	0.303581914	4134.12	10.39749441		11.76886055	5.823915443	0.159076923
1999	0.328375473	3112.8	11.24665858		12.7300243	6.299555068	0.172068748
2000	0.456152537	2695.548	15.62294467		17.68351585	8.750830264	0.239023929
2001	0.398940857	3229.152	13.66347973		15.46560943	7.653281407	0.209045009
2002	0.330489806	1838.376	11.31907321		12.81198997	6.340116443	0.173176658
2003	0.204241321	1589.532	6.995140009		7.917756343	3.918165506	0.107022452
2004	0.181249982	2812.272	6.207700753		7.026458648	3.477099662	0.094974991
2005	0.140202102	3291.384	4.801836027		5.435168933	2.689637128	0.073465902
2006	0.114562537	3557.232	3.923696632		4.441208303	2.197767704	0.060030769

Species	*Synaphobranchus kaupi*	*Lepidorhombus whiffiagonis*
Gear	demersal trawl / total	demersal trawl / total
Year		
1974	0	0
1975	0	0
1976	0	0
1977	0	0
1978	0	0
1979	0	0
1980	0	0
1981	0	0
1982	0	0
1983	0	0
1984	0	0
1985	0	0
1986	0	0
1987	0	0
1988	1.67994E-05	0.002263506
1989	0.007465505	1.005884676
1990	0.018274059	2.462203794
1991	0.023280669	3.13678278
1992	0.022112183	2.979343745
1993	0.021591215	2.90914972
1994	0.019826252	2.671342655
1995	0.021542534	2.902590534
1996	0.019692283	2.653292104
1997	0.019912375	2.682946743
1998	0.017370532	2.340464768
1999	0.018789185	2.531610707
2000	0.02610041	3.516707982
2001	0.022826837	3.075634539
2002	0.018910164	2.547911161
2003	0.011686402	1.574598466
2004	0.01037087	1.397346739
2005	0.008022168	1.080888107
2006	0.006555108	0.883219877

Appendix 3: Unbalanced model data.

	Group	Biomass	P/B	Q/B	EE	P/Q
1	Cetaceans	0.02	0.075	6.775		
2	Shallow sharks	0.002	0.26	3.05		
3	Intermediate sharks	0.97	0.14	1.8		
4	Deep sharks	0.019	0.17	1.84		
5	Large demersals	0.027	0.16	2.01		
6	Skates and rays	0.0007	0.14	1.62		
7	Coryphanoides L	0.26	0.15	1.2		
8	Coryphanoides S	0.00525	3	9.582		
9	Monkfish	0.04	0.11	1.3		
10	Orange roughy		0.05	2.9	0.95	
11	Argentine		0.21	10.17	0.95	
12	Blue whiting		0.3	9.06	0.95	
13	Black scabbard fish	0.532	0.17	2.2		
14	Blue ling	0.059	0.15	1.6		
15	Ling	1E-07	0.22	1.8		
16	Greater forkbeard	0.01	0.23	2.1		
17	Bairds smoothhead	2.76	0.13	1.8		
18	Bulls eye black cardinalfish	0.004	0.07	2.4		
19	Kaups arrowtooth eel	0.074	0.57	1.7		
20	Megrim L. whiffiagonis	0.00002	0.21	2.8		
21	Mesopelagic fish	0.002	0.97	6		
22	Benthopelagic fish	0.025	0.27	3.53		
23	Benthic teleosts	0.013	0.31	4.08		
24	Chimeras	0.108	0.22	3.7		
25	Cephalopods	0.084	2.5	9		
26	Prawns and shrimp	0.03	2.5	8		
27	Gelatinous plankton		2.858		0.95	0.45
28	Large zooplankton		2.979		0.95	0.3
29	Small zooplankton		9.2	30	0.95	
30	Polychaetes	10.2	2.28			0.2
31	Echinoderms	3.12	2	8		
32	Other benthic inverts	6.86	3	10		
33	Phytoplankton	41.76	70			
34	Detritus	50				

Diet matrix: Rows indicate prey and columns predators, groups numbers as in Appendix 3. Group 35 is import

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1			0.00001													
2	3.4E-05	1E-06			1E-06				1E-06					1E-07	1E-07	
3	3.4E-05		1E-06						1E-06					1E-06	1E-07	
4	3.3E-05			1E-06												
5	0.008		0.008		0.021				0.01						1E-07	
6			1E-07	1E-06		1E-06			1E-06					1E-07	1E-07	
7			0.035											0.06	0.06	
8		1E-06	1E-06	1E-06					1E-06					0.06	0.06	
9		1E-06	1E-06						1E-06					1E-06	1E-07	
10			1E-06	0.032					1E-06					1E-06		
11				0.013	0.0003									0.466	0.465	
12	0.645	0.2	0.051	0.439	0.741				0.73			0.02	0.44	0.307	0.307	
13			1E-06													
14		1E-07							1E-06					1E-06	1E-07	
15									1E-06							
16		0.167	1E-06						1E-06					1E-06	1E-07	
17			0.035	1E-06					1E-06				1E-06	1E-06		
18		1E-06	1E-06	1E-06									1E-06	1E-06		
19		1E-06	1E-06	1E-06			0.173		1E-06				1E-06	1E-07		
20		1E-07	1E-06		0.00024				1E-06					1E-07	1E-07	
21		0.163	0.043	0.018	0.005		0.301	0.239		0.334	0.267	0.05				
22	0.141	0.1	0.096	0.089	0.071				0.16	0.117			0.061	0.056	0.056	0.018
23			1E-08		0.08				0.026							
24			0.035	1E-07		0.867			0.025					1E-07	1E-07	
25	0.005	0.14	0.69	0.144	0.007		0.118		0.04	0.066		0.01	0.497	0.048	0.048	0.068
26	0.002	0.2	0.006	0.266	0.031		0.31	0.423	0.007	0.389	0.004	0.34	0.002	0.004	0.004	0.667
27		0.004					0.012			0.005	0.389					
28	0.129	0.016	0.001	0.0001	0.013	0.042	0.014	0.044		0.004	0.259	0.57		9.5E-05	9.5E-05	0.003
29	0.069					0.00034	0.007	0.102		1.1E-05	0.00032	0.01				
30					0.00014	0.048	0.019	0.176		0.0006	0.01					0.006
31																
32	0.0005	0.01			0.03	0.043	0.046	0.017	0.002	0.085	0.071					0.239
33																
34																
35																

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12			0.772	0.113			0.58									
13																
14																
15																
16																
17																
18																
19						0.129		0.086								
20				0.001												
21		0.316	0.054		0.728					0.12						
22	0.38			0.266		0.065	0.04									
23				0.049												
24				0.049												
25	0.012	0.006	0.057	0.003		0.009	0.1		0.05							
26	0.096	0.649	0.1	0.252		0.357	0.0006	0.027	0.09	0.01						
27	0.325	0.002					0.005		0.09		0.2					
28	0.017	0.007	0.0009	0.056	0.258	0.043	0.01	0.003	0.39		0.4	0.038				
29	0.002	0.00047			0.013	0.007	0.0003	1E-07	0.08		0.2	0.601		0.011		0.2
30	0.085	0.001	0.0003	0.014		0.049	0.06	0.012	0.09	0.06				0.016	0.03	
31	0.014	0.00029				0.011	0.114	0.012							0.07	
32	0.07	0.018	0.016	0.197		0.33	0.09	0.86	0.09	0.147				0.011	0.3	0.2
33										0.479	0.2	0.24	1			
34										0.304		0.12		0.962	0.6	0.6
35																

Appendix 4: Balanced-fitted model data

Biomass in t•km^{-2}, P/B = production / biomass ratio (year^{-1}) and Q/B = consumption / biomass ratio (year^{-1}). EE = ecotrophic efficiency and P/Q = production/biomass ratio.

	Group	Biomass	P/B	Q/B	EE	P/Q
1	Cetaceans	0.02	0.075	6.775		
2	Shallow sharks	0.013	0.3	3.05		
3	Intermediate sharks	0.7	0.14	1.8		
4	Deep sharks	0.019	0.17	1.84		
5	Large demersals	0.15	0.19	2.01		
6	Skates and rays	0.013	0.2	1.62		
7	Coryphanoides L	1.3	0.15	1.2		
8	Coryphanoides S	0.0262	3	9.582		
9	Monkfish	0.2	0.3	1.3		
10	Orange roughy	0.1	0.05	2.9		
11	Argentine		0.28	10.17	0.95	
12	Blue whiting	7	0.45			0.1
13	Black scabbard fish	0.6	0.17	2.2		
14	Blue ling		0.2	1.6	0.95	
15	Ling		0.25	1.8	0.95	
16	Greater forkbeard	0.1	0.23	2.1		
17	Bairds smoothhead	1.2	0.13	1.8		
18	Bulls eye black cardinalfish	0.004	0.07	2.4		
19	Kaups arrowtooth eel		0.57	1.7	0.95	
20	Megrim L. whiffiagonis	0.012	0.21	2.8		
21	Mesopelagic fish		0.97	6	0.95	
22	Benthopelagic fish		0.27	3.53	0.95	
23	Benthic teleosts		0.31	4.08	0.95	
24	Chimeras		0.22	3.7	0.95	
25	Cephalopods		2.5	9	0.95	
26	Prawns and shrimp		2.5	8	0.95	
27	Gelatinous plankton		2.858		0.95	0.45
28	Large zooplankton		2.979		0.95	0.3
29	Small zooplankton		9.2	30	0.95	
30	Polychaetes	10.2	2.28			0.2
31	Echinoderms	3.12	2	8		
32	Other benthic inverts	6.86	3	10		
33	Phytoplankton	41.76	70			
34	Detritus	50				

Diet matrix: Rows indicate prey and columns predators, groups numbers as in Appendix 3. Group 35 is import

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1			0.00001													
2	3.4E-05	1E-06			1E-06				1E-06					1E-07	1E-07	
3	3.4E-05		1E-06						1E-06					1E-06	1E-07	
4	3.3E-05			1E-06												
5	0.008		0.008		0.021				0.01						1E-07	
6			1E-07	1E-06		1E-06			1E-06					1E-07	1E-07	
7			0.005											0.01	0.01	
8		1E-06	1E-06	1E-06					1E-06					0.005	0.005	
9		1E-06	1E-06						1E-06					1E-06	1E-07	
10			1E-06	0.032					1E-06					1E-06		
11				0.013	0.0003									0.569		
12	0.645	0.2	0.051	0.01	0.741				0.05			0.01	0.44	0.307		
13		1E-06														
14		1E-07							1E-06					1E-06	1E-07	
15									1E-06							
16		0.167	1E-06						1E-06					1E-06	1E-07	
17			0.065						1E-06				1E-06	1E-06		
18		1E-06	1E-06	1E-06									1E-06	1E-06		
19		1E-06	1E-06	1E-06			0.173		1E-06				1E-06	1E-07		
20		1E-07	1E-06		0.00024				1E-06					1E-07	0.0001	
21		0.163	0.154	0.446	0.005		0.301	0.239		0.334	0.267	0.025			0.05	
22	0.01	0.1	0.01	0.089	0.01				0.01	0.05			0.01	0.01	0.2	0.018
23			1E-08		0.08				0.026							
24			0.01	1E-07		0.1			0.025					1E-07	1E-07	
25	0.005	0.14	0.69	0.144	0.007		0.118		0.04	0.066		0.001	0.548	0.048	0.048	0.068
26	0.002	0.2	0.006	0.266	0.031		0.31	0.423	0.007	0.389	0.004	0.17	0.002	0.004	0.281	0.668
27		0.004					0.012			0.005	0.389					
28	0.191	0.016	0.001	0.0001	0.013	0.042	0.014	0.044		0.004	0.259	0.285		0.047	0.00095	
29	0.069					0.00034	0.007	0.102		1.1E-05	0.00032	0.005				
30					0.01	0.315	0.019	0.176		0.0006	0.08				0.15	0.006
31															0.155	
32	0.07	0.01			0.081	0.543	0.046	0.017	0.002	0.152	0.001				0.1	0.24
33																
34																
35									0.83			0.504				

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12			0.01	0.113			0.58									
13																
14																
15																
16																
17																
18																
19						0.129		0.086								
20				0.001												
21		0.316	0.054		0.05					0.12						
22	0.005			0.266		0.01	0.01									
23				0.049												
24				0.049												
25	0.012	0.006	0.057	0.003		0.009	0.1		0.05							
26	0.096	0.649	0.1	0.252		0.357	0.0006	0.027	0.09	0.01						
27	0.699	0.002					0.005		0.09		0.2					
28	0.017	0.007	0.0009	0.056	0.7	0.043	0.01	0.003	0.39	0.097	0.4	0.01				
29	0.002	0.00047			0.25	0.062	0.0003	1E-07	0.08		0.2	0.63		0.011		0.2
30	0.085	0.001	0.0003	0.014		0.049	0.06	0.012	0.09	0.06				0.016	0.03	0.1
31	0.014	0.00029				0.011	0.114	0.012							0.07	
32	0.07	0.018	0.016	0.197		0.33	0.12	0.86	0.09	0.05				0.011	0.3	0.05
33										0.479	0.2	0.24	1			
34										0.304		0.12		0.962	0.6	0.65
35			0.762													