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# Options for the Assessment and Management of Deep-water Species in the ICES Area

by

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## Abstract

Most deep-water fish species are long-lived, have low fecundity and slow growth, and experience in other parts of the world has shown that stocks can be depleted very quickly and that recovery is slow. The main characteristics of deep-water fisheries in the ICES area are described and available fisheries, biological and life history data are reviewed. The methods used in ICES assessments of deep-water stocks are reviewed and compared with those applied to deep-water stocks off Australia and New Zealand. Surplus production and DeLury models will continue to be used and age based methods, stock reduction models and life history models may become useful when sufficient biological information is available. The scientific case for carrying out regular surveys of deep-water species is examined. The latest ICES assessments indicate that most deep-water stocks are currently outside safe biological limits. Deep-water fisheries in the ICES area are almost completely unregulated, and it is now widely recognised that management measures are urgently required. The latest management advice from ICES is reviewed and the advantages and disadvantages of a range of management options are discussed. Some deep-water species in the North Atlantic straddle across and beyond areas of national, EU and NEAFC jurisdiction and it is vital that any management and enforcement measures introduced should be harmonised as far as possible across all areas.

## Introduction

It is widely recognised that deep-sea ecosystems, including deep-sea fish stocks, are highly vulnerable to exploitation (Merrett and Haedrich, 1997; Koslow *et al*., 2000; Anon., 2001a). According to an Oslo-Paris Commission (OSPAR) quality status assessment, deep-sea habitats may be regarded as sensitive and therefore deserve protection (OSPAR, 2000). Experience in other parts of the world has shown that deep-water fish stocks can be depleted very quickly (Koslow *et a*l., 2000) and that recovery will be slow (Anon., 2001a). Unfortunately, stocks are often exploited before information is available on the biology and productivity of the species present and before time-series of fisheries data are available for stock assessments. Consequently, reliable information on the state of stocks and the potential for fisheries frequently lags behind exploitation. It is now generally agreed in the scientific community that because of the general sensitivity of these stocks and the inadequate knowledge of the biology of deep-water species, initial exploitation rates should be very low (Anon., 2001b). The general approach should be not to significantly exploit these resources until good progress has been made in understanding their biology and stock dynamics. This is consistent with a precautionary approach because impacts on such stocks will be difficult to reverse. Since there has already been substantial development of some deep-water fisheries in the ICES area, it is probably too late to adopt such a precautionary standpoint for most commercially exploited deep-water species. Moreover, for most stocks the effect of increased levels of fishing is difficult to determine because of a lack of scientific data. Under Article 7.5 of the FAO Code of Conduct for Responsible Fisheries, however, this is now no longer justification for not attempting assessments or for delaying introducing management measures (Anon., 2001b).

Serious collation of fisheries and biological data for use in assessments of deep-water species did not start until 1993. In that year ICES established a Study Group on the Biology and Assessment of Deep-Sea Fisheries Resources (SGDEEP), and this group met for the first time in 1994 (Gordon, 1998). In 2000 the group was re-established as an ICES Working Group (WGDEEP). Since 1994 the group has reported annually to the ICES Advisory Committee on Fishery Management (ACFM). The present overview is largely based on the authors' participation in SGDEEP, WGDEEP and ACFM.

## General Review of Deep-water Fisheries in the ICES Area

Deep-sea fisheries in the ICES area are quite diverse. Long-line and trawl fisheries predominate, ranging from coastal artisanal fisheries to highly efficient, mechanised high-seas operations. Some fisheries are directed at single species but most are mixed fisheries with a few or many target species. Some fisheries have developed recently whilst others have been established for many decades. A full description of the deep-water fisheries in the ICES area is beyond the scope of this paper. More detailed information is given in another paper in the same volume (Gordon *et al*., 2001). In this paper we attempt to describe the general nature of deep-water fisheries using particular fisheries as examples.

Longstanding deep-water fisheries comprise the handline and long-line fisheries off the Azores for a range of species including red (blackspot) seabream (*Pagellus bogaraveo*), alfonsinos (*Beryx* spp) and, until recently, kitefin shark (*Dalatias licha*), off Madeira and Portugal (principally for black scabbardfish (*Aphanopus carbo*)) and off Iceland, Norway and the Faroes (for ling (*Molva molva*) and tusk ( *Brosme brosme* )). The long-line fishery for ling and tusk has a very long history and is now prosecuted on a large scale by highly efficient, mechanised vessels fishing over a wide geographical area in the northern parts of the NE Atlantic (Bergstad and Hareide, 1996; Magnússon *et al*. 1997). Although these species appear to have withstood increasing levels of fishing effort without becoming severely depleted, catch rates in most areas have now been declining for many years and this is a cause for concern. Taking tusk at the Faroes as an example, international landings gradually increased throughout the last century to a peak in the 1980s and then declined thereafter (Figure 1). During the last two decades catch rates have declined by 50%.

However, not all longstanding fisheries show signs of depletion. An example is the long-lasting and almost self-regulatory Norwegian fishery for greater argentine (*Argentina silus*) in deep water off the Norwegian coast (Monstad and Johannessen, 2001). This is a comparatively localised operation within the Norwegian EEZ, and a limited access policy and the use of landings only for a domestic human consumption market may have prevented overfishing.

In contrast, the bottom trawl fishery for deep-water species in the ICES area is a comparatively recent development. The origins of the fishery can be traced back to the late 1960s, when Soviet and other eastern bloc countries began to exploit roundnose grenadier (*Coryphaenoides rupestris*) and alfonsino in international waters to the west of the British Isles and on the Mid-Atlantic Ridge. In the early 1970s, German trawlers exploited blue ling (*Molva dypterygia*) for a few years. By the mid to late 1970s, French trawlers, which traditionally fished along the shelf edge for species such as saithe (*Pollachius virens*), had also moved into deeper water to exploit blue ling (Charuau *et al*., 1995). In the early years of this fishery the by-catch of species such as roundnose grenadier, black scabbardfish, deep-water sharks and many other less abundant species was discarded. It was only in 1989 that these species began to be landed as a result of a marketing initiative by the French industry. Deep-water trawl fisheries then expanded quickly throughout the 1990s, partly as result of improving markets, but also due to the decline of traditional fisheries on the continental shelf and the related need for increasingly restrictive fisheries management regulations. In contrast, deep-water stocks were largely unexploited and unregulated.

As fishing skippers became increasingly competent at trawling deep-water grounds, they began to take note of developments in other deep-water fisheries around the world. The prosperous orange roughy (*Hoplostethus atlanticus*) fisheries in the Southern Hemisphere stimulated the search for this species in the NE Atlantic by French and Faroese trawlers. Spawning aggregations were located in ICES Sub-area VI and a fishery quickly developed from 1991 onwards. After an initial peak, landings quickly declined to less than 200 t per annum (Figure 2).

Fishing effort also quickly declined from an initial high level. These trends appear to be consistent with a 'mining' approach towards populations of this species. Aggregations are located and then fished out on a sequential basis.

There are also strong indications of other species showing fishery-induced depletion. Landings of the red (blackspot) seabream from ICES Sub-areas VI, VII and VIII peaked at 24,000 t in 1974 and have since declined continuously to around 100 t in recent years (Anon. 2000a).

Some trawl fisheries are for single species and have a relatively small by-catch of other species, e.g. fisheries for greater argentine, spawning aggregations of blue ling and orange roughy. Other trawl fisheries are mixed, have relatively few target species and the target species can change according to season and fishing depth. For example, to the west of Scotland the French fleet, when not fishing for blue ling, may target roundnose grenadier, and the quantities of other species landed, such as black scabbardfish and deep-water sharks, will depend on factors such as fishing depth. The Scottish fleet in the same area tends to fish on the upper continental slope and targets high value anglerfish (*Lophius* spp.) and lands other deep-water species as a by-catch. The crustacean trawl fishery off Portugal targets several species that occur in deep water such as the rose shrimp (*Parapenaeus longirostris*) and the Norway lobster (*Nephrops norvegicus*). The exploitation of deep-water crustaceans depends on factors such as availability and market price. The species composition of the fish by-catch depends on the depth of fishing.

In recent years, deep-water fishing activity in the ICES area has continued to increase for the reasons described earlier. Fishing vessels from France, Norway, Spain, Portugal, Russia, Ireland, United Kingdom, Iceland, Faroes, Poland and the Netherlands are now actively involved in deep-water fisheries. Exploratory cruises by commercial fishing vessels continue to identify potential fisheries, particularly in international waters on the Hatton Bank and the Mid-Atlantic Ridge.

A feature of all deep-water fisheries, whether they be longstanding or new, artisanal or mechanised, is that almost all have developed without programmes in place to collect biological and fisheries data. Consequently, our understanding of the population dynamics of deep-water species and of the impact of fishing upon them has lagged behind exploitation.

## Availability of Fisheries and Biological Data for Assessments

At the 1994 meeting of SGDEEP, and at a meeting in 1996, the Group concentrated on collating background information on what was known about deep-water species and fisheries in the ICES area (Anon., 1994, 1996). This work continues and the data collated have been sufficient to attempt assessments of some species (see later). These data have also been supplemented from other sources e.g. national and international research projects. For example, in 1995 the European Commission funded a three year FAIR project entitled "Developing deep-water fisheries: data for their assessment and for understanding their interaction with and impact on a fragile environment" (CT95/655) (Gordon, 1999a). Descriptions of deep-water fisheries were prepared, available fisheries-independent survey data were worked up and archived, steps were taken to ensure that deep-water species being landed or discarded were recorded, and the biology of both targeted and by-catch species was investigated. However, although the quality and quantity of fisheries and biological data available for assessments has improved considerably in recent years, there are still a number of important areas where further work is required.

Although the quality of deep-water landings data provided to ICES is slowly improving, for some species groups, in particular deep-water sharks, there are still problems caused by catches being recorded by species groups (Gordon, 1999b). Furthermore, in some countries sometimes only livers and oils are landed and expensive onboard inspection is required to obtain species-specific information. A further concern is the quality of landings data from international waters outside the EEZ and coastal state jurisdiction. Some deep-water stocks straddle EEZ, national and international waters and there is an urgent need to harmonise recording and reporting procedures.

There are also concerns regarding the availability of discard data. The effect of changes in pressure as deep-water fish are brought to the sea surface almost guarantees that fish landed on deck and subsequently discarded will not survive. Also, many deep-water species are susceptible to damage by trawls because their skin is not covered by mucus. Thus, it is also probable that a high proportion of fish entering trawls and subsequently escaping through meshes will die (Connolly and Kelly, 1996, Koslow *et al*., 2000). Notwithstanding, few studies of discard data have been carried out on a regular basis. Some short-term studies of discarding in the French and Scottish trawl fisheries indicate that the discard rate varies strongly between species (Blasdale and Newton, 1998; Dupouy *et al*., 1998). Given the general lack of time-series data on discards, estimating the total catch of deep-water species is very difficult. This not only has an effect on the quality of stock assessments, but given that discards and escapees also include non-commercial species, it is also difficult to evaluate the impact of fishing on the deep-water ecosystem.

Although biological studies of deep-water species have increased considerably in the last decade (Gordon, 1999a, Magnússon *et al*., 1997, Menezes *et al*., 2001), our knowledge of the primary biological processes such as growth, feeding, maturation and fecundity still lags considerably behind that of commercially exploited shelf-based species. Areas where our current knowledge is particularly poor are recruitment processes and variation, stock identity, fish migration and fish behaviour. Knowledge in these areas is required to expand our understanding of the population dynamics of deep-water fishes, which in turn is needed to underpin stock assessments. Studies using submersibles and ROVs have started to throw some light on the behaviour of deep-water fishes and it is hoped that these programmes will be expanded. The recent development of remote tagging devices for deep-sea fish coupled with the use of data storage tags should allow progress to be made in understanding the migration pathways of commercially important species. In recent years there has also been some improvement in the biological sampling of commercial landings for length and age, but there is scope for significant improvement for many species. Where data are available the time-series remain short for assessment purposes (frequently less than 5 years), and for some species, e.g. ling and tusk, sampling has not been fully implemented and remains incomplete because of lack of funding.

Age-disaggregated landings data are rare for deep-water fish, and where present are only available as short time-series. Age determination of deep-water species is more difficult than for most exploited species on the continental shelf. Calcified structures such as otoliths frequently display a large number of rings, making interpretation and validation difficult. For many species age determination is problematic and age estimates are unvalidated. Amongst the deep-water species currently assessed in the ICES area, the greatest progress in age determination has been made with roundnose grenadier, orange roughy, ling, black scabbardfish and blue ling. Of these species age determination of roundnose grenadier and ling is the most straightforward. Interpretation of the annuli in otoliths of these species is reasonably clear (Bergstad, 1995; Kelly *et al*., 1997) and for roundnose grenadier is partly validated (Gordon and Swan, 1996). Age determination of blue ling is not as straightforward (Bergstad *et al*., 1998), and there are inconsistencies between the results from different countries. However, there is general agreement that this species recruits to the fishery at 6 to 8 years of age and that most of the catch comprises age groups 8-20. Unvalidated age estimates suggest that, unlike many other deep-water fishes, the black scabbardfish has a relatively rapid growth rate and a longevity of between 8-12 years (from whole otoliths) and approximately 25 years (from sectioned otoliths) (Morales-Nin and Sena-Carvalho, 1996, Santos, 2000). Radiometric ageing has confirmed the longevity of orange roughy (up to 125 years) (Fenton *et al*., 1991; Francis, 1995; Smith *et al*., 1995), but the value of age-based assessments of this species has been questioned because in some stocks in the Southern Hemisphere there has been little change in the length composition of catches after 20 years of exploitation (Clark *et al*., 2000; Clark, 2001).

There have been very few studies of the stock-stucture of deep-water fish species in the ICES area (Anon., 2000a, Menezes *et al*., 2001). For assessment purposes, stock units have been defined on the basis of current knowledge of species distribution and similarity of observed catch-rate trends between ICES areas (Anon., 1998). Thus, stock units are currently individual or groups of ICES Sub-areas or occasionally ICES Divisions. This is not ideal because these ICES statistical areas were devised for the continental shelf and are, in many instances, inappropriate for deep-water fisheries. For example, ICES Sub-area VI is divided into two Divisions. Division VIa covers the shelf along the continental margin and VIb the Rockall Plateau. Division VIa, however, includes both the Rockall Trough and a part of the Faroe-Shetland Channel. The deep-water fish faunas of these two areas have little in common (Gordon, 2001). Division VIb extends westwards from the Rockall Plateau and is contiguous with Sub-area XII at longitude 18°W and in doing so bisects the Hatton Bank, which has a rapidly developing deep-water fishery, which is in international waters. Sub-area XII covers a vast area of the northeastern Atlantic that includes large parts of the Mid-Atlantic and Reykjanes Ridges. Whilst it may be reasonable to assume a stock separation between the slopes of the Rockall Trough and Mid-Atlantic Ridges, the Hatton Bank probably has more affinity with the Rockall area. However, a proportion of the landings from Sub-area XII cannot be readily attributed to the Hatton Bank and are therefore excluded by the ICES Study Group from the assessments of the Rockall area. Thus, there is an urgent need to reconfigure some existing ICES areas so that they are biologically meaningful in terms of the distribution of deep-water species. Studies into the genetic identity of deep-water stocks should also be expanded (Anon., 2000b). Alternative methods such as otolith microchemistry may be useful tools for stock discrimination. The European Commission funded such a study on black scabbard as a contribution to the BASBLACK project (EC DGXIV 97/84) (Swan *et al*., 2001) and is currently funding a FAIR project entitled "Otolith microchemistry as a means of identifying stocks of deep-water demersal fish (EC FAIR 98/4365)". The objective is to use the chemical signal embedded in otoliths to discriminate between stocks of deep-water species. DNA studies may also be useful in this context. Studies of the population genetics of the red (blackspot) seabream and alfonsinos using DNA based analyses have been carried out in the Azores (EC DGXIV 97/081).

Estimates of natural mortality (M) are required for some of the methods currently used to assess deep-water stocks in the ICES area. Estimates of M are currently available from two sources: from catch curves using data collected pre-exploitation (from exploratory surveys); and by using the equation $M = \log_e 100/\text{maximum age}$, where the maximum age is the age to which 1% of the population survives in an unexploited stock (Annala, 1993). The estimates of M currently used in assessments were recently reviewed by ICES (Anon., 2001c).

Regarding the availability of fisheries independent survey data for deep-water species in the ICES area, there is almost a total lack of surveys designed to generate time-series data for use in assessments. Most surveys have to date been either of an exploratory nature or designed for the collection of biological data. It is recognised that there is an urgent need to increase survey activities, and possible options are reviewed later in this paper.

The lack of fisheries independent survey data has meant that assessments have had to rely on abundance indices derived from catch and effort data from commercial fishing vessels. Although the quantity and quality of these data is slowly improving, some important time-series have not been updated in recent years, e.g. the Norwegian series for long-liners fishing for ling and tusk (Bergstad and Hareide, 1996). Most of the current ICES assessments of deep-water stocks use annual abundance indices calculated from catch and effort data from the French commercial deep-water trawl fleet. A part of this fleet has been fairly constant in terms of engine power, age and fishing gear, and comprises vessels specialising in fishing for deep-water species. For each species, catch and effort data are filtered to exclude trips directed at other species (Biseau, 1998) and then analysed using a multiplicative model including factors for month and ICES Sub-areas, weighted by fishing effort. Estimates of annual standardised catch-per-unit-effort (CPUE), derived from this model for individual or combinations of ICES Sub-areas, are then used as an index of abundance in assessments (Lorance and Dupouy, 2001). Although these indices are considered to be reasonably robust, there are concerns regarding the effects of changes in the depth of fishing on CPUE for some species. Depth of fishing is currently not recorded in EU logbooks. There are some depth data available for an individual trawler (recorded voluntarily by the fishing skipper), and analysis of these data suggests that the effect of depth on CPUE is minor (Girard *et al*., 2000). However, further data are required to confirm this. Changes in the spatial distribution of fishing within ICES Sub-areas may also effect estimates of annual standardised CPUE. Again, this requires further investigation.

## Life History Characteristics

Deep-water fish are frequently described as long-lived, slow growing with low reproductive capacity, but in reality these descriptions only apply to some deep-water fishes - there are some species whose life history characteristics are more comparable with species found on the continental shelf. Similarly, orange roughy is often referred to as a typical deep-water species, when it is really an extreme form of the type. The life history characteristics of deep-water species in the ICES area have recently been compiled (Anon., 2001c). These data are useful when attempting to identify suitable assessment methods and for identifying the species most likely to be vulnerable to fishing pressure. Deep-water species in the ICES area were ranked according to their longevity, growth rate, natural mortality, fecundity and length/age at first maturity, but only longevity and growth rate are considered here (Table 1).

Orange roughy and roundnose grenadier are the longest lived and slowest growing, whilst species such as alfonsino and black scabbardfish are comparatively short-lived with considerably faster growth rates.

**Stock Assessment Methods Currently Used and Options for the Future**

The terms of reference for each meeting of ICES WGDEEP (and formerly SGDEEP) are set to provide ACFM with the information required to provide advice on the state of stocks and management options to member states, the North-East Atlantic Fisheries Commission (NEAFC) and the Fisheries Division of the European Commission. The most recent assessments of deep-water stocks in the ICES area are those carried out by WGDEEP in 2000, based on assessment methods determined by the availability of fisheries and biological data and the life history characteristics of each species.

Length frequency data of commercial catches of a slow growing, long-lived species such as orange roughy (Figure 3) show no obvious multi-modal structure or modal progression, suggesting a wide range of ages at any particular length.

Length-based assessment methods, which rely on a strong link between modal length and age structure, are therefore considered unsuitable for such species. Age-based methods are also rarely used because of a lack of reliable age estimates for most species. The principal time-series fisheries data available for most commercially exploited deep-water species in the ICES area are of total international catches and catch and effort for individual commercial fleets, and the main method of assessment is depletion modelling using surplus production and modified DeLury models (Anon., 1998 and 2001c). These models provide estimates of current and virgin exploitable biomass ($B_0$), from which it is possible to calculate a 'depletion ratio' for each stock[1]. However, there are some major concerns regarding the application of these methods and their results should be treated with caution.

Concerns regarding the quality of catch statistics and assumptions made regarding stock structure for some species have already been described. If time-series catch data are incomplete, initial population size and all subsequent population estimates will be underestimated. Depletion models also assume that all catch and effort data are from a single stock (i.e. there is no immigration from or emigration to other populations) and if this is not the case then estimates of population size will be distorted. Depletion methods require an index of relative population size, which should vary in proportion to any changes in stock size with time, i.e. catchability and fishing power effects should be constant. However, as described earlier, changes in the spatial and depth distribution of the fishing effort of French trawlers may have influenced the catchability of some species with time. Also, for species occurring in aggregations, such as orange roughy, indices of abundance may be biased if depletion reduces the size of aggregations rather than fish density (Clarke *et al*., 2000; Clark, 2001). Sequential depletion or 'mining' of these aggregations can also give rise to biased estimates of overall abundance. A further concern is that the modified DeLury model assumes constant recruitment with time whilst production models assume that recruitment is determined by current stock size, without any environmental effects or other sources of variation. Very little is known about the recruitment processes for deep-water fish. Notwithstanding these concerns, and in line with the Precautionary Approach, some progress has been made in using these methods to assess some of the deep-water stocks in the ICES area on a regular basis.

The DeLury model uses time-series of catch in number and an index of population abundance (CPUE) to estimate the catchability coefficient (q) of the CPUE index and the unexploited population size in number (K). The method requires an estimate of M and the ratio between the population size at the start of the time-series to the unexploited population size. Sensitivity analysis is used to evaluate the effect on results (goodness of fit, residual plots, model parameter and population estimates) for a range of error models and assumptions for stock size in the first year as a proportion of virgin biomass. Confidence limits about model parameters and population estimates are calculated by bootstrapping.

The production models used are biomass dynamic models that do not assume that stock is in equilibrium with the fishery. Production models assume that biomass in the current year is related to biomass in the following year (or several years thereafter), because of growth and recruitment.

Time-series of catch in weight and an index of population biomass are used to estimate the catchability coefficient of the CPUE index (q), the population production rate (r) and carrying capacity (K). Confidence limits about model parameters and population estimates are calculated by bootstrapping. Sensitivity analysis of outputs

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1 Where the fit of these models is poor, smoothed time-series of CPUE from commercial trawlers have been used directly as an index of exploitable biomass and for calculating depletion ratios.

is used to evaluate the effect of error models and the ratio of initial to carrying capacity (defined as the unfished equilibrium stock size). A zero time-lag is used because available time-series of catch and CPUE are too short (frequently 8-10 years) to explore the effect of time-lag over a range of years commensurate to age of recruitment. It is assumed, therefore, that growth rather than recruitment is the main contributor to biomass production. For some stocks, available CPUE data show a decline across the time period studied (Figure 4) which may give unreliable results (the so called ‘one way trip’).

Production models provide estimates of exploitable biomass for the calculation of depletion ratios and also estimates of maximum sustainable yield (MSY). Confidence limits about these values are very wide, suggesting that MSY is currently poorly estimated.

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

There are two main uses for estimates of MSY. First, ratios of $MSY/B_0$ highlight potential differences between the levels of yield that can be expected from slow-growing, long-lived species, compared to the more familiar commercial species, such as gadoids. For example, Beddington-Cooke ratios of $MSY/B_0$ (Beddington and Cooke, 1983) for a typical gadoid, with an M of 0.2 and a growth rate of around 0.3, could be around 0.07 to 0.08 or higher, depending on the age of recruitment to the fishery. In contrast, ratios for the deep-water stocks can be as low as 0.02 or 0.03. Second, estimates of MSY indicate the likely order of magnitude of sustainable catches. For example, are sustainable catches likely to be of the order of 100s or 1000s of tonnes? (Basson *et al*., in press.).

Attempts have also been made to derive fisheries independent estimates of virgin stock biomass from fish densities, calculated using the swept area method, observed during a series of German trawl surveys from 1974 to 1980 (Anon., 1998). These surveys were carried out pre-exploitation and provide data on the virgin stocks of roundnose grenadier, blue ling and orange roughy in ICES Sub-area VI and adjacent Divisions VIIb, c over a depth range of 400 to 1400 m. Information on the selectivity of the trawl used on the German surveys is not available, and for this study was assumed to be unity for each of the three species analysed. It should be noted that benthopelagic species can have a variable distribution in the water column and this may lead to under-estimation of stock size using swept area methods. Values of $B_0$ are therefore minimum estimates.

For some species where the only biological data available are partial length or age compositions for individual years, estimates of the total instantaneous mortality rate (Z) have been estimated from catch curves. Given knowledge of M, it is then possible to derive an estimate of fishing mortality (F). However, catch curves fitted to data for individual cohorts assume that F, M and q have remained constant with time and those fitted to data for individual years also assume that recruitment has been constant with time. Consequently, these methods only provide information on the scale of Z/F, i.e. whether it is high or low, rather than accurate estimates.

Regarding future assessments, opportunities to use a wider range of assessment methods and to produce more robust evaluations of the state of stocks will largely depend on securing improvements in the quantity and quality of fisheries and biological data available (see above). Countries participating in fisheries should be encouraged to collate catch and effort data and prepare abundance indices for use in assessments. ICES has recently reviewed the applicability for assessment purposes of different types of survey for different types of deep-water species and different hydrographic and bathymetric conditions (Anon., 2001c). Abundance indices derived from fisheries independent surveys will generally be more reliable in assessments than indices derived from commercial fisheries, because trends in catchability can be minimised by using the same vessel and fishing gear at the same time of year over a constant grid of stations. Fully randomised surveys are unlikely to be successful because of the high probability of gear damage on deep-water grounds. The type of fishing gear used will depend on the species surveyed, but it is envisaged that, for most bentho-pelagic species, demersal trawls and/or long-lines would be used whilst midwater trawls , probably in conjunction with acoustic surveys, would be used for pelagic or semi-pelagic species such as argentines and alfonsinos.

Surveys can also be used as an important source of fisheries independent estimates of stock biomass. Fish density data from demersal trawl surveys, obtained using the swept area or volume method, can be raised to the total area/volume inhabited by the stock (see earlier). However, to be successful, such an approach would require further studies of gear selectivity and the behaviour of deep-water fish in relation to trawls. Acoustic surveys can be used to estimate the total stock biomass of pelagic and other species that are acoustically reflective, orange roughy, greater argentine and roundnose grenadier, for example. Egg production surveys can be used to back-calculate estimates of total stock biomass if information on egg development rate, mean fecundity, sex ratio and maturity composition in the stock is available. Although biological information on the deep-water stocks in the ICES area is improving, the use of egg production methods would require further studies of the general and reproductive biology of the species to be investigated. For species where spawning is widely scattered and eggs are distributed over a range of depths and areas, the level of sampling effort required for this method is likely to be prohibitive.

Age-based assessments may soon become possible for two deep-water species in the ICES area. There are almost sufficient time-series catch-at-age data for ling at the Faroes (ICES Division Vb) and red (blackspot) seabream at the Azores (ICES Sub-area X) to attempt virtual population analyses. It is likely that extended survivors analysis will be used for tuning, using catch and effort data from Faroese commercial long-liners and an Azorean long-line survey, respectively. The success of these assessments will depend largely on the reliability of catch data, the quality of age determination, the extent to which catchability is constant in tuning fleets and the assumptions made regarding stock structure. If the problems regarding age determination of blue ling can be overcome and biological sampling of roundnose grenadier continues, age-based assessments of these species may be possible in the next five years (Lorance *et al.*, 2001).

The use of stock reduction models (sometimes known as delay-difference models) and life history tables to assess deep-water stocks in the ICES area should be investigated. Life history tables can be used as a basic tool for evaluating and projecting stock structure, and can be updated as species knowledge increases. Stock details such as length structure can be included, and this is particularly useful for species, such as elasmobranchs, where age determination is difficult (Heesen, 2001). Stock reduction models can be considered to be a conceptual hybrid of surplus production and age-based models (Heessen, 2001). The basic dynamics of an age-structured population are predicted without requiring annual records of population age structure.

Stock reduction models have been used extensively to assess deep-water stocks off New Zealand and Australia. However, experience has shown that for some stocks, e.g. orange roughy off New Zealand, a combination of assessment methods (stock reduction models, annual trawl surveys, egg production surveys, acoustic surveys and analyses of commercial CPUE) is more successful at estimating the size of stocks than any single technique (Clark, 1996). It is too early to say whether this will also apply to deep-water stocks in ICES area. In the short term, it is envisaged that depletion models will continue to be used and supplemented, where possible, with stock reduction models, life history models and age-based methods. If more data from fisheries independent surveys become available these may provide independent estimates of stock biomass for some species and, if carried out on an annual basis, indices of abundance for use in assessments in four or five years time.

## Biological Reference Points used in Assessments

The biological reference points used by ICES as a basis for statements on the status of deep-water stocks have recently been reviewed (Anon. 2001b). It is recognised that the life history characteristics of deep-water species should be an important determinant of biological reference points. Deep-water species are, to varying degrees, less productive than species on the continental shelf. Sustainable exploitation rates are therefore lower and the time required for stocks to respond to management measures aimed at improving stock status is longer. A second factor influencing the choice of biological reference points is uncertainty, both in assessments and in knowledge of the population dynamics of deep-water species. Research and biological monitoring of deep-water species in the ICES area has increased in recent years, but data available for assessments still remain sparse in comparison with commercially exploited species on the continental shelf. Taking both of these factors into consideration, limit reference points should be set to ensure that the condition of deep-water stocks is more precautionary than for shelf stocks. Similarly, precautionary reference points should be set further from limit reference points than is the case for most shelf stocks. ICES has recently recommended that the limit and PA reference points used for deep-water stocks since 1998 should continue to be used. These are:-

$$F_{lim} = F_{35\%SPR} \qquad B_{lim} = 0.2 \times B_{max}$$

$$F_{pa} = M \qquad B_{pa} = 0.5 \times B_{max}$$

For most deep-water stocks the only information available on F is from catch curves (assuming knowledge of M) and consequently $F_{lim}$ and $F_{pa}$ are rarely used. For many stocks there is no absolute biomass estimate available and instead ICES uses indices of biomass, e.g. a CPUE index from logbook data from commercial fishing vessels or from a research vessel survey (preferably). These indices are denoted by U, so that $U_{lim}$ is an index for $B_{lim}$ etc. The reference points thus become:-

$$U_{lim} = 0.2 \times U_{max}$$ (maximum observed biomass indicator, may be a smoothed index)

$$U_{pa} = 0.5 \times U_{max}$$

In recent years ICES has defaulted to this notation for all deep-water stocks in the ICES area.

The primary management objective is to introduce management measures to maintain $U_{current} > U_{pa}$. If $U_{current}$ is between $U_{pa}$ and $U_{lim}$, then the stock is declared 'outside safe biological limits' and appropriate management measures are recommended, currently a 30% reduction in exploitation. If $U_{current}$ is close to $U_{lim}$, stronger management measures are recommended e.g. a reduction in exploitation by 50%. If $U_{current}$ is below $U_{lim}$, then ICES has recommended that directed fisheries should be closed and measures implemented to reduce/minimise by-catches.

Within ICES, MSY is not accepted either as a precautionary limit reference point (Anon., 1997) or a long-term target (Anon., in prep.). This is mainly because there are uncertainties about calculating MSY (based on yield per recruit curves and a stock and recruit relationship), particularly when data are poor.

## Current state of Deep-water Stocks in the ICES Area

The most recent information on the state of stocks in the ICES area is that given by ACFM in May 2001 (Anon., 2001b), based on assessments carried out in 2000 (Anon., 2000a), and this is summarised in Table 2. Most exploited deep-water species in the ICES area are at present considered to be harvested outside safe biological limits. The effect of this harvesting on the deep-water ecosystem, particularly by trawling, is also a concern because of the high mortality of escapees and discards.

## Options for Fisheries Management

Fishing effort for deep-water species in the ICES area has been largely uncontrolled and, as a result, most deep-water stocks are now outside 'safe biological limits'. ICES has recommended an immediate reduction in these fisheries (referred to as Category 2 fisheries in Table 3) unless they can be shown to be sustainable. When these fisheries have been reduced, consistent with the precautionary approach, ICES has recommended that fishing should not be allowed to expand faster than the acquisition of information necessary to provide a basis for sustainable exploitation (Anon., 2001b). New fisheries, expansion into unexploited areas or significant changes in fisheries, such as the introduction of new gears or fleets (collectively referred to as Category 1 fisheries in Table 3) should be permitted only when fisheries expand very slowly, and are accompanied by programmes to collect data which allow evaluation of stock status.

Whilst there is general agreement within the scientific community that these measures are appropriate and urgently required, it is the responsibility of fisheries management bodies (European Commission, NEAFC and national governments) to decide on the type of management methods to be used to attain management objectives. For long-lived, slow-growing species such as orange roughy, the sustainable yield may only be 1-2% per year of the pre-exploitation biomass. Furthermore, the rate of rebuilding after depletion may be as low as 2.5% of virgin biomass per year (Anon., 2001b). Given this, it is vital that the management methods used are fully effective in achieving objectives. ICES is in the process of making management recommendations for deep-water species (Anon., 2000a, Anon., 2001b) and the following section discusses the advantages and disadvantages of different management methods.

Managing deep-sea fisheries in the north-eastern Atlantic using total allowable catches (TACs) as a primary tool has several advantages and disadvantages. TACs can be introduced quickly and can provide a relatively straightforward method of dividing catches between participating countries (i.e. national quotas). Their effectiveness as a management tool, however, depends on the quality of landings data and on enforcement. Also, many deep-water fisheries are mixed fisheries, and TACs for different species may be taken at different rates. This could encourage fleets to harvest species with available quota and to discard species whose TAC is exhausted. The mortality of escapees and discards from trawls is high and consequently continued fishing will result in a high mortality of all fish taken, including non-commercial species. Thus zero TACs for individual species will generally only be effective in single species trawl fisheries. For mixed fisheries, the entire fishery may have to be closed. This may also apply to mixed fisheries using other gears, long-lines for example.

Some deep-water stocks in the ICES area straddle international waters and waters under EU and national jurisdiction, and if TACs are introduced, catches could be misreported to the former (which may remain unregulated). Even if NEAFC, the EU and national governments jointly impose TACs it is likely that catches in international waters will be underestimated because landings statistics may not reflect the true scale of recent fisheries activities outside national EEZs. These concerns could be addressed by having independent observers aboard vessels fishing in international waters, improving reporting procedures and introducing satellite monitoring.

Managing deep-water fisheries in the ICES area by effort regulation (vessel licensing and number of days at sea, for example) also has advantages and disadvantages. Such a system would probably be easier to enforce than catch restrictions and could more easily be referenced to different sub-areas in the NE Atlantic by using satellite monitoring. However, unavoidable mortality in mixed fisheries may still pose a problem. Given the parlous state of most deep-water stocks in the NE Atlantic and the urgent requirement for management measures, a possible drawback of an effort regulation scheme is that it may take some time to construct and introduce.

Regarding other types of management methods, technical measures such as the use of mesh size regulations and selectivity grids are unlikely to be effective for deep-water fisheries because of a very high mortality of escapees. Imposing closed areas is also unlikely to be effective because most deep-water species in the NE Atlantic have a wide geographical range. Closed areas may be appropriate for protecting spawning concentration, of blue ling for example, and species associated with topographical features, e.g. orange roughy and seamounts. However, such features can be geographically widely scattered and may require a patchwork of closed areas that would be extremely difficult to monitor and enforce effectively. Trawl exclusion areas or even no-take zones may be suitable for protection of cold-water coral reefs and possibly seamounts where fish populations are heavily depleted. Most deep-water trawling for mixed species is in areas of soft bottomed sediments and the impact on the communities of benthic invertebrates is unknown.

The final decision on the type of management regime applied lies with the European Commission, NEAFC and national governments. Whatever is chosen, it is vital that it be put in place quickly. There is an urgent need for effective management of deep-water fisheries in the NE Atlantic.

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Table 1. Deep-water species in the ICES area ranked according to (1) longevity and (2) growth rate (summarised from Anon., 2001c).

| Species | Longevity (years) (rank in brackets) | Growth rate (k ($y^{-1}$)) (rank in brackets) |
|---|---|---|
| Orange roughy | 125 (1) | 0.06-0.07 (1) |
| Roundnose grenadier | >60 (2) | 0.06-0.13 (2) |
| Deep-water squalid sharks: | | |
| *Centroscymnus coelolepis* | Not known | Not known |
| *Centrophorus squamosus* | 60-70 (2) | Not known |
| Blue ling | 30 (3) | Not known |
| Argentine | 35 (3) | 0.17-0.20 (4) |
| Ling | 20 (4) | Not known |
| Tusk | 20? (4) | Not known |
| Black scabbardfish | 8-12 from whole otoliths<br>25 from sections (4) | 0.25 (5) |
| Red (blackspot) seabream | 16 (4) | 0.10-0.17 (3) |
| Greater forkbeard | 15? (4) | Not known |
| Alfonsino: | | |
| *Beryx decadactylus* | 13 (5) | 0.11-0.17 (3) |
| *Beryx splendens* | 11 (5) | 0.13-0.14 (4) |

Table 2. Current state of deep-water stocks in the ICES area (Anon., 2001b)

| Species | ICES Sub-area/Division | Assessment type | State of stock |
|---|---|---|---|
| Blue ling (*Molva dypterygia*) | Mainly II,V, VI, VII & XII | CPUE | Below $U_{lim}$ in V, VI & VII. Unknown in other areas. |
| Ling (*Molva molva*) | Almost all areas | CPUE Catch curves | Uncertain and variable across its range. Below $U_{pa}$ in some areas. |
| Tusk (*Brosme brosme*) | Mainly IIa, IV, V &VI | CPUE | Stock decline in all areas except Va. Probably below $U_{lim}$ in Vb. |
| Roundnose grenadier (*Coryphaenoides rupestris*) | I, II, III, IV, Va, Vb, VI & VII,VIII, IX, X | DeLury Schaefer | Near to $U_{pa}$ in Vb, VI & VII. Unknown in other areas. |
| Black scabbardfish (*Aphanopus carbo*) | Vb, VI,VII, VIII, IX, X & XII | DeLury Schaefer | Below $U_{pa}$ & possibly below $U_{lim}$ in V, VII,VII & XII. Uncertain in other areas. |
| Greater Argentine (*Argentina silus*) | I, II, III, IV, V, VII &VII | No assessment | Unknown |
| Orange roughy (*Hoplostethus atlanticus*) | Va, Vb, VI, VII, IX & XII | DeLury Schaefer | Below $U_{lim}$ in VI Unknown in other areas. |
| Red (blackspot) Seabream (*Pagellus bogaraveo*) | IX, X & partly in VI,VII &VIII | No assessment | Unknown in X. Possibly below $U_{lim}$ elsewhere. |
| Greater forkbeard (*Phycis blennoides*) | All areas but mainly VI, VII,VIII & IX | No assessment | Unknown |
| Alfonsino (*Beryx splendens*) | Mainly X | No assessment | Unknown |
| Deep-water squalid sharks | Va, Vb, VI, VII, VIII, IX & X | DeLury Schaefer | No information given by ACFM |

Table 3. Summary of the latest ICES advice for deep-water stocks in the NE Atlantic (Anon., 2001b).

| Species/stock | Category 1<br>Developing new fisheries | Category 2<br>Fully or overexploited |
|---|---|---|
| Blue ling | | All populations<br>No directed fisheries for this species and measures be implemented to reduce/ minimise catches in mixed fisheries. |
| Ling | | All populations<br>Fishing effort be reduced by 30% |
| Tusk | Hatton bank fishery (part of Sub-areas VI & XII) | All areas except Hatton Bank<br>Fishing effort be reduced by 30% |
| Roundnose grenadier | All fisheries outside Sub-areas VI, VII & Vb. | Sub-areas VI,VII & Vb<br>Fishing effort be reduced by 50% |
| Black scabbardfish | Fishery in Sub-area X | Sub-areas VI, VII,VII, XII and possibly IX.<br>Fishing effort be reduced by 50% |
| Greater Argentine | All fisheries | |
| Orange roughy | All fisheries except in VI | Sub-area VI<br>Fishing effort be reduced by 50% |
| Red (blackspot) seabream | | All populations |
| Greater forkbeard | All fisheries | |
| Alfonsinos | All fisheries | |
| Deep-water squalid sharks | All fisheries | |

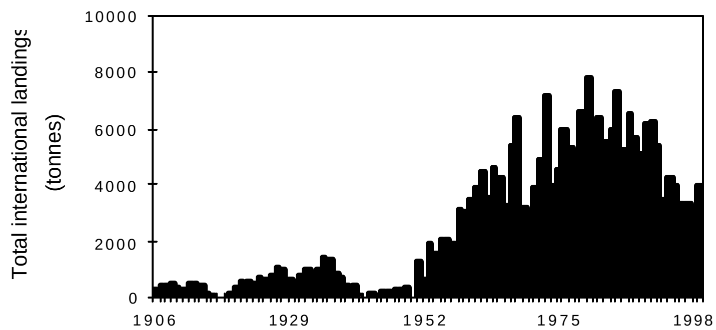


Figure 1. Total international landings of tusk (*Brosme brosme* ) from the Faroes (ICES Division Vb).

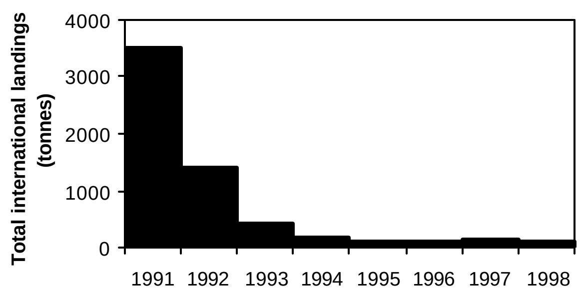


Figure 2. Total international landings of orange roughy (*Hoplostethus atlanticus*) from ICES Sub-area VI.

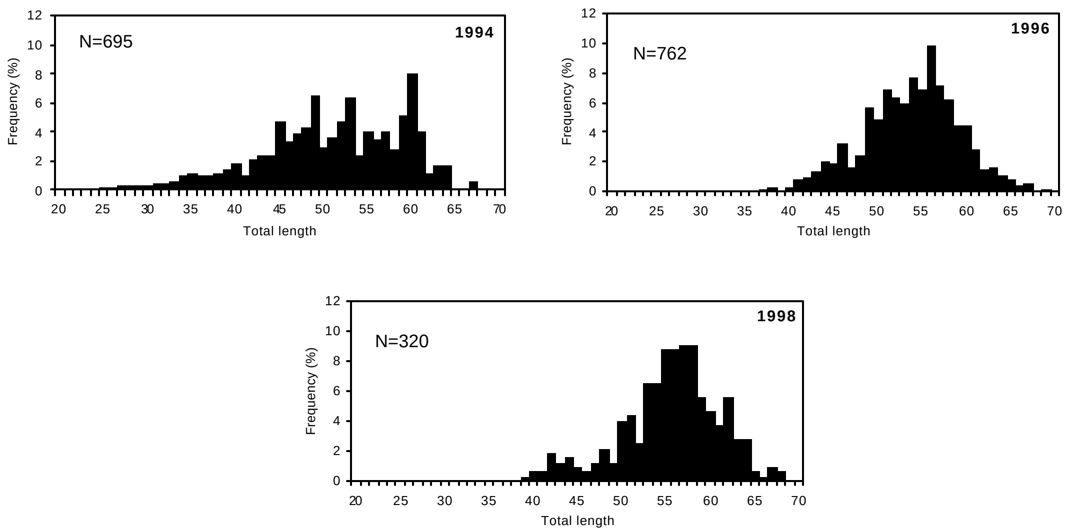


Figure 3. Length distribution of French landings of orange roughy (*Hoplostethus atlanticus*) from Sub-areas VI and VII, 1994, 1996 and 1998 (N = number of fish sampled).

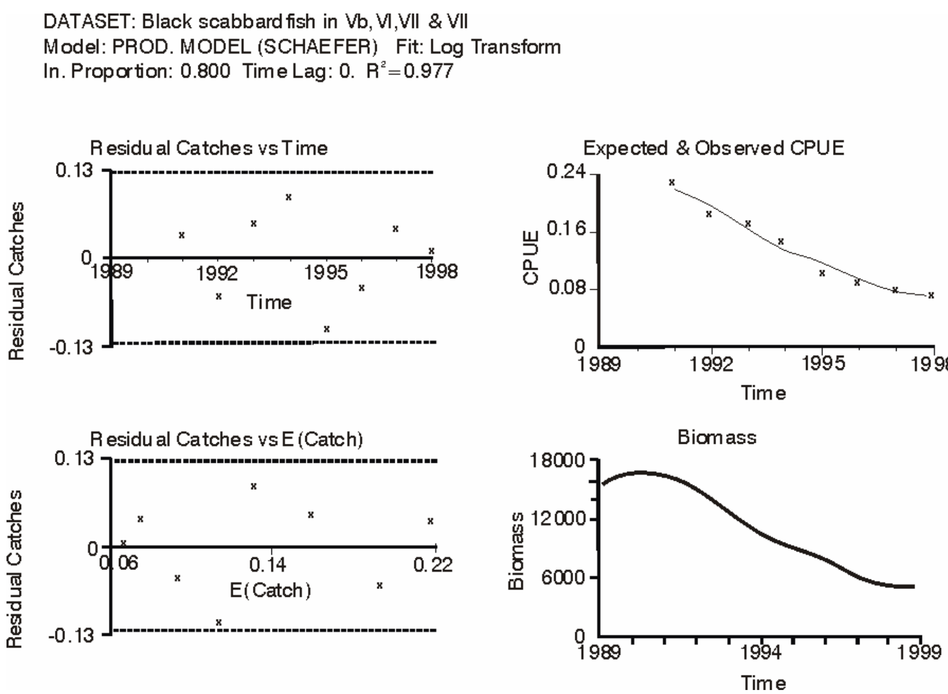


Figure 4. Black scabbardfish (*Aphanopus carbo*) in Sub-areas VI, VII, XII and Division Vb. Schaefer model.