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Effect of discards on roundnose grenadier stock assessment in the Northeast Atlantic

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Abstract – In the Northeast Atlantic fishery for roundnose grenadier *Coryphaenoides rupestris*, discards account for about 30% of the catch in weight. Data on discards are scarce; however, length distributions and discard rates appear to be relatively stable from year to year. In contrast, landings data available since 1990 show that the average pre-anal fin length has decreased from 20.7 cm in 1990 to 15.2 cm in 2008, resulting in a 58% reduction of the mean individual weight (850 g in 2008) and an increasing occurrence of overlapping class sizes between landings and discards in recent years. For stock assessment, the method of separable virtual population analysis (SVPA) was used. However, because of the lack of discard data for many of the years covered by the study, the catch data used as input to the assessment model had to be reconstructed from the available information (landings, discards, fishing effort and bathymetric distribution of the stock) using two methods. The first method relied on the assumption that the recent length distributions of discards were applicable to the earlier years (1990-1997). It resulted in unrealistic bimodal length distributions, suggesting a change in discarding practices through time, with larger individuals being discarded in the early days. The second method, based on the fishing effort and length distribution by depth strata, produced unimodal distributions for the whole period and confirmed that the average length of discarded fish was higher in the early days of the fishery. In both cases, the estimates of biomass follow parallel trends, suggesting a strong decline in the population. The available information and methods are discussed.

Key words: Stock assessment / Fishing effort / Discards / Time series / Macrouridae / *Coryphaenoides rupestris* / Atlantic Ocean

Résumé – Les rejets de grenadier de roche *Coryphaenoides rupestris* au sein des pêcheries de l'Atlantique Nord-Est représentent 30 % des captures en poids. Ces rejets, pour lesquels il existe peu de données, présentent des distributions et des proportions relativement stables d'une année à l'autre. En revanche, les données de débarquements disponibles depuis 1990 montrent que leur taille moyenne (la longueur pré-anale) est passée de 20,7 cm en 1990 à 15,2 cm en 2008, ce qui correspond à une réduction de 58 % du poids individuel moyen (850 g en 2008), avec une superposition de plus en plus fréquente des classes de taille rejetées et débarquées au cours de ces dernières années. Pour évaluer le stock, la méthode d'analyse séparable des populations virtuelles (SVPA) a été utilisée. Cependant, du fait du manque de données sur les rejets pour la plupart des années, les données de captures utilisées pour l'évaluation ont dû être reconstruites à partir des informations disponibles (débarquements, rejets, effort de pêche, distribution bathymétrique du stock) selon deux méthodes. La première méthode repose sur l'hypothèse que les distributions récentes des rejets peuvent s'appliquer aux années antérieures (1990-1997). Elle produit des distributions bimodales irréalistes, suggérant ainsi un changement dans les pratiques de rejet au début de la pêcherie. La seconde méthode, basée sur l'effort de pêche et la distribution des tailles par strate de profondeur, produit des distributions unimodales pour toute la période étudiée et confirme que la longueur moyenne individuelles des poissons rejetés était plus grande lors du commencement de cette pêche. Dans les deux cas, les estimations de la biomasse suivent des tendances parallèles qui suggèrent un fort déclin de la population. Les informations disponibles et les méthodes appliquées sont discutées.

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1 Introduction

Roundnose grenadier (*Coryphaenoides rupestris*: Macrouridae, Gadiformes) has been the main species in the landings of deep-water trawlers in the Northeast Atlantic since the late 1980s (Charuau et al. 1995; ICES 2008). At that time, offshore French trawlers began to harvest the deep waters along the continental slope west of the British Isles and around banks and other areas located further west and north, e.g. Rockall, Bill Bailey, Hatton, Faeroe banks and Anton Dohrn Seamount (Fig. 1). This species is mainly caught in a multi-species fishery, where blackscabbard fish (*Aphanopus carbo*) and deepsea sharks (mainly *Centrophorus squamosus* and *Centroscymnus coelolepis*) are the main other species. West of the British Isles, the roundnose grenadier is mainly caught by bottom trawlers. It is distributed over the slope, ridge and other deep-water bottom features of the North Atlantic. It is also found in the Norwegian shelf basins and fjords and is abundant in the Skagerrak (Atkinson 1995; Bergstad 1990). Its dynamics and genetic population structure are poorly known. Current hypothetical stock delimitations consider that populations in Sub-areas VI and VII and Divisions Vb and XIIb of the International Council for the Exploration of the Sea (ICES) form a single stock unit, whose dynamics are independent from those of fish distributed further west, around Iceland and on the Mid-Atlantic Ridge, or further east in the Norwegian Sea (Lorance et al. 2008). Former ICES Divisions like VIb have been split in recent years into VIb1 and VIb2 in order to identify fishing activities within and outside of the EEZ. In Sub-area VII, only divisions where roundnose grenadier is likely to be caught are dealt with.

To the west of the British Isles, roundnose grenadier is mainly found from 700 to 1800 m and is most abundant at 1000–1500 m (Bridger 1978; Ehrich 1983; Gordon and Bergstad 1992; Gordon et al. 1996). All available data suggest that the biological productivity of its populations is low because of high longevity, which is clearly over 50 years. Growth is slow, ,with adult fish hardly reaching 2.5 kg (Lorance et al. 2008). Sexual maturity is reached between 8 and 14 years (Kelly et al. 1996, 1997; Allain 2001). Although some aggregations may occur locally, the distribution of the species is primarily dispersed, and almost any fishing tow from a bottom trawl at suitable depths will yield some grenadiers. Adults and juveniles are found on the same grounds but in changing proportions so that the length distribution of the stock changes with depth (Gordon 1979; Lorance et al. 2008). To the west of Scotland, roundnose grenadier comprise mainly large fish in the shallowest (500–750 m) part of the depth range, mixing with juveniles in the mid-range (~1000 m); at greater depth fish of intermediate size become increasingly dominant (Fig. 2) (Gordon 1979). Nevertheless, any fishing tow will yield both large commercial and small not-marketable fish and, as a consequence, a portion of the catch is not marketable and is discarded at sea.

As for most deep-water species, there is no time series of roundnose grenadier recruitment to the west of the British Isles. Long periods of weak recruitment have been hypothesised for some deep-water species, in particular for orange roughy (see e.g. Clark 2001) and may occur for roundnose

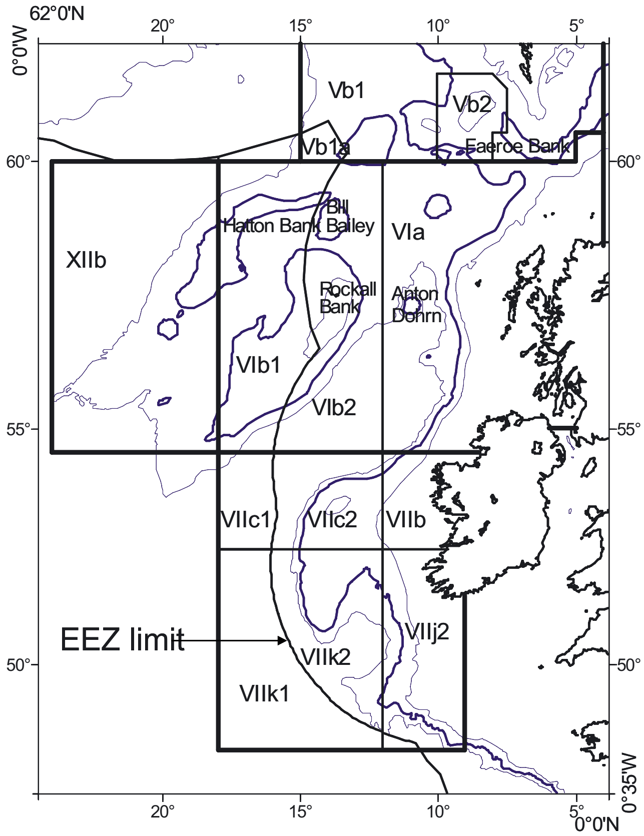

Fig. 1. ICES Divisions and main banks frequented by the trawl fishery for roundnose grenadier in Sub-areas V, VI and VII. Depth contours are for 200, 1000 and 2000 m.

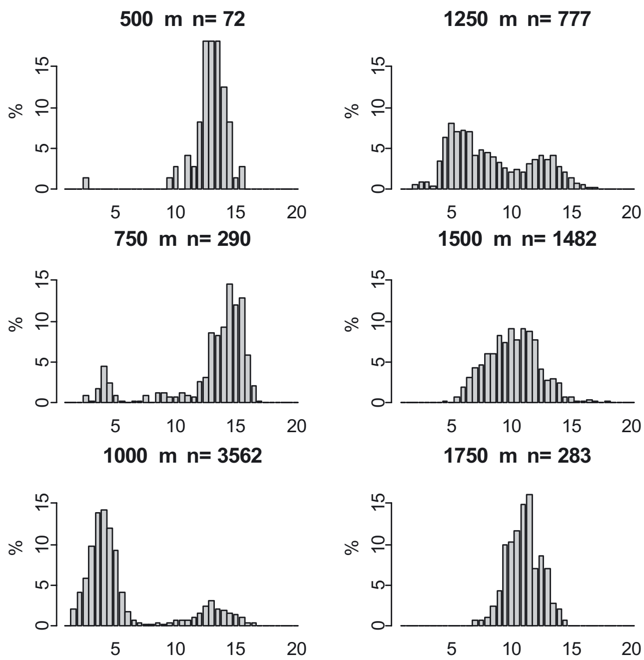

Fig. 2. Head length distribution of roundnose grenadier *Coryphaenoides rupestris* per depth strata in the Rockall Trough (West of Scotland). Data from SAMS, redrawn from Lorance et al. (2008).

grenadier in the Skagerrak (Bergstad pers. comm.). However, like the orange roughy, the Skagerrak population of roundnose grenadier spawns during a short season (Bergstad and Gordon 1994), while the population found west of the British Isles spawns almost year round (Allain 2001). This reproductive strategy might lead to less variable recruitment as all eggs and larvae are not exposed to the same good or bad seasonal environmental conditions in a given year. Therefore, this study builds on an underlying hypothesis of rather stable recruitment.

Catching juveniles implies that recruitment of both the spawning and the commercial portions of the stock, made up of individuals of commercial size, is reduced due to fishing mortality of juvenile age classes. There might be some density-dependent compensation. Another more technical consequence of discarding is that it creates data deficiencies. As landings are often used as a surrogate for catches in population dynamics models, large discards result in biased fishing pattern (mortality at age) and total stock biomass estimates. The current perception of the exploitation of roundnose grenadier to the west of the British Isles is that the stock has been seriously overharvested since the start of the fishery. Although data have been generally insufficient for reliable stock modelling, trends derived from both fishery statistics and scientific survey indices suggest a severely declining abundance (ICES 2007; Basson et al. 2002).

In this study, we attempt to combine landings and discard data to carry out a more realistic stock assessment. However, because discard data are much scarcer than data on landings, we explored several assumptions to fill data gaps using two methods based on different types of available data sets. We first present an overview of the available information and the two methods used to reconstruct catches. Then, we explore and discuss the quality of the reconstruction and the outcomes from exploratory assessments carried out on those rebuilt data sets. Due to the uncertain nature of the information used in this study, the assessments have to be considered as exploratory, providing a range of possible stock trajectories.

2 Material and methods

Data on landings of roundnose grenadier from ICES Subareas VI and VII and Division Vb were available from 1990 to 2008 (ICES 2009, Table 1). Due to doubts about the reliability of data for Division XIIb, this area was not considered in this study. The very high catch in that area in 2001, more than 31 000 t (ICES 2008), would have strongly affected stock estimates. Moreover, the fleets exploiting Division XIIb are different, and the length distribution of their landings and discards may be different but were not available. Length distributions of the French landings were available for each year over the same period. Some length distribution data from other countries were derived from the ICES working group report but they were not used in the present study because they did not provide a complete time series. Therefore, the length distribution of the French landings was considered as representative of all international landings; this is a reasonable assumption because French landings make up the bulk of the total landings and there is no reason to believe that other fleets target other stock components or have a substantially different selectivity. Discards data (length distribution and proportion in the total catch) of the French fleet were available from Scottish (1997-2001) and French on-board observations (1997-1998, 2004-2006). The stock assessment made by the ICES Working Group on the Biology and Assessment of Deep-Sea Fisheries Resources in 2009 was used as reference. It was only based upon the landings data for 1996-2008 (ICES 2009). Additional information about the depth distribution of the stock was obtained from the scientific literature. A database of fishing effort per depth strata and year was provided by PROMA/PMA, a producers organisation from Brittany, and EURONOR, a ship owner, from Boulogne-sur-mer. This database contains the fishing time and the catch on a haul-by-haul basis. Mainly tows from 1992 to 2008 were available. This database includes about 20% (1999-2008) of the French catch of roundnose grenadier and was considered representative of all the French fishing fleet.

The time series does not have a sufficient number of years where both landings and discard data are available to carry out an assessment. Therefore, for years where discards data were missing, length distributions and weights were interpolated (2002-2003) or extrapolated (1990-1996, 2007-2008) using the neighbouring years. As the purpose of this work was to reconstruct discards data back to 1990 and to carry out exploratory assessments over the 1990-2008 period, the missing information on discards was constructed using two different methods: 1) extrapolating length distributions from neighbouring years with discard data, 2) combining fishing effort and the stock length distribution with depth. These two methods will be referred to hereafter as landings and discards method (L-D) and effort and depth distribution method (E-DD). The observations in years when both landings and discard data were available were used to check the consistency of the estimated catch length distributions for both methods.

2.1 Extrapolating discard length distributions (L-D method)

In this method, the same data as those available to the ICES working group were used. As length distributions of discards were found to be stable over time (i.e. no substantial change from one year to another), this method extrapolates an average discard length distribution back in time.

Sample length distributions of landings in number of individuals can easily be raised to total landings using the weight of measured fish and of total landings. For discards, only discard rates (discard/catch) in weight were available from observed fishing trips. Allain et al. (2003) estimated total discard weights for 1996 and 1997. As such estimates are not available for all years, it was necessary to make some assumptions about discard rates in order to be able to combine landings and discard length distributions.

For transforming numbers into weight, we used the following allometric relationship (P. Lorance, unpublished data) with pre-anal fin lengths, L (Pre-anal fin length, PAFL) and weights, W:

$$W = 0.2136 \cdot L^{2.9874}. \tag{1}$$

For transforming the proportion at length in numbers f_l into proportion at length in weight p_l for length class l, the

Table 1. Landings of roundnose grenadier in ICES Divisions Vb, XIIb and Sub-areas VI, VII. The totals of Vb,VI and VII are used as landings estimates for the assessments in this study. The totals include landings in Vb, VI, VII, XIIb, as well as unallocated landings (effective landings for this stock without assigned divisions or areas).

Year	Landings in ICES divisions & sub-areas						Total
	Vb	VI	VII	XIIb	Unalloc.	Vb,VI,VII	
1988	1	32	0	0	0	33	33
1989	258	2218	222	52	0	2698	2750
1990	1549	5515	215	0	0	7279	7279
1991	2311	7304	489	172	0	10 104	10 276
1992	3817	6782	1556	13	0	12 155	12 168
1993	1681	8205	1916	328	0	11 802	12 130
1994	668	5938	1922	486	0	8528	9014
1995	1223	6472	1295	644	0	8990	9634
1996	1078	6044	1051	1528	0	8173	9701
1997	1112	6032	1038	2725	0	8182	10 907
1998	1667	5207	1157	3964	0	8031	11 995
1999	1996	5642	896	6493	0	8534	15 027
2000	1791	8956	859	13 822	0	11 606	25 428
2001	2016	14 773	1354	31 774	208	18 143	49 917
2002	1031	11 538	1058	5394	504	13 627	19 020
2003	1532	6598	587	18 745	952	8717	27 461
2004	1575	5990	568	10 067	0	8133	18 200
2005	1837	3694	246	6012	5003	5777	11 790
2006	1775	2122	386	5286	0	4283	9569
2007	1700	1599	227	5737	0	3526	9263
2008*	1011	1421	87	0	0	2519	2519

*Preliminary

following equation was used:

$$p_l = \frac{W_l \cdot f_l}{\Sigma_{l=1}^{n} W_l \cdot f_l} \quad (2)$$

where W_l is the weight of an individual in length class l and n the total number of length classes. These proportions in weight were calculated for landings and discards and then combined using the discard rate d:

$$p_l^{\text{catch}} = (1-d)p_l^{\text{landings}} + d \cdot p_l^{\text{discard}}. \quad (3)$$

For years with no discard data, we interpolated the discard rate from neighbouring years (with known discard rate). For the period from 1990 to 1996, we assumed the discard rates were similar to the first years with observations (1997, 1998) and used an average value from those years (24.3%).

As p_l^{catch} provides for each size class its relative contribution to the weight of the catch, C, the number of individuals N_l caught per size class is calculated from equation (4):

$$N_l = p_l^{\text{catch}} \cdot W_l. \quad (4)$$

2.2 Combining depth distributions of fishing effort and sizes (E-DD method)

This method estimates the length distribution of the catch by combining information on fishing time per depth strata and per year (Fig. 3) and for each year, an estimated length distribution by depth strata taken from the scientific literature (Gordon 1979; Mauchline and Gordon 1984; Gordon and Hunter 1994; Allain 1999; Lorance et al. 2008). The oldest data taken from the literature (Gordon 1979; Mauchline and Gordon 1984) provide length distributions for the period 1979-1984. No information was available between 1984 and 1990, the first year used for the stock assessment by ICES. We assumed the fishery has started to land significant amounts of roundnose grenadier in the late 1980s and considered, therefore, that the size distribution observed in 1979-1984 was stable up to 1988. The reference fleet is assumed to be representative of the activity of all fleets, for which depth data is available, targeting roundnose grenadier. The fishing gears used in both scientific surveys and in the commercial fishery are assumed to have the same selectivity for individuals larger than 7 cm PAFL. This simplistic assumption is based on a comparison between reconstructed catches and actual landings and discards distribution, as no proper method was available to convert survey distributions into fishery ones for roundnose grenadier. The major difference is the absence of individuals smaller than 7 cm in the distributions from the fishing vessels. Therefore, individuals smaller than 7 cm PAFL caught in the scientific surveys are simply ignored in the distributions and subsequent calculations. This "rough" assumption seemed fine here to convert survey distributions into pseudo-fishery distributions as no major differences appeared in the mode and overall shape of both reconstructed and actual catch distributions. Where needed, total lengths (*TL*) were converted to *PAFL* using the relationship $PAFL = 0.196\,TL + 2.29$ from Lorance et al. (2001) and head length (*HL*) to *PAFL* from the relationship $PAFL = 1.354\,HL - 0.272$ from Gordon and Hunter (1994). Relative length distributions were calculated for 5 depth strata z (600–799 m, 800–999 m, 1000–1199 m,

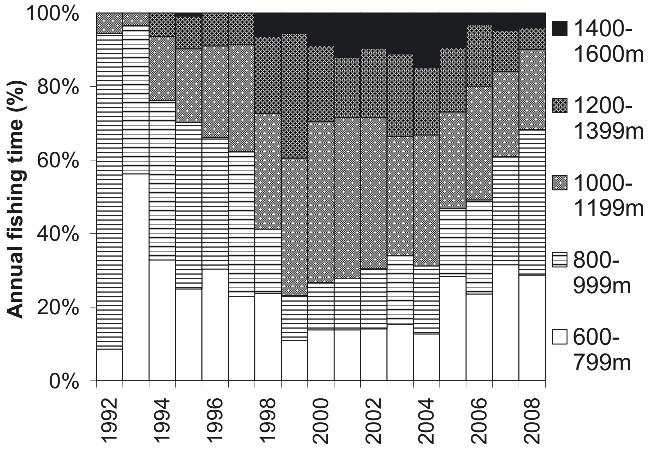

Fig. 3. Distribution of fishing time per depth range for 30 French vessels targeting roundnose grenadier in ICES Divisions Vb, VI, VII. The percentages represent the proportions of the total fishing time each for each year spent in each depth band.

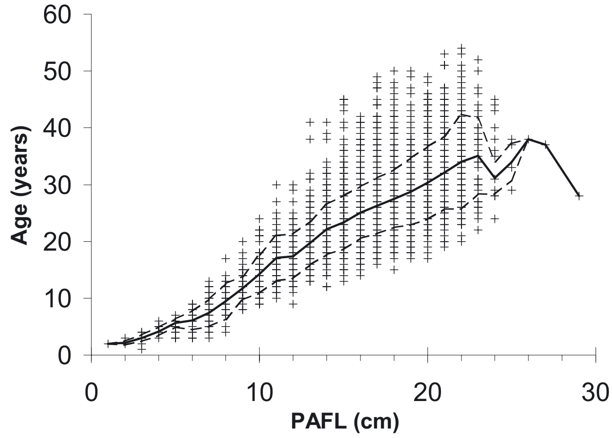

Fig. 4. Average age (-) according to pre-anal fin length (*PAFL*) based on age-reading of otolith (+). Dotted lines represent the average age at length ± standard deviation.

Table 2. Summary of the available sources of information used for the exploratory stock assessments.

Method	Data	Years	Sources
L-D	Landings	1990-2008	Fishries statistics
	Discards	1997-2001	Observer programs (Scotland)
		2004-2006	Observer programs (France)
E-DD	Fishing effort	1992-2008	French fishing industry
	Vertical distribution	prior 1988	Gordon 1979, Mauchline and Gordon 1984
		1996	Allain 1999
		1999	Allain 1999
		2004-2006	Observer programs (France)

1200–1399 m, 1400–1600 m) for years where distributions were available (Table 2) and then used to interpolate distribution for the years with no information. The haul-by-haul fishery data was used to estimate the effort E_z by depth stratum z for each year. The length distribution of the total catch was estimated each year from the frequency $f_{l,z}^{\text{observation}}$ of each size class in each depth stratum based upon survey data and the fishing effort E_z assuming the same catch rate in all strata (Eq. (5))

$$f_l^{\text{catch}} = \frac{\Sigma_{z=1}^{5} E_z \cdot f_{l,z}^{\text{observation}}}{\Sigma_{l=1}^{n} \Sigma_{z=1}^{5} E_z \cdot f_{l,z}^{\text{observation}}}. \quad (5)$$

As in the L-D method, the relative contribution of each size class to the total weight is estimated from equations (1) and (2) to compute directly p_l^{catch}. The discard rates are also estimated with the same interpolation as in the L-D method. Equation (4) is then used to calculate the number of individuals caught for each size class and subsequent preparation of data.

2.3 Exploratory stock assessments using SVPA

A series of exploratory runs of a separable virtual population analyses (SVPA) model using VPA95 (CEFAS, Lowestoft, UK) were performed. In order to be consistent with assessments made by the ICES working group, the same parameters were used for this study: (i) the model was run on age groups 16 to 40, the 40 group being a plus group (40+); (ii) the reference age group was the 25 years old group; (iii) terminal fishing mortality F was set to 0.1, and (iv) the selectivity factor S was set to 0.8.

Three assessments were carried out using catch-at age matrices derived from the L-D and E-DD methods and from the length distributions of the landings only. The latter assessment is used as reference and is the same as the one presented in ICES (2008) but with a temporal extension back to 1990. The same age-length key (Fig. 4) was used in all cases to convert catch-at-length into catch-at-age matrices.

3 Results

3.1 Reconstruction of data

The average individual size of landed roundnose grenadier has decreased from 20.8 cm in 1990 to 15.2 cm in 2008 (Fig. 5). This has resulted in a 58% decrease of the average of individual weight (2031 g in 1990, 850 g in 2008). The decline mainly occurred from 1990 to 1998 when the fishery moved to deeper waters (Fig. 3). Since then, the mean length of landed fish has not changed substantially. The available data indicate that the mean length of discarded fish has been more stable (12.4 ± 0.8 cm) than that of landed fish (17.3 ± 1.6 cm) for the years where both landings and discards data were available. Modes of the discard length distributions ranged between 11.4 and 14.5 cm, with no clear trends towards increase or decrease, considering the insufficient number of years (8) of the time series. The individual mean weights ranged between 355 and 571 g. The average discard rate – obtained dividing the quantities discarded by the total catch (Rochet and Trenkel 2005) – is 47% in number of individuals and 28% in weight.

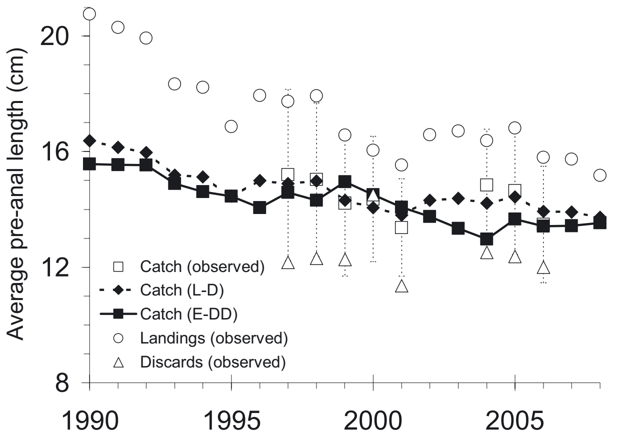

Fig. 5. Evolution of average pre-anal fin lengths (*PAFL*) for the different type of available observations and the two re-estimations of catch time series for the period 1990-2007. Error bars represent standard deviation for *PAFL* from observed catches.

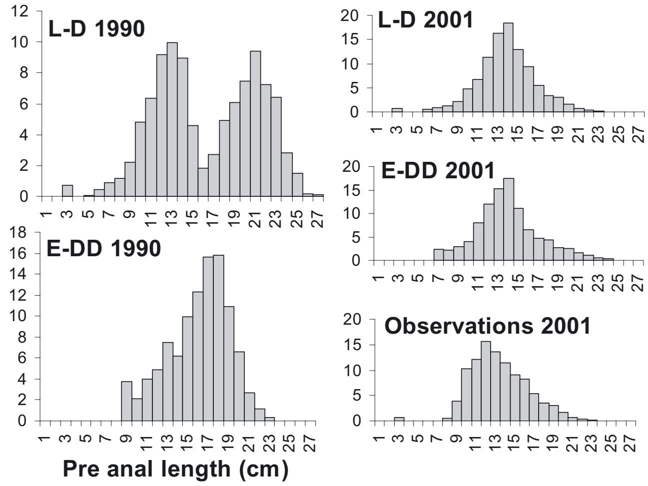

Fig. 6. Length distribution of the catch reconstructed by L-D and E-DD methods (1990, 2001) and from observations (2001).

Using the L-D method, the average PAFL of the total catch declined from 16.4 cm in 1990 to 13.7 cm in 2008. The E-DD method indicates a decline in the mean size of the total catch from 15.6 cm in 1990 to 13.5 cm in 2008 (Fig. 5). The E-DD mean size is respectively 4.4 and 1.4 cm smaller in 1990 and 2008 than the L-D one. The results are however very consistent with results from the observations: except for 2004, the differences between observations and simulations of catches are always less than 0.8 cm.

The catch data reconstructed using the L-D method has a bimodal length distribution in the early 1990s (Fig. 6), with two modes at about 13 and 21 cm. The appearance of a second mode is the result of combining a constant length distribution of discards to the length distributions of the landings which, at that time, shifted towards larger individuals. Assuming there is only one stock and no marked change has occurred in recruitment strength, a single-mode distribution could only be observed if the average individual length of discards was higher in the early days of the fisheries than it was in 2008. This idea is also supported by the fact that the two modes become closer and then merge in the mid-1990s with the decreasing mean size in the landings. All the distributions from the E-DD method have a single mode, around 18 cm in 1990 and 14 cm in 2001, one of the years with observations of both landings and discards and used here as a reference for comparison. The later value is consistent with observations. The general shape of the distribution also matches well observations made in 2001.

The E-DD and L-D methods also provide consistent conclusions about the size of individuals being discarded in the early day of the fishery: the average discard size which was estimated to be 13.2 cm in 1990, decreased to 11.5 cm in 2008. The simulated mean sizes of the discards show little trend (no more than 0.5 cm, corresponding to one size class) after 1994, but with two marked decreases in 1995 and 2000-2001 (Fig. 7). These size reductions are not related to changes in fishing effort but to substantial changes in the length distributions observed for the landings for those years (Fig. 5). As discards are estimated from the removal of the length distribution of landings from the estimated catch, any discrepancies in landings will affect the estimation of discards.

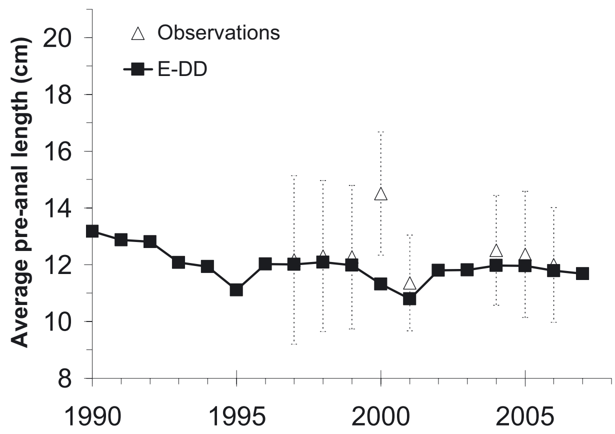

Fig. 7. Comparison of the average pre-anal lengths of discards from observation and reconstructed data sets using the E-DD method. Errors bars represent the standard deviation for observations.

Intermediate results from catch and landing-at-age tables show that the average age of the population has decreased for all assessments (Fig. 8) from 1990 to 2008. As expected, the average age based from the landing-at-age table shows the strongest decrease with a change from 31 years in 1990 to 23 years in 2008 because the assumed length distribution of the discards is more stable. The L-D method results in an average age decreasing from 22 to 20 years from 1996 to 2008, while the E-DD method estimates a change from 23 to 21 years for the same period. All methods suggest that the fishery has been catching an increasing proportion of younger individuals. The E-DD method estimates younger average ages, especially in the early days of the fisheries. The difference might be linked to our choice of removing individuals with PAFL smaller than 7 cm. Data from scientific surveys before the onset of the fishery had a substantial number of individuals in the smallest class sizes leading to bimodal distributions for some depth layers (e.g. Gordon 1979; Mauchline and Gordon 1994). In the

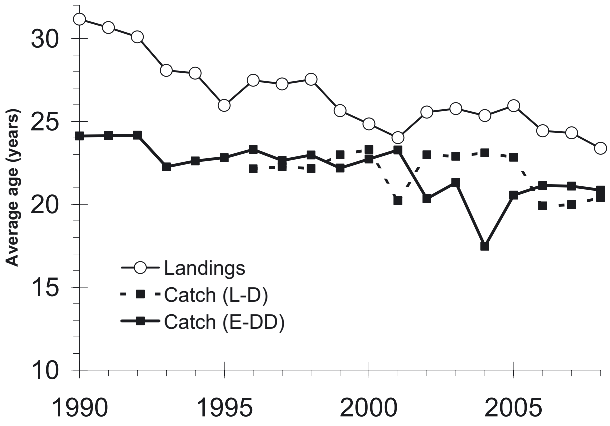

Fig. 8. Evolution of the average age in the catch- and landing-at-age tables used for the exploratory assessments on roundnose grenadier.

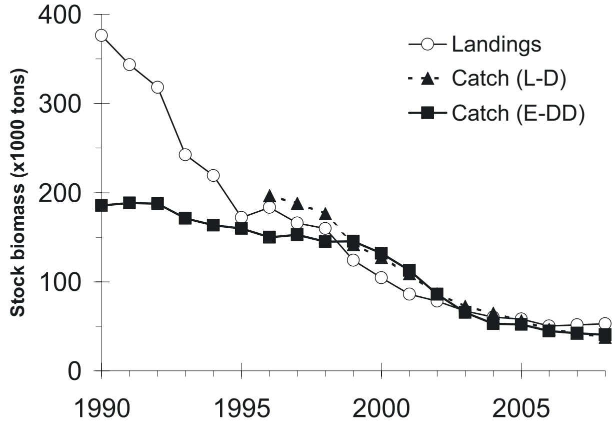

Fig. 9. Estimates of stock biomass based on landings and two methods of reconstructed catch data based on separable VPA, for roundnose grenadier in Vb, VI, VII. Terminal F is set to 0.1 and S to 0.8.

1990s, as the used datasets were a mix between fishery statistics and data from observer programs, results are based only on commercial fishing gears with no small size class caught and a single mode.

3.2 Exploratory stock assessment

As the length distributions rebuilt from L-D method were considered erroneous before 1996, the stock assessment based upon the catch-at-age table derived from this method was restricted to the period 1996-2008. For the E-DD method, the complete time series (1990-2008) was used.

Differences between initial stock biomass estimates, respectively 380 000 and 186 000 t are set between the reference assessment (landings) and the E-DD method (Fig. 8). This strong difference is most likely explained by the fact that the reference assessment is based on big-size classes while the E-DD methods is based also on non-commercial size classes including discarded and non-caught size classes. All methods show biomass estimates converge to around 180 000 t in 1996 and then decline to 41 000 t in 2008 with more or less the same slope.

The fact both E-DD and L-D methods converge towards the reference assessment could be a consequence of a lower influence of discards in the recent years. This idea is conflicting with observations which indicate that the discard rate has not substantially changed and the occurrence of overlapping class sizes has even increased. However, estimates from method L-D are not mathematically independent from the reference assessment since they rely partly on the same data sets (landings). On the contrary, the E-DD method provides independent estimates of biomass but still converges on the same estimate as the reference assessment. This observation validates this method, at least for recent years, as the combination of fishing effort and stock distribution-at-depth provide a good estimate of the distribution of the catch.

For all three assessments, fishing mortalities (Fig. 10) exhibit the same pattern, with a slow rise from 0.02–0.04 to 0.07–0.08 in 1998 before a peak at 0.28 in 2001. Then fishing mortality slowly converges towards the terminal F value of 0.1 in 2008. All methods provide very similar estimates of F. For most years, the L-D method matches perfectly the reference assessment while the E-DD method tends to provide slightly higher values of F.

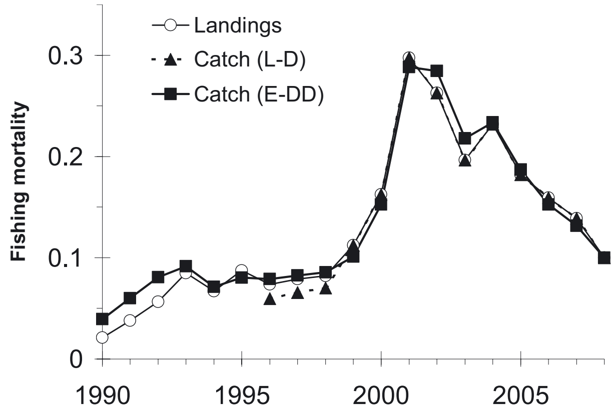

Fig. 10. Fishing mortality for roundnose grenadier in Vb, VI, VII.

4 Discussion

Integrating discards into the assessment of roundnose grenadier leads to (i) strongly different estimates in the early days of the fisheries, (ii) converging estimates of stock biomass in recent years and (iii) the same strong declining trend in the population since the beginning of its exploitation.

To carry out this study, we explored the stock trends, based upon two limited but independent data sets and assumptions to fill the gaps in the time series of discards. The first simulated data set combines the available data from on-board observations of the discard rate and length distributions, samplings of the length distribution of the landings at the fish markets and fishery catch statistics in order to produce one time series of length distributions of the catch (L-D method). The second data set is based upon survey-derived length distributions of the species by depth strata and a time series of the distribution of fishing effort by depth strata (E-DD method).

The length distributions reconstructed by the two methods are different at the start of the fishery where: (i) the L-D method produces bimodal length distributions, and (ii) the larger fish observed in the landings were not caught during scientific cruises and do not appear in the catches simulated by the E-DD method (Fig. 6). This discrepancy may be explained by: (i) some differences in gear selectivity of fishing depths sampled by the fishery and the survey vessels, or (ii) a change in fisher's targeting behavior. Therefore, these simulations suggest that the actual changes in landed fish size over time are closely related to the intensity and patterns of the exploitation of this stock. The decline in the proportion of larger fish might have induced some changes in fishing depths (Fig. 3). The trend towards deeper fishing grounds implies a higher proportion of smaller fish in the catch which also results in a decrease of the individual size of the landed fish. Moreover, a change in the way the catch was sorted (i.e. selection process by the fishers of the fishes to be landed and those to be discarded) may have occurred because the market for this species was new in the early 1990s and it is likely that only large fish were bought and processed by fishmongers at that time. This might be a reason for the bimodal length distribution produced by the L-D method. Considering the slow growth and high longevity of the roundnose grenadier, a bimodal length composition of the population is, however, hardly realistic. Assuming a single stock, where all individuals would have the same catchability, the simulated bimodal length composition of the catch would be erroneous and suggests that the fish that were discarded in the early days of the fisheries were larger than today. Our simulation indicates that the initial assumption that the size distribution of discards in the early days was similar to that observed after 1997 is probably incorrect. However, survey data show that the length distribution of roundnose grenadier may be bimodal at some depth. Indeed, available survey data show that, at the shallower depths exploited by the fleets in the early 1990s (Fig. 3), there is a higher proportion of larger fish, and a bimodal length composition occurs (e.g. Gordon 1979; Lorance et al. 2008). However, in such distributions, the first mode is around 5 cm (PAFL length) and is not consistent with the length distribution of discards in the mid-1990s. No catches of such small juveniles have been reported by onboard observers. It must be concluded, therefore, that the reconstructed bimodal distributions obtained for the early 1990s do not reflect the bimodal distribution of the stock as seen by the surveys. In addition, it is felt that fishers targeting larger fish in deeper waters at that time would not have caught those smaller size classes. Additional information about recruitment and its fluctuation from year to year could perhaps provide a different explanation about the bimodal distribution in the early 1990s. Testing that assumption would require information that is presently not available as well as additional hypotheses exploratory assessments.

The strong difference in biomass estimates in the early days of the fishery is an issue for the management of this fishery as in the absence of reliable information on recruitment, no biological reference points can be set. Biological reference points are one of the key elements required to evaluate if the exploitation is within safe boundaries. Current stock biomass estimates suggest that the population tends to stabilize at a very low level (11–22% of the biomass in 1990 depending on the initial estimates) while discards are still high. For this stock to recover, the already low TAC should probably be further reduced, and any option to reduce discards should be considered. The lack of reliable quantitative assessments is critical, considering all methods show a strong decline in the population of roundnose grenadier as well as a decrease of the average individual size.

The evolution of the fishing depths over time might have been driven by a declining abundance of large fishes at their preferred depth and a shift in fishing strategies, targeting other species. This implies that the selectivity pattern (i.e. the distribution of the fishing mortality over depths and, therefore, over sizes or ages) has changed over time. The SVPA model may therefore not be entirely appropriate to assess the roundnose grenadier stock assessment because it assumes a constant fishing pattern. In addition, the change may have been driven also by higher catches and retention of smaller fish in recent years because of the lesser abundance of large fish in the stock and changes in fishing depth (Rochet and Trenkel 2005). The likely change in the sorting pattern of the catch is a further problem which, if not accounted for, might result in underestimating the stock biomass in earlier years, where more and bigger fish may have been discarded due to a market constraint and higher availability of bigger individuals (as confirmed by anecdotal reports from fishers).

The E-DD method is based on the assumption that the fishing strategy of a French fleet can be extrapolated to all fleets involved in this fishery. Fishing depths have changed with years, and this study is based on the hypothesis that the stock is spatially homogeneous with length distribution-at-depth being the same everywhere within the fishing area.

Although these assumptions add uncertainties to the assessment, the reconstruction of catch length distributions for years where data on discards are missing is consistent with the observations for years where discards records exist, and this is a strong signal in favor of the validation of this method.

Reconstructed catch data rely on the knowledge of length distribution-at-depth over the years. Roundnose grenadier being a long-lived species, fishing mortality might have had a strong effect on age and length composition of the population. Survey data are too scarce to estimate the changes over time of the length composition of the stock. However, according to all assessments, in 2001 the fishing mortality peaked at more than 0.25. Although this may not appear as very high compared to fishing mortality applied to other shelf stock, it is clearly unsustainable for a long-lived species for which natural mortality is believed to be around 0.1 (implying that 1% of the recruits still survive after 50 years). These assessments are exploratory, and the main interest of this study is to investigate the effect of possible discarding practices (and changes in such practices with time) on the estimation of stock trends. Although the discard rate is presently high for the roundnose grenadier, similar trends in stock size are estimated with or without discards.

The different assessments undertaken in this study are constrained by strong assumptions which affect their reliability as this stock is clearly in a data-poor situation because:

1. sampling of the landings is incomplete, e.g. age length keys are not available for all years;

2. there are gaps in the catch statistics, e.g. there were landings reported in France in 1988-1989 but the species was not recorded separately in catch statistics before 1990 (see Charuau et al. 1995);
3. stock distribution (geographical? bathymetric?) and biological parameters are poorly known;
4. stock structure is not yet clear. Fish occurring in ICES Division Vb and Sub-areas VI and VII are treated as a population unit, while the current understanding of the population structure[1] suggests that fish from Division XIIb (western slope of the Hatton Bank) belong to the same population. Division XIIb was not included in our analysis due to severe doubts on landings data and unavailability of their length distribution. Ignoring a part of the catch for which the fishing patterns may be different because it is exploited by a different fleet implies that the present assessment should be regarded as exploratory.

This situation has been improving thanks to the implementation of on-board observation programs and the increasing availability of discard data, but most time series on discards still have many gaps, and length distributions-at-depth from scientific surveys are nearly inexistent. Fortunately, partnerships with the industry through self-sampling programs, haul-by-haul databases and future scientific surveys will bring more information as the basis for more accurate stock assessment models than the current SVPA, which might not be the best candidate considering the change in fishing patterns and the shortness of time series.

5 Conclusion

This preliminary study is a first attempt to use most of the available information on this stock. It was based on a set of heterogeneous information, comprising both fishing effort and data from survey cruises. In future, more data may still be recovered, verified (in particular the time series of landings in Area XIIb) and integrated into assessment modeling. Nonetheless, the dynamics of the roundnose grenadier stock will remain challenging, as the various changes in fishing patterns through time may require more complex models and knowledge of the fisheries than presently available.

While the results from the different methods are consistent in showing similar trends of declining stock biomass, the uncertainties linked to the lack of data and assumptions are still clouding the reconstruction of the stock history especially at the beginning of the fishery. An accurate knowledge of the state of the stock in the early days of its exploitation is of interest to ensure appropriate management measure (such as setting biological reference points). In order to improve results, further compilation of data, exchanges between marine institutes and the fishing industries are required to reduce uncertainties.

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[1] A recent genetic study suggested however that roundnose grenadier populations were more spatially structured than previously thought (Knutsen et al. 2009).

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