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Preliminary estimates of French deepwater fishery discards in the Northeast Atlantic Ocean

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Abstract: French deepwater fish exploitation (500 m) began off the West coast of the British Isles in 1973. It further developed in the 1980s, and intensified in the 1990s. In 1997, the French fleet comprised 49 boats, and since 1995 has landed yearly about 19,500 t of deepwater fish species, of which, the grenadier Coryphaenoides rupestris (Macrouridae) has been the most abundant. Discard data were sampled on-board by observers on French high sea trawlers from 1995 to 1997. Eight species were identified as totally landed, 43 non-commercial species as totally discarded and only one, the grenadier, as both landed and discarded. The mean discarding rate by haul was 48.5% in weight, whereas the mean grenadier discarding rate was 21.2%; these rates increased with depth. Discard species composition and discard quantities varied with depth, and depended on the specific composition of the fish communities, species abundance and their length–frequency distribution. The latter, established for grenadier and Alepocephalus bairdii (Alepocephalidae), assumes a bathymetric ontogenic migration. Annual discards of the fishery accounted for about 17,500 t in 1996 and 1997, but the results are quite uncertain.

Keywords: *Alepocephalus bairdii*; *Coryphaenoides rupestris*; Discarding rate; Discards; Length–frequency distribution

Introduction

The exploitation of deepwater species by the French fleet began in 1973 when blue ling *Molva dypterygia* (Pennant, 1784) (Lotidae) were caught off the West coast of the British Isles in depths of 500-600 m. This fishery developed throughout the 1980s and intensified throughout the 1990s with the landing of additional species taken in deeper water (down to 1400 m) such as roundnose grenadier *Coryphaenoides rupestris* (Gunnerus, 1765) (Macrouridae), black scabbard fish *Aphanopus carbo* (Lowe, 1839) (Trichiuridae) and orange roughy *Hoplostethus atlanticus* (Collett, 1889) (Trachichthyidae) (Charuau et al., 1995). This fishery takes place in ICES Divisions V, VI and VII and is undertaken by high-seas trawlers (Lorance and Dupouy, 2001). In 1997, 49 boats participated in the fishery, of which 21 were specialised for it (i.e. they spent more than 50% of their annual fishing hours targeting deepwater fishes) (Allain, 1999a). In 1997, around 19 000 t of deepwater species were landed, including 7200 t of *C. rupestris*.

Only a few species are targeted by the French fishery; the non-commercial species or small individuals are discarded. Because of physiological injuries, fish do not survive the rapid raising from several hundred meters depth, and are discarded dead or dying. Discards of commercial species contribute to fishing mortality and should be quantified for stock management purposes. Furthermore, discards represent an economic and ecological waste, and seeking solutions to alleviate the problem requires local studies to determine the scale and variability of discarding (Saila, 1983). Our study conducted from 1995 to 1997 on French high-seas trawlers, is complementary to two other studies on deepwater fishery discards conducted at the same time and in the same area by Connolly and Kelly (1996) and Blasdale and Newton (1998). Our aim was to identify the species discarded, to determine their discarding rate and to provide a preliminary estimate of the total quantities discarded by the French deepwater fleet.

Material and methods

The weights of landed and discarded fish were estimated by on-board observers for 55 trawl hauls made at depths between 800 m and 1400 m, and sampled during eight two-week trips on two high-seas trawlers (38 m long). These trips took place between December 1995 and September 1997 at the rate of one per quarter. The fishing area was off the West coast of the British Isles, between 47°N 7°30'W and 59°N 15°45'W, and the fishing gear was a bottom trawl with a 100 mm (stretched mesh) codend.

The fish were sorted by species and identified from the check list given by Whitehead et al. (1984). Rays were grouped in the family Rajidae and some unidentified Dalatiidae were also recorded by their family name. The two sharks *Centrophorus squamosus* (Bonnaterre, 1788) (Centrophoridae) and *Centrocymnus coelolepis* (Bocage & Capello, 1864) (Dalatiidae) were grouped under their commercial name, 'siki'.

On board, the fishermen estimated the number of 50-kg boxes of each species retained for landing, while the scientific observers counted all the discarded fish. Because of the difficulties of weighing at sea, and because the length distributions of most species were very narrow, numbers of discarded fish and weights of landed fish were converted into approximate weights and numbers, respectively. The values in Table 1 were obtained from series of measurements carried out to establish, for a species, the number of individuals in a given weight. The weights of scarce or small species were not estimated.

Data were standardized to a four-hour haul, which is the typical duration of a commercial tow. The total- or by species-discarding rate is the discarded weight-to-caught weight ratio.

Two methods were considered for estimating the total weights of fish discarded by the fleet each year: one based on fishing effort, and the other based on the discarded-to-landed ratio. The effort method was tested by extrapolating the quantities of landed grenadier sampled on-board for the whole fleet. Differences between estimated and observed landings varied between –67% and +52% per quarter (Allain, 1999a). The effort method was not used for these preliminary results. Moreover, real effort is difficult to estimate because the proportions of time spent on deep-sea and continental shelf fishing grounds during the same trip are not known. The estimates of the total weights of fish discarded by the fleet each year were then based on the observed ratios of the weights of discards to the landed weights of roundnose grenadier, *Coryphaenoides rupestris*. *C. rupestris* was chosen as the reference species because it was the target species of the fishery, it was the only species both landed and discarded, and it was the most common species in the catches of deepwater commercial trawlers (Allain and Kergoat, 1997).

Table 1.
Relationship between the number of fish (No.) and weight (kg) of the most abundant discarded and landed species.

Discards *	No.	kg	Landings **	No.	kg
Coryphaenoides rupestris	100	40	*Coryphaenoides rupestris*	60	50
Alepocephalus bairdii	15	48	*Aphanopus carbo*	54	50
Deania calcea	12	39	Siki	9	50
Lepidion eques	100	37	*Hoplostethus atlanticus*	20	50
Trachyrincus murrayi	150	37	*Molva dypterygia*	11	50
Hydrolagus mirabilis	17	40	*Mora moro*	47	50
Hydrolagus affinis	30	13	*Lophius piscatorius*	10	50
Caelorinchus labiatus	150	37	*Trachyscorpia crist. echinata*	21	50
Alepocephalus rostratus	55	48			
Rhinochimaera atlantica	5	30			
Halargyreus johnsonii	150	32			
Harriotta raleighana	10	22			
Sharks	24	39			

* Five baskets were weighed per species, the inter-baskets differences were less than 3 kg.
** Five 50 kg-boxes were counted per species, the inter-boxes differences were less than 5 individuals.

The mean and pooled ratios (Table 2) were applied to the total annual landings of *C. rupestris* to estimate the quantities rejected each year by the whole fleet. Annual landings of deepwater fish were extracted from French statistical data.
The length-frequency distributions of the two main discarded species were established. *A. bairdii* standard lengths were used to measure 31 randomly sampled sets of 10 to 200 individuals caught between 780 and 1300 m depth. Roundnose grenadier *C. rupestris* were measured from the tip of the nose to the first ray of the anal fin, i.e. the pre-anal length. Thirty-two sets of landed fish (1 to 2 baskets of 15-120 individuals per set), and discarded fish (0.5 to 1 basket of 15-100 individuals per set) were randomly sampled from the same hauls. All fish were caught between 860 and 1300 m. Next, the total quantity of grenadiers landed and discarded during each haul was estimated and the landed weight to discarded weight ratios applied to the respective proportions of the landed and discarded sub-samples to establish the length-frequency distributions of the total catch.

Table 2.
Mean and pooled discarded species-to-landed grenadier weight ratios per year; mean over 28 hauls in 1996 and 19 hauls in 1997, confidence interval (p = 0.05) and percentage that confidence interval represents compared to mean, minimum and maximum values by haul and pooled annual ratio (sum of the discard weights from all sampled hauls of the year/ sum of the landing weights from all sampled hauls of the year).

	Discarded grenadier-to-landed grenadier ratio		Discarded *A. bairdii*-to-landed grenadier ratio		Discarded other species-to-landed grenadier ratio		Discarded all species-to-landed grenadier ratio	
	1996	1997	1996	1997	1996	1997	1996	1997
Mean	0.316	0.213	2.569	1.871	0.693	0.459	3.584	2.544
Confidence interval (%)	0.075 (21.87)	0.074 (33.33)	1.637 (63.81)	0.698 (37.43)	0.173 (24.64)	0.157 (34.78)	1.718 (48.04)	0.775 (30.31)
Minimum	0.044	0.013	0	0	0.058	0.029	0.523	0.186
Maximum	1.018	0.752	20.640	6.512	1.774	1.791	21.883	7.038
Pooled annual ratio	0.311	0.213	1.533	1.749	0.551	0.410	2.395	2.369

Table 3.
Mean quantity by weight (kg) and by number (No.) per four-hour haul of the landed (L) and discarded (D) species.

	L (kg)	L (No.)	D (kg)	D (No.)		L (kg)	L (No.)	D (kg)	D (No.)
Coryphaenoides rupestris	340.6	409.5	103.5	255.8	*Bathygadus melanobranchus*			*	0.02
Aphanopus carbo	123.7	133.7	*	0.2	*Coryphaenoides guentheri*			*	0.04
Siki	115.5	20.8			*Nesiarchus nasutus*			*	0.02
Hoplostethus atlanticus	68.8	27.5			*Molva molva*			*	0.07
Molva dypterygia	55.6	12.3	*	0.1	*Rouleina sp.*			*	0.3
Mora moro	13.9	13.1	*	0.6	*Lycodes sp.*			*	0.02
Lophius piscatorius	1.8	0.4			*Bathypterois dubius*			*	0.1
Trachyscorpia crist. echinata	0.2	0.1			*Borostomias sp.*			*	0.02
Raja batis	*	0.02			*Xenodermichthys copei*			*	0.04
Alepocephalus bairdii			480.7	150.9	*Phycis blennoides*			*	0.2
Deania calcea			101.8	31.7	*Synaphobranchus kaupi*			*	0.04
Lepidion eques			31.9	88.0	*Helicolenus dactylopterus*			*	0.6
Trachyrincus murrayi			29.0	117.5	*Gaidropsarus vulgaris*			*	0.3
Dalatiidae			17.4	19.0	*Epigonus telescopus*			*	0.2
Hydrolagus mirabilis			8.3	3.5	*Argentina silus*			*	0.04
Hydrolagus affinis			6.3	14.5	*Antimora rostrata*			*	0.02
Caelorinchus labiatus			4.9	19.8	*Glyptocephalus cynoglossus*			*	1.7
Alepocephalus rostratus			4.7	5.4	*Argyropelecus sp.*			*	0.04
Rhinochimaera atlantica			2.6	0.4	*Spectrunculus grandis*			*	0.02
Halargyreus johnsonii			1.2	5.8	*Oxynotus paradoxus*			*	0.1
Harriotta raleighana			0.5	0.2	*Pseudotriakis microdon*			*	0.02
Cottunculus thomsonii			*	1.5	*Apristurus sp.*			*	3.5
Neocyttus helgae			*	0.6	*Rajidae*			*	2.2
Notacanthus chemnitzii			*	0.3	*Hexanchus griseus*			*	0.02
Notacanthus bonapartei			*	0.2	*Dalatias licha*			*	0.1
Nezumia aequalis			*	2.6					

* Fish quantity too low to be weighed on-board.

Results

From the 55 hauls sampled, eight species or groups of species were identified as totally landed (Table 3). The most abundant were the black scabbard fish *A. carbo*, the 'siki' sharks and the orange roughy *H. atlanticus*. Forty-three species were totally discarded, of which *A. bairdii* was the most abundant. Only the roundnose grenadier *C. rupestris*, was both landed and discarded. Grenadier discards consisted of the smallest individuals and the discarding rate for this species was 23% by weight for pooled data, and 21.2%±3.1 (± 95%-confidence interval) for mean by haul.
The total discarding rate, by weight, for pooled data was 52.4%; an average four-hour haul contained 720 kg of landed species and 793 kg of discarded species. The mean total discarding rate by haul was 48.5%±21.1 (range: 2.4%-82.4%).
Both the mean and pooled total and grenadier discarding rates increased with depth (Table 4). The mean total discarding rate rose significantly from 25.1% in the 800 m depth stratum to 55.4% in the 1000 m stratum and non-significantly to 60.9% in the 1200 m stratum. The mean grenadier discarding rate increased from 17.4% at 800 m to 19.9% and 28.2% at 1000 and 1200 m, respectively, however, it is not statistically significant. The mean landings of commercial species concomitantly decreased non significantly from 871 to 679 and 626 kg.4 h^{-1} while the total discards increased significantly from 346 to 874 kg.4 h^{-1} and non-significantly to 1393 kg.4 h^{-1}, at the 800, 1000 and 1200 m depth strata respectively.

Table 4.
Mean and pooled discarding rates in weight (%) and mean quantities of discards and landings ($kg.4\ h^{-1}$) by four-hour haul and by depth zone, ± confidence interval (p = 0.05).

Depth zone	Number of hauls sampled	Total discarding rate (%)		Grenadier discarding rate (%)		Quantity of total landings ($kg.4\ h^{-1}$)	Quantity of total discards ($kg.4\ h^{-1}$)
		mean	pooled	mean	pooled		
800-999 m	15	25.1±6.0*	28.5	17.4±5.4°	21.9	871±309°	346±171*
1000-1199 m	27	55.4±5.6°	56.1	19.9±4.0°	21.3	679±161°	874±199°
1200-1399 m	13	61.0±11.0	66.5	28.2±6.5	30.9	626±226	1393±709

* Value statistically different from the following value, Mann & Whitney p<0.05
° Value non-statistically different from the following value, Mann & Whitney p>0.05

Catch composition also varied with respect to depth (Table 5). The grenadier *C. rupestris* was the most abundant species caught in the 800 m depth stratum with 38.4%, whereas *A. bairdii* became preponderant in the 1000 and 1200 m depth strata with 35.1% and 50.9%, respectively, against 28.7% and 22.3% for *C. rupestris*. The grenadier, however, was the most abundant species landed, whatever the depth. The percentage of the second species landed at 800 m, the black scabbard fish *A. carbo* decreased when fishing deeper whereas siki and orange roughy *H. atlanticus* percentages rose. Moving from 800 m to 1000 m, and 1200 m showed a substantial increase of *A. bairdii* in the discards whereas there were less *Deania calcea* and *Lepidion eques*. The grenadier discards remained at the same level and the other discarded species generally represented less than 1% of the total catch by weight.

Table 5.
Percentage of landed (L) and discarded (D) species that represent more than 0.1% of the weight of the catch by depth range (m).

	800-999 m		1000-1199 m		1200-1399 m	
	L	D	L	D	L	D
Coryphaenoides rupestris	30	8.4	22.6	6.1	15.4	6.9
Aphanopus carbo	19.8		6.2		1.7	
Siki	7		6.8		9.9	
Hoplostethus atlanticus	0.2		5.5		6.5	
Molva dypterygia	11		2.2			
Mora moro	2.9		0.5			
Lophius piscatorius	0.5					
Alepocephalus bairdii		3.1		35.1		50.9
Deania calcea		11.9		7.4		0.7
Lepidion eques		3.9		2.2		0.3
Trachyrincus murrayi				2.3		2.8
Dalatiidae		0.1		1		3
Hydrolagus mirabilis		0.4		0.7		0.4
Hydrolagus affinis		0.6		0.4		0.2
Caelorinchus labiatus				0.3		0.7
Alepocephalus rostratus				0.3		0.6
Rhinochimaera atlantica				0.2		0.4
Halargyreus johnsonii				0.1		0.1

The total discards of the deepwater fishery were estimated to be approximately 26 050±12 500 t and 18 500±5600 t in 1996 and 1997, respectively, based on the mean ratio, and 17 528 and 17 423 t, respectively, based on the pooled ratio (Table 6). The high value observed in 1996 when calculated with the mean ratio is an anomaly induced by the large amount of *A. bairdii* caught in one haul. By removing this data, total discard estimates were 20 681±8077 t in 1996, probably a more realistic value, closer to the one obtained by calculating with the pooled ratio. These quantities of discards were in the same range as the total landings of all the deepwater fish, 19 650 and 19 100 t in 1996 and 1997, respectively. More grenadiers were discarded in 1996 than in 1997, although landings were similar (ca. 7300 t).

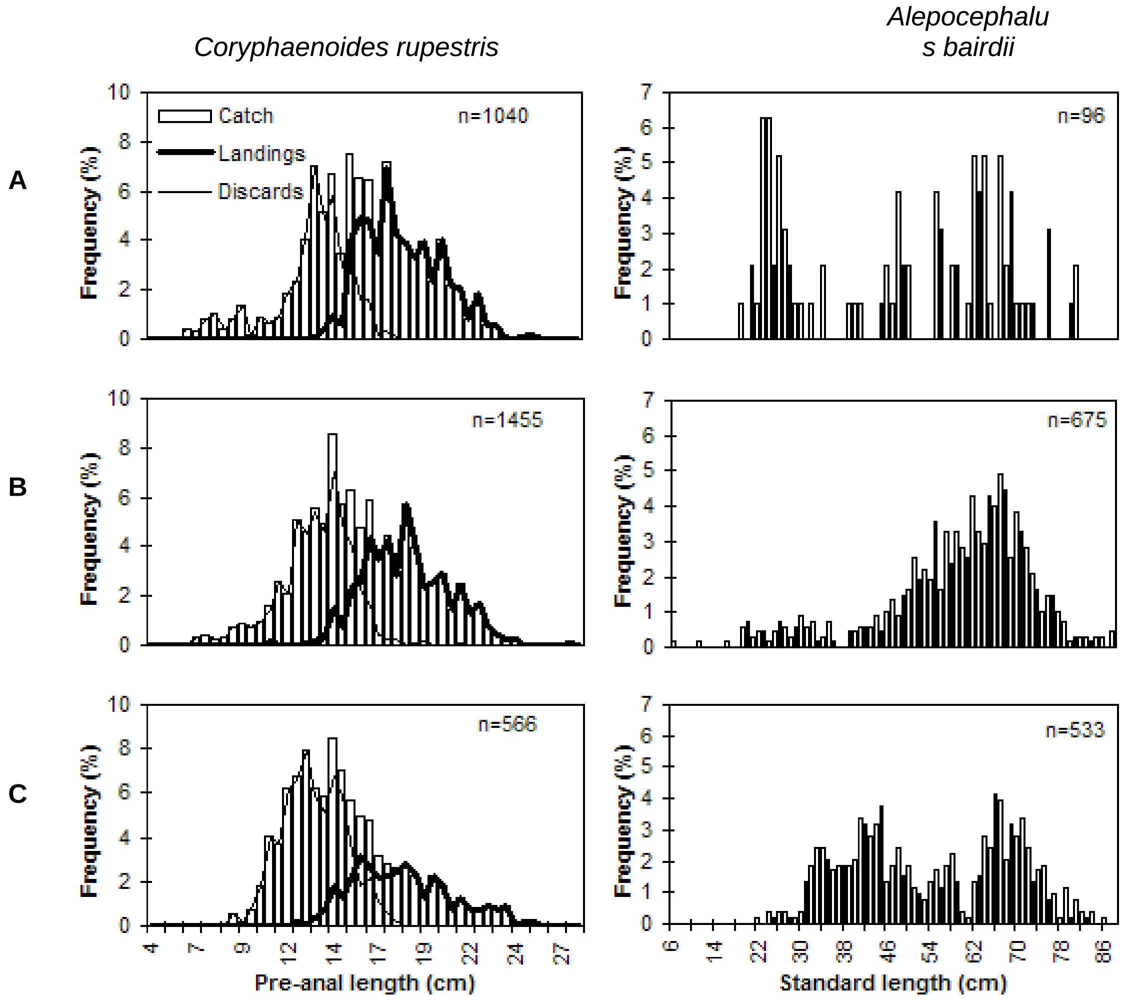
Table 6.
Annual weights of discarded species estimated from the mean and pooled discarded-to-landed ratios (Table 2) and the annual landings of grenadiers in 1996 and 1997, ± confidence interval ($p = 0.05$).

		1996 (t)		1997 (t)	
		mean	pooled	mean	pooled
Annual landings	Landed grenadier	7277		7287	
	All deep-sea fish*	19 652		19 103	
Annual estimations	Discarded grenadier	2329±509	2278	1530±510	1564
	Caught grenadier	9606±509	9555	8817±510	8851
	Discarded *A. bairdii*	18 702±11 934	11 216	13 626±5100	12 859
	Discarded other species	5021±1327	4034	3352±1166	3000
	All discarded deep-sea fish	26 052±12 515	17 528	18 509±5611	17 423

* The main eight species in Table 3.

The pre-anal lengths of discarded grenadiers *C. rupestris* ranged from 4 to 19 cm (mean: 12.8 cm), whereas the landed grenadiers measured from 10.5 to 27 cm with a mean length of 17.9 cm (Fig. 1). The discards mainly consisted of males because they were smaller (mean length: 14.3 cm) than females (mean length: 18.1 cm) (Allain and Kergoat, 1997). The modes of the grenadier length-frequency distribution were difficult to distinguish, whatever the depth. The smallest fish were observed in the 800 m and 1000 m depth zones, but the proportion of juvenile fish increased with depth. Juveniles corresponded to individuals below 11.5 cm, the size at first female maturity according to Allain (2001) (male maturity was more difficult to establish with accuracy). These juveniles accounted for 9.6%, 11.1% and 17.1% of the fish in the 800 m, 1000 m and 1200 m depth zones, respectively. The mean length of the total catch correspondingly decreased from 15.6 cm at 800 m to 14.6 cm at 1200 m. Thus, if we consider a constant catchability of grenadiers of different development stages with depth, most grenadier juveniles live in the 1200-1400 m bathymetric zone, the maximum depth investigated in this study, whereas adults are more widely distributed. These results are consistent with the hypothesis of a bathymetric ontogenic migration undertaken by *C. rupestris*.
Standard lengths of *A. bairdii* ranged between 6 cm and 88 cm (Fig. 1). The biggest fish (mean length: 59.1 cm) were found in the 1000-m-bathymetric zone, the smallest (mean length: 48.6 cm) in the 800-m zone, and the intermediate (mean length: 54.0 cm) in the 1200-m zone. The length-frequency distributions in the different bathymetric zones were bimodal. Whereas the upper mode was similar in the three zones (ca. 66 cm), the position of the lower mode varied with depth and increased from 23-24 cm at 800 m, to 30 cm at 1000 m and 45 cm at 1200 m. The proportions of fish in the two modal groups also varied with depth. When going deeper into the three bathymetric zones, the smaller fish represented 34.4%, 9.3% and 59.8% of the population, respectively. So, the small fish live mainly in the 800-m-depth zone. While still growing, they swim across the 1000-m-bathymetric zone to finally settle in the 1200-m zone, where they become sexually mature at 55 cm for females and 58 cm for males (Allain, 1999b). Once mature, adults are found at all depths, but concentrate in the 1000-m zone. Thus, A*. bairdii* also seems to undertake a bathymetric ontogenic migration.

Fig.1. Length-frequency distributions of *Coryphaenoides rupestris* and *Alepocephalus bairdii* by depth: 800-999 m (A), 1000-1199 m (B), 1200-1399 m (C).



Discussion

The estimates of discarding rates and of the annual discarded quantities presented here should be regarded as preliminary. Comparing these preliminary results with those obtained by Connolly and Kelly (1996) in the same geographical area and depth-range on an Irish demersal trawler in November-December 1995, some differences appear. Indeed, in their study, sharks were the most abundant discards, followed by grenadiers, and the weights of *A. bairdii* were extremely low. The discard rates, as defined in the present study and calculated from Connolly and Kelly data, accounting to 31.5% for total discards and 12.4% for grenadier discards, were below ours, 48.5 and 21%, respectively. Connolly and Kelly estimated the total discards of deepwater fish in ICES area VI in 1995 to be 7520 t. The relatively small quantities of *A. bairdii* in their samples can explain the difference with our results (ca. 17 500 for pooled ratio). Another study conducted in September 1996 on commercial trawlers in the same area (Kelly et al., 1997) provided a total discards estimate of 16 783 t, which was closer to our results.
Still keeping in mind the preliminary nature of the results, the French deep-sea trawling fishery, with a mean total discarded-to-landed ratio by weight of 1.396±0.369 (pooled ratio is 1.101), should rank below the top 20 fisheries with the highest ratios (14.71 - 2.01; the 10 lowest ratios are from 0.118 to 0.011) (Alverson et al., 1994). The fishery under study is in the lowest part of the range of highest ratios for non-pelagic fish trawl (5.28 - 2.01).

Using the mean and the pooled ratios gave different results in the estimation of the discards. As observed by Hay et al. (1999), estimates based on the mean of individual tows appear to overestimate discards. These authors conclude that estimates based on the pooled ratio are more reliable. Because the distributions of the discarded-to-landed ratios are not normal, the mean is not a good representative of the data set, the pooled ratios are better representations of the diversity of the data. In this study, however, only 55 hauls were sampled over a two-year period, representing a coverage rate of 0.13%. The sampling took place on two sister-ships from the same fleet. This sampling is then poorly representative of the normal haul-to-haul variability in quantity and composition of the catch, and both mean and pooled data are subject to great uncertainty. The haul-to-haul variability can be explained by several factors. First it appears that some species such as *A. bairdii* or *H. atlanticus* are caught in large aggregations, which implies a non-regular or non-random spatial distribution of the fish. Second, variations in densities are highly probable according to the area and depth, bottom type and other abiotic and biotic factors. And third, variations in the composition of the species assemblage are also observed. The low representative sampling, when considering the haul-to-haul variability, explains the great uncertainty of the results.
To improve the accuracy of the discard estimates it is necessary to increase the coverage rate and to stratify the sampling strategy. Simulations conducted by Vølstad et al. (1997) indicated that with random selection of observed trawlers, estimates with acceptable error bounds can be made for frequently occurring species by sampling 30% of the vessels. For less frequently occurring species, a much larger proportion of the fleet would need to be sampled. Hence the need to increase the coverage rate is considerable and a stratification by fleet seems essential. This stratification was used by Blasdale and Newton (1998) (large and small high sea trawlers) in the same area, and according to the analyses of Lorance and Dupouy (2001), three French fleets showing different fishing powers should be sampled: two fleets of large offshore trawlers (49-55 m long) and one fleet of smaller high-seas trawlers (30-38 m long). Another factor that should be taken into account for the stratification of the sampling is the depth. Actually, as underlined in this study and by Lorance (1998), depth is a major factor in the determination of species composition and discard rates. As also highlighted by Blasdale and Newton (1998), the depth-related variations of discarding rates and quantities are linked to differences in species composition of the fish communities and in the length-frequency distribution of some species. Species replace each other according to their bathymetric and geographical preferences. Thus, *A. bairdii* is particularly abundant between 1000 and 1250 m, which explains the increase of both discarding rate and fish biomass in the 1000 m bathymetric zone in the Northeast Atlantic Ocean (Gordon, 1986). The increase with depth in the discarding rate for *C. rupestris*, although not statistically significant, is due to the fact that individuals too small for marketing were mainly observed in the deepest area exploited as shown in this study. The calculation of a discarded-to-landed ratio by depth range should improve the accuracy of estimates, but it also implies depth-stratified fishery statistical data, which are not available at the present time.
In the deepwater fishery, most species are totally discarded, including some large-bodied species such as *A. bairdii*. An increase in mesh size would therefore not lower the discarding rate in the deepwater fishery. Furthermore, many deepwater fish have fragile skin that is quickly damaged by friction with other fish or with trawl meshes, which is likely to compromise the survival of fish escaping from the trawl (Connolly and Kelly, 1996; Kelly et al., 1998). Discarding could be reduced by developing a commercial market for the discarded species as has been done in Iceland in collaboration with professionals (Thorsteinsson and Valdimarsson, 1995). However, attempts in France to market *A. bairdii*, which can account for up to 70% of the discards by weight, were unsuccessful.

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