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An analysis of discards from the French trawler fleet in the Celtic Sea

Marie-Joëlle Rochet, Isabelle Péronnet, and Verena M. Trenkel

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Discards of the French trawler fleet operating in the Celtic Sea in 1997 were studied. Twenty-six trips, representing 0.8% of the total fishing effort, were sampled. This fleet consists of three métiers, benthic trawlers, Gadoid trawlers and *Nephrops* trawlers. The fleet discarded an estimated 30 000 tons of animals in 1997, while landing 63 000 tons. The total quantity discarded did not differ among métiers, but the species composition of discards did. Benthic trawlers discarded mainly by-catch species, whereas Gadoid and *Nephrops* trawlers discarded primarily their target species. Whiting, megrim, *Nephrops* and hake were discarded in larger numbers than landed. Hence discards should be taken into account in catch-based assessments. However, discards were found to be highly variable between trips and between years. In addition, no reliable auxiliary variable could be found when various factors were investigated to explain the quantities of commercial species discarded. The only explanatory factor valid for any species was the smallest size of that species in the catch. Hence there is a need for regular sampling of discards.

Keywords: anglerfish, Celtic Sea, discard sampling, flatfish, gadoids, *Nephrops*, non-commercial species, trawlers.

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Marie-Joëlle Rochet and Verena Trenkel: Laboratoire MAERHA, IFREMER, Rue de l'Ile d'Yeu, B.P. 21105, 44311 Nantes Cedex 03, France. Tel: +33 2 40 37 40 00; fax: +33 2 40 37 40 75; e-mail: mjrochet@ifremer.fr. Isabelle Péronnet: Laboratoire Ressources Halieutiques, IFREMER, 8, rue François Toullec, 56000 Lorient, France. Tel: +33 2 97 87 38 17; fax: +33 2 97 87 38 01.

Introduction

Discarding of unmarketable, undersized or damaged fish is common practice in most fisheries worldwide (Alverson *et al.*, 1994). The importance of discards compared to landings depends strongly on the gear used. Non-pelagic trawlers usually discard as much as they land, and some of them discard up to 5 kg per kg landed; discards from fisheries targeting shrimp or *Nephrops* can even be higher (Alverson *et al.*, 1994).

Another common feature of discards is their high variability in space and time (Andrew and Pepperell, 1992; Alverson *et al.*, 1994; Kennelly, 1995). Heterogeneous spatial distributions of species as well as variations in year class strengths are responsible for this. In addition, discarding behaviour is expected to vary depending on current market conditions and legislation. This high variability makes discards sampling expensive, as large sampling efforts are needed for achieving even moderately precise estimates. However, due to the quantity of discards and their variability, it seems important to carry out sampling programs to get reliable estimates of total catches for stock assessments of commercial species. Discard estimates are also necessary for evaluating the impact of fishing on non-commercial species and the ecosystem as a whole (Alverson *et al.*, 1994; Hall, 1999), and for obtaining empirical information for studying the process of discarding. Another use of discards data is for evaluating the effectiveness of technical conservation measures aimed at reducing fishing mortality, such as mesh size increases or the design of marine protected areas. In multi-species, multi-fleet fisheries, technical and biological interactions will make any of these assessments difficult (Alverson *et al.*, 1994). Hence, there is a need for detailed studies looking at all components of the fishery: commercial

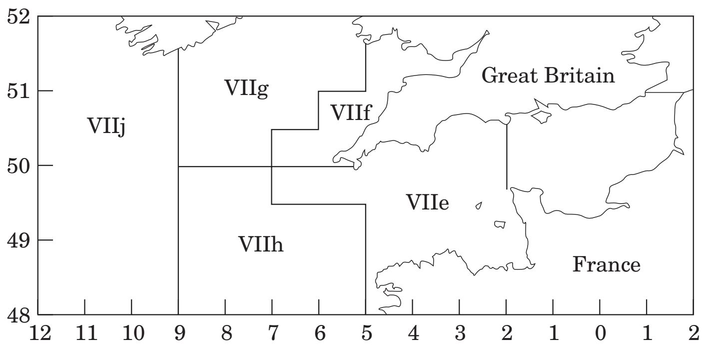

Figure 1. Map of the Celtic Sea, which consists of the labelled ICES fishing areas.

and non-commercial species, as well as diverse fishing practices.

This paper focuses on discards by the French trawlers operating in the Celtic Sea (Figure 1). The Celtic Sea covers an area of around 200 000 km^2. Due to a complex geological structure, the continental shelf is partitioned by pits and sub-marine valleys, allowing a variety of fishing métiers to coexist in small areas. A fishing "métier" is defined by the target species, the fishing gear used and the area visited (Laurec *et al*., 1991). Although other types of gear are employed, trawling is by far the most important method. In 1997 the French fleet in the Celtic Sea consisted of 330 trawlers. Sampling of discards by this fleet, which is operating from harbours located in the South of Brittany, has been carried out approximately every six years. Previous studies were carried out in 1984 (Charuau, 1985; Biseau and Charuau, 1989) and 1991 (Péronnet, 1991). The present paper describes the methods and results of the 1997 discard study and compares them with the previous studies.

The main objectives of this study were the estimation of the total biomass discarded in 1997 by the French fleet in the Celtic Sea, the species and length composition of discards, and the age composition of discards for the species assessed by international working groups. In addition, as discards studies require a high sampling effort, the data were used to consider the question of how sampling schemes might be improved. Factors that would enable the prediction of discards, avoiding sampling them, were also sought.

Materials and methods

Sampling design

For landings sampling and stock assessment purposes, the French trawlers operating in the Celtic Sea are usually grouped into three métiers on the basis of the species composition of their landings. These métiers are

(i) Gadoid trawlers fishing in ICES Divisions VII f and g (see Figure 1); the target species are whiting, hake and cod.
(ii) benthic trawlers fishing in ICES Divisions VII h and g; the main target species are anglerfish, skates, megrim, ling and hake.
(iii) *Nephrops* trawlers fishing in ICES Division VII g and h. *Nephrops* is the main target species, together with whiting, hake and megrim.

As each métier corresponds to a specific behaviour and exploitation pattern, discards are expected to vary more in terms of species composition and quantity between métiers than within métiers. In addition, landings sampling is carried out by métier. Hence the sampling of discards was stratified by métier.

The primary sampling unit within a métier was the fishing trip. The main reason for this was that landings were sampled by trip after return to port; in addition, trips are convenient sampling units in contrast to hours fished or isolated hauls. As several métiers can be fished during a given trip, each fishing trip was allocated to the métier which was exercised primarily (based on an analysis of the landings' composition). Consequently, it was not possible to definitely assign a trip to any métier before the vessel had returned to port. This means that some reallocation between métiers occurred after the sampling exercise (three from 26 trips). Another consequence is that the total number of fishing trips for each métier is unknown. It was estimated from the total number of hours fished by métier, and the mean time fished per trip by métier in the present study.

A stratified sampling design with the métiers as strata and the following levels was used: (i) fishing trip (about 14 d), (ii) haul (about thirty hauls per trip), (iii) fraction sampled; one basket (about 40 kg) was taken, whatever the total amount of discards.

Sampling was random at each level. Sampling of trips was spread over the whole year. A haul was randomly selected on the first day of the trip, then one haul per day was systematically sampled for the duration of the trip.

Two sampling procedures were used. For most *Nephrops* trawlers, an onboard observer carried out sampling and measuring; in this case more than one haul could be sampled per day. Otherwise the sample was stored by the fishermen for later analysis in the laboratory. Species were separated, weighed and individually measured (total length TL for fish, carapace length CL for *Nephrops*). The landings of the selected fishing trips were also sampled using standard procedures (Talidec, 1998; Gaudou, 1999). Trip landings are routinely recorded by métier, aggregating all hauls belonging to a given métier. Thus landings information was not available at the haul level.

Estimators

Saila (1983) recommended the use of ratio-estimators for raising discard samples when an auxiliary variable correlated with discarded quantities is available, e.g. landings or fishing effort. However, the few studies that investigated auxiliary variables did not conclude that ratio-estimators were more accurate or precise than simple estimators (Clarke *et al.*, 1995; Stratoudakis *et al.*, 1999; Allen *et al.*, 2001). Moreover, Evans *et al.* (1994) found that higher proportions of *Nephrops* were discarded when total catches were large than when they were small. In addition, the ratio-estimate is more accurate than the simple estimate only if the correlation of discards with the auxiliary variable is larger than half the ratio of the coefficients of variation:

$$\rho > \frac{1}{2}\frac{\mathrm{CV(auxiliary\ var.)}}{\mathrm{CV(discards)}}$$

(Cochran, 1977). This was not the case here for either of the two potential auxiliary variables (landings and time spent fishing). Therefore a simple estimator was used.

Estimators and variances of numbers discarded by species and length or age class are given in Table 1, following Cochran (1977). Similar estimators were used for the weights discarded. One basket was sampled in each haul: each basket is considered a unit sample (size = 1), and the total amount of discards in a haul is calculated by multiplying with $1/f_{ij}$. As the sampling fraction f_{ij} is assumed to have been measured without error, the variance of total discards at the sampling level is zero. As only one unit was sampled in each haul, the within-haul variance for the number of individuals by species and class (length or age) was calculated using a hypergeometric distribution (Cochran, 1997).

The size distribution of discards was summarized by the parameter DL_{50}. On a curve relating the probability of discarding a fish to its length, DL_{50} is the length at which the probability of being discarded is 0.5 (Stratoudakis *et al.*, 1998). DL_{50} was estimated by fitting a logistic model to discarded proportions at length by species, by métier. These estimates were then compared to minimum legal landing sizes (MLS).

Models

Various analyses were performed to find factors explaining the discarded quantities, both for a better understanding of the discarding processes and for attempting to estimate discards without sampling them. The factors investigated were the fishing method, the available quantity of small fish represented by incoming year-class strength, the amount caught (which is assumed to be related to the amount landed when the catch is not known), and the expected monetary value of the catch. Most analyses were performed by trip. A more comprehensive assessment of the role of these factors in the discarding process would need a time-series of comparable estimates of discards, which unfortunately is not available.

For testing the hypothesis that the total amount discarded per trip depended on the fishing area (Figure 1), the quarter of the year or the métier, an analysis of variance was carried out. The log transformed weight of discards was used as the dependent variable and area, quarter and métier as qualitative explanatory variables.

To examine the hypothesis that discarded quantities are influenced by year-class strength, the estimated numbers discarded from the three studies (1984, 1991 and 1997) were related to recruited numbers estimated by the Stock Assessment Working Group (Anonymous, 2000). The data were standardized and pooled across species to increase the power of the analysis: numbers discarded by species were scaled by their means and standard deviations, and incoming recruitment was scaled by the means and s.d. of the available recruitment series (anglerfish: 1986–1997, megrim: 1984–1997, whiting: 1982–1997; hake: 1978–1998, cod: 1971–1998).

Linear models to explain the quantities of each species discarded per trip were automatically selected using a forward stepwise method, for those species which were caught and discarded in a sufficient number of trips. Two analyses were performed. In the first one the predictors described the landings and fishing operations: landed weights (total, of the target-species, or of the species of interest); smallest size in landings and number landed of "small fish" (in the smallest 10-cm length class) of the species of interest. Fishing operation descriptors included métier, days at sea, area, gear used, mesh size and length of the headline, and vessel tonnage. These predictors are available, whether or not discards are sampled. In a second analysis aimed at explaining the process of discarding, the smallest and largest length of individuals caught and DL_{50} were also included. The response variable, discarded weight, was transformed as $\log(\hat{W}+\alpha)$, to meet the assumption of normally

Table 1. Estimators for discard numbers by species and length or age class and their variances.

Stratum	Population size	Sample size	Sampling fraction	Estimator	Variance
Sample	$\frac{1}{f_{ij}}$	1	f_{ij}	y_{ijkl}	$Var(y_{ijkl})$
Haul	H_i	h_i	$\pi_i = \frac{h_i}{H_i}$	$\hat{Y}_{ijkl} = \frac{y_{ijkl}}{f_{ij}}$	$\hat{s}^2_{ijkl} = \frac{Var(y_{ijkl})}{f^2_{ij}}$
Trip	N	n	$f = \frac{n}{N}$	$\hat{Y}_{ikl} = \sum_{j=1}^{h_i} \hat{Y}_{ijkl} \frac{H_i}{h_i}$	$Var(\hat{Y}_{ikl})$
Fleet				$\hat{Y}_{kl} = \sum_{i=1}^{n} \hat{Y}_{ikl} \frac{N}{n}$	$Var(\hat{Y}_{kl})$

where:
i=subscripts for trips, j for hauls, k for species and l for length- or age-classes.
y_{ijkl}: number of fish of species k, length l in the sampled fraction f_{ij} of the discards in haul j, of trip i.
$\hat{Y}_{ijkl}$: estimated number of fish of species k and, length l discarded from haul j during trip i.
$\hat{Y}_{ikl}$: estimated number of fish of species k and length l discarded during trip i.
$\hat{Y}_{kl}$: estimated number of fish of species k and length l discarded by the fleet during the year.

$$Var(y_{ijkl}) = \left(\sum_k \sum_l \hat{Y}_{ijkl} - \sum_k \sum_l y_{ijkl}\right) \sum_k \sum_l y_{ijkl} \hat{p}_{ijkl}(1-\hat{p}_{ijkl}) \Big/ \left(\sum_k \sum_l \hat{Y}_{ijkl} - 1\right) \text{ with } \hat{p}_{ijkl} = \frac{y_{ijkl}}{\sum_k \sum_l y_{ijkl}}.$$

$$Var(\hat{Y}_{ikl}) = \frac{H_i^2}{h_i}(1-\pi_i)s^2_{ikl} + \frac{H_i}{h_i}\sum_{j=1}^{h_i}\frac{1-f_{ij}}{f^2_{ij}}\hat{s}^2_{ijkl} \text{ with } s^2_{ikl} = \frac{\sum_{j=1}^{h_i}\left(\hat{y}_{ijkl} - \frac{\hat{y}_{ikl}}{H_i}\right)^2}{h_i - 1}, \text{ and}$$

$$Var(\hat{Y}_{kl}) = \frac{N^2(1-f)}{n} \frac{\sum_{i=1}^{n}\left(\hat{Y}_{ikl} - \frac{\hat{Y}_{kl}}{N}\right)^2}{n-1} + \frac{N}{n}\sum_{i=1}^{n}\frac{H_i^2(1-\pi_i)}{h_i}s^2_{ikl} + \frac{N}{n}\sum_{i=1}^{n}\frac{H_i}{h_i}\sum_{j=1}^{h_i}\frac{1-f_{ij}}{f^2_{ij}}\hat{s}^2_{ijkl}$$

distributed residuals. The results were not sensitive to the value of α (chosen as 0.1, 1 or 10).

The estimated numbers and proportion of the catch discarded per species were also related to the average price per kg of these species during 1997, in the markets where the sampled vessels sold their production (taken from the National Fisheries Statistics).

Results

Sampling rates

Due to reallocation of trips between métiers, the sampling design resulted in sampling fractions that differed between métiers (Table 2). The fraction of hauls sampled within each trip varied from 1/18 to 1/2 (Figure 2A). The sampling fraction within each haul was highly variable, ranging from 1/60 to 1 (Figure 2B).

Total biomass discarded

The French fleet operating in the Celtic Sea discarded an estimated 30 000 tons of animals in 1997, while landing about 63 000 tons (Table 3). Gadoid and *Nephrops* trawlers caused the majority of discards. As the variability within each métier was higher than the differences between métiers, the stratification did not improve much the precision of the total discarded biomass estimate. The coefficients of variation of total biomass estimates were high, around 40% for Gadoid and *Nephrops* trawlers. Estimates of discard by benthic trawlers were more precise due to a higher sampling effort for this métier.

Discards by species

Relative species composition of discarded biomass differed between métiers (Figure 3; see appendix 1 for a

Table 2. Estimated total number of trips by métier carried out by the French trawlers in the Celtic Sea in 1997; number of trips sampled and sampling fractions; number of hauls sampled.

Métier	Total number of trips (N)	Sampled trips (n)	Sampling fraction (%)	Number of hauls sampled
Benthic trawlers	717	11	1.5	141
Gadoid trawlers	1243	6	0.5	92
Nephrops trawlers	1119	9	0.8	229
Whole fleet	3080	26	0.8	462

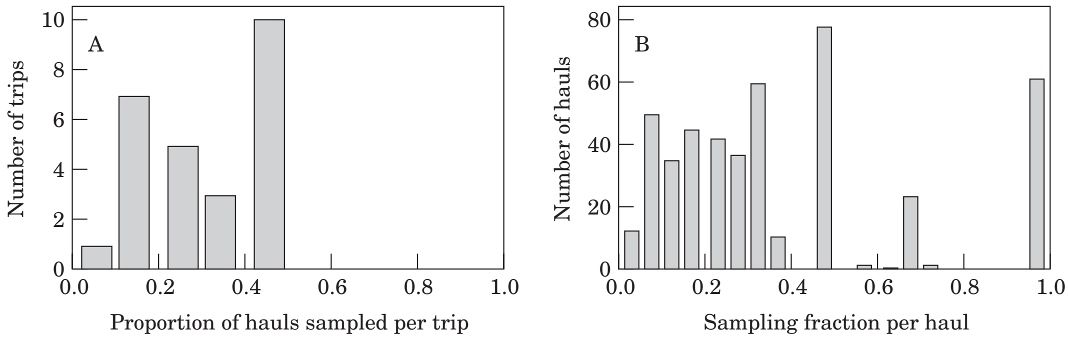

Figure 2. (A) Distribution of the proportion of hauls sampled per trip. (B) Distribution of the sampling fraction per haul.

Table 3. Estimated total biomass discarded by métier.

Métier	Total discarded (t)	Variance	C.V. (%)	Landings (t)	Prop. of the catch discarded
Benthic trawlers	5469	872 608	17	16 930	0.24
Gadoid trawlers	12 083	21 425 508	38	35 191	0.26
Nephrops trawlers	13 566	29 117 218	40	11 089	0.55
Whole fleet	29 773	34 646 639	20	63 210	0.32

list of English and Latin names of species caught). Benthic trawler discards were made up primarily (60%) of four by-catch species: red gurnard, horse mackerel, boar fish and grey gurnard. In contrast, Gadoid trawlers discarded mainly their target species: whiting and haddock (together 47%), and also grey gurnard (13%). Discards by *Nephrops* trawlers were dominated in biomass by whiting (41%), followed by the target *Nephrops* (20%).

Looking at the whole fleet, whiting was by far the most discarded in biomass among all commercial species (Figure 4). Considering discards in numbers, whiting, *Nephrops*, megrim, hake and haddock were the most discarded commercial species. Among by-catch species, boar fish and red and grey gurnard dominated in numbers. The coefficients of variation of biomass estimates varied from 0.20 to 1.15 (mean 0.55); those for abundance estimates were of similar magnitude. The most important component of variance was due to differences between trips (96% on average, Figure 4). The differences between hauls within trips contributed very little to the total variance (mean 0.2%). The within-haul variance was the most variable between species, because rare species have a low probability of being included in a sample and hence a high variance due to sampling.

Estimated discards and landings biomass and numbers for some selected commercial species by métier and for the fleet as a whole are presented in Table 4. The picture differed, depending on whether weights or numbers were considered, because discards consisted of smaller fish than landings. Megrim, whiting and *Nephrops* were discarded in larger numbers than landed, and also probably hake and plaice (this is deduced from the comparison of weights but cannot be stated firmly because landed numbers were not available). By

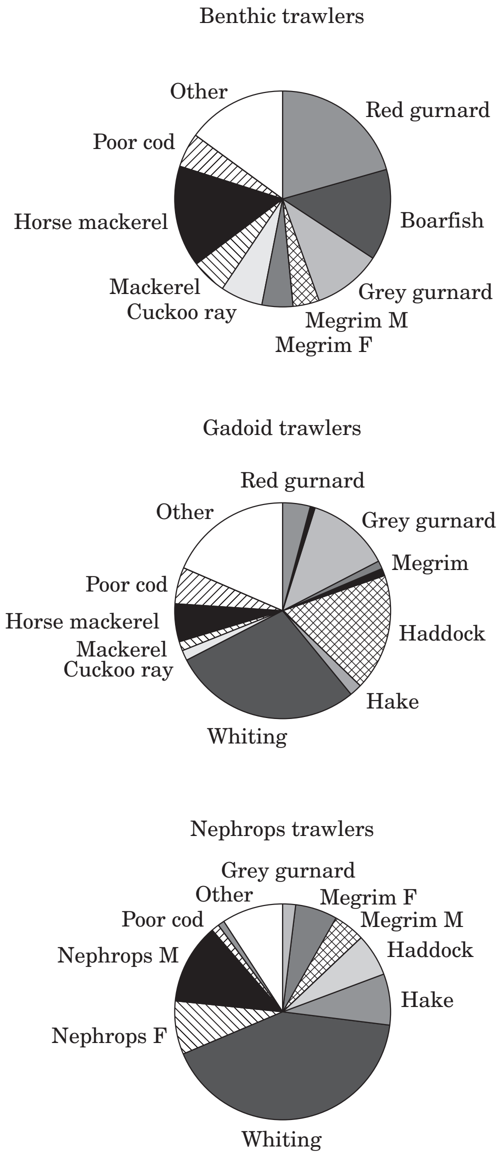

Figure 3. Mean species composition of discards per trip, by métier, in weight. Only the most discarded species are shown.

contrast, cod and anglerfish were kept in large numbers than discarded. Coefficients of variations were generally between 20 and 50% and comparable for estimates in numbers and biomass.

Based on an analysis of the amounts discarded as a function of the catch, three types of species were identified: high-valued species which were not discarded, unmarketable species which were not landed and intermediate species which were partly discarded (Table 5). In the latter category, the amounts discarded varied between trips, but when plotted against total catch, no obvious relationship was found.

Structure of discards for some commercial species

For most species caught by the French trawlers in 1997 in the Celtic Sea, the length at which 50% of the fish were discarded (DL_{50}) was larger than the minimum legal landing size (Table 6). The difference was generally small, but was found to be as large as 7–9 cm for hake and whiting and 1 cm for *Nephrops* discarded by *Nephrops* trawlers. Cod is the only species landed significantly smaller than the legal size.

As the amounts of each species discarded differed between métiers, it would be desirable to present estimated age- or length-structures separately for each métier. However, the precision of these estimates was low. Therefore the age structure of commercially important species (length-structure for *Nephrops* and hake, which are difficult to age) was estimated for the whole fleet only (Figure 5). Even so, discard numbers were not well estimated for whiting, small hake and female *Nephrops*, with some CVs as large as 50%.

Historic comparison

In 1984, the fleet comprised 375 trawlers. A stratified sampling design was applied with four areas and quarters as strata. From *Nephrops* trawlers, 183 hauls were sampled, and 84 from the rest of the fleet. An estimator of the number of discards per haul was used. The CVs of total numbers, discarded estimates varied between 15 and 25%. The most important species discarded were grey and red gurnard, megrim (35% of the number caught), whiting (30%) and skates (50%); 50% of *Nephrops* caught were discarded (Charuau, 1985).

In 1991, sampling was stratified by métier as in the present study. An estimator of the number of fish of each species per kg of total discards was used and raised by the weight of discards per hour fishing. The CVs of these estimates were between 20 and 35%. Whiting, megrim and hake were the most discarded species (Péronnet, 1991).

A comparison of the estimated numbers discarded by fleet in different years is shown on Figure 6, for those species which were included in all three studies. The comparison between 1991 and 1997 is more straightforward, because the sampling designs were similar. There has been a sharp increase in the number of whiting discarded from 1984 to 1991. Discards of megrim and *Nephrops* were consistently high, whereas discards of cod, haddock and hake by each métier varied in magnitude.

Factors explaining discarded quantities

The analysis of variance for the total weight discarded showed that neither the fishing area, nor the season

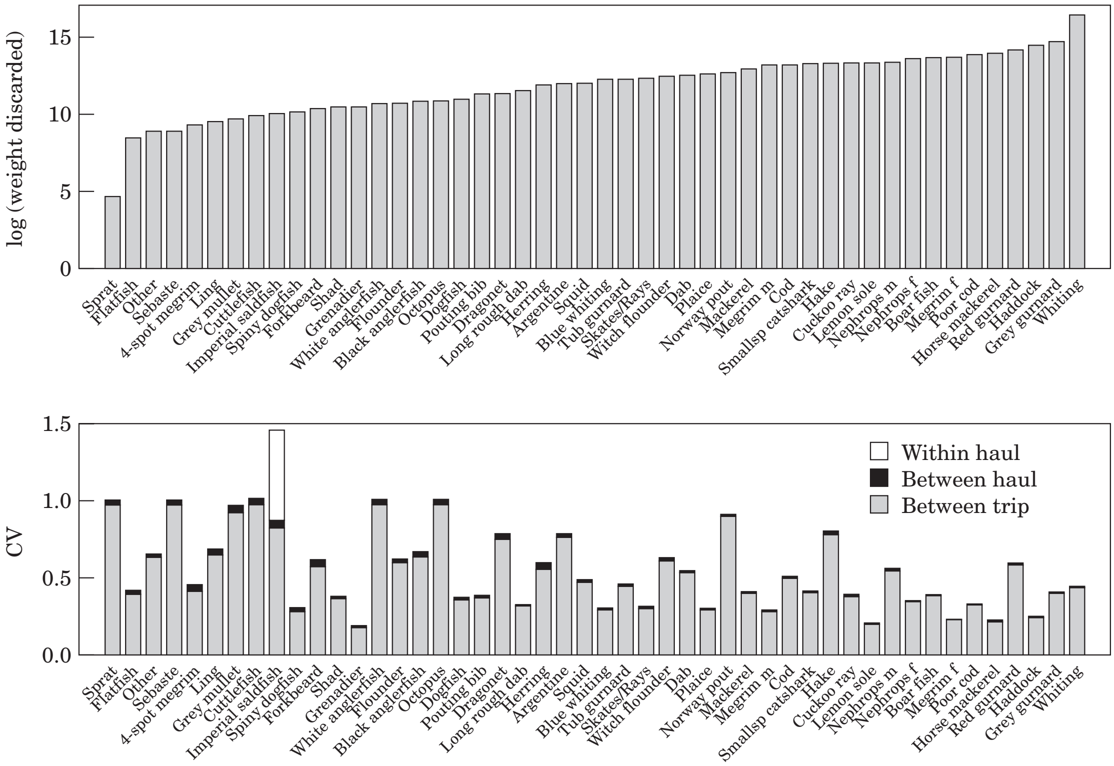

Figure 4. Estimated weights discarded (kg) by the whole fleet for each species in 1997, and their coefficient of variation (the blocks are the components of the CV due to each stratum of the sampling design).

of the fishing trip nor the métier were significant in explaining the observed differences between trips (Table 7).

Discarded numbers and year-class strength, standardized and pooled across species, were positively correlated ($r=0.45$, $p=0.08$; Figure 7).

The models explaining the quantities discarded per trip differed between species when predictors describing the landings and fishing operations only were used (Table 8). Overall ten factors were selected from the 12 available, zero to four per species; they explained 0 to 88% of variance (mean 49%). The most commonly selected factors were the métier (five species), the number of small fish landed (positive relationship for five species) and smallest size in landings (two species), and landed weights (eight species). The duration of the trip in days was also a recurrent factor, which had a positive coefficient for the most perishable species (cuckoo ray, hake and red gurnard) and a negative one for megrim and *Nephrops*. By contrast, when predictors describing the catch were added, the models included the smallest size in the catch for all species except *Nephrops* (Table 9): the smaller the length in the catch, the higher the amount discarded. Among the 15 factors available, only six were selected, one or two for each species. They explained on average 54% (13 to 80) of response variability.

No clear relationship was found between the numbers or proportions of the catch discarded and the average market price. However, the species categories defined in Table 5 had different prices: from low for all-discarded species (on average 4.29 FF/kg, s.d.=7.6) to high for all-landed species (21.06 FF/kg, s.d.=17.2) and those handled differently among métiers (22.45 FF/kg) with a high variability for the latter (s.d.=22.7). The partly-discarded species sold at intermediate prices (14.21 FF/kg, s.d.=8.0).

Improved sampling scheme

The results of the present study were used to propose improved sampling designs in order to achieve more precise estimates of discarded numbers for selected species. Discarding practices do not affect all commercial species in the same way. The ratio of discarded to landed fish indicates species for which discard estimates would be essential for stock assessment purposes (whiting, megrim, *Nephrops* and hake) and those for which they are less important (black and white

Table 4. Weights and numbers discarded and landed by the French fleet in the Celtic Sea in 1997, and by each métier. Discards are estimated from the present study.

Species	Weight discarded ($\times 10^3$ t)	CV (%)	Weight landed ($\times 10^3$ t)	Number discarded ($\times 10^6$)	CV (%)	Number landed ($\times 10^6$)
Cod	0.5	46	7.3	1.4	45	1.9
Megrim	1.4	19	2.9	15.1	20	8.1
Black angler	0.05	31	3.6	0.4	34	1.4
White angler	0.04	23	5.8	0.4	22	2.3
Hake	0.5	27	0.9	5.4	24	Not available
Whiting	13.7	43	10.4	58.7	46	26
Nephrops	1.4	33	2.6	81.8	32	51.1
Plaice	0.3	44	0.3	1.4	49	Not available

Species	Weight discarded (t)	CV (%)	Weight landed (t)	Number discarded ($\times 10^3$)	CV (%)	Number landed ($\times 10^3$)
Benthic						
Cod	8.0	60	515	35	57	Not available
Megrim	340.8	16	1755	3428	19	3972
Black angler	35.8	40	2416	304	46	885
White angler	7.7	32	2947	98	36	1040
Hake	11.3	28	323	89	31	Not available
Whiting	9.7	57	375	32	49	Not available
Nephrops	0.4	146	0	15	96	0
Gadoid						
Cod	37.7	32	5398	108	36	Not available
Megrim	186.4	51	371	1288	50	1918
Black angler	2.1	40	614	23	38	249
White angler	13.0	47	2021	83	33	884
Hake	157.9	58	338	1134	56	Not available
Whiting	4854.9	73	8650	22 362	77	Not available
Nephrops	0.2	83	0	10	72	0
Nephrops						
Cod	468.0	51	1413	1222	50	Not available
Megrim	845.6	28	698	10 395	28	2221
Black angler	8.7	45	593	107	47	245
White angler	17.2	34	845	186	35	353
Hake	378.6	30	172	4219	28	Not available
Whiting	8803.6	54	1416	36 292	57	Not available
Nephrops	1378.8	33	2589	81 762	32	51 080

Landings are from ICES stock assessment Working Groups (Anonymous, 1999; Anonymous, 2000).

anglerfish). The magnitude of this ratio varies depending on the métier or the time of the year.

For most commercial species, one or two age groups are the most discarded. Hence the task at hand reduces to estimating the total discards biomass and the proportion of each selected species. Discarded biomass can be estimated by counting the number of baskets thrown overboard. Currently, the corresponding entry in E.U. fishermen log books is optional and rarely filled in. Making it mandatory would enable to estimate total discards without any additional sampling effort.

Given a multi-stage sampling design with for example trips at the first level, hauls at the second level and the fraction of each sampled haul that is being examined at the third level, the sampling effort at each stage should be guided by the following considerations. Firstly, the sampling fraction, i.e. the number of baskets at the haul level should be commensurate to the proportion of the species of interest in the discards and the variance of this proportion across hauls and trips. The smaller the proportion or the larger its variability, the larger the sampling fraction has to be (Cochran, 1977). Secondly, for estimating total discards, sampling effort has to be concentrated at the levels of largest variability. In the Celtic Sea the variability between trips was found to be far greater than at the between and within haul level. Vessel as well as crew discard behaviour are probably the key-factors explaining differences among trips, and

Table 5. Species classification according to discarding susceptibility.

All discarded	All landed	Partly discarded
Argentine	Black anglerfish	Cukoo ray
Blue whiting	Conger eel	Hake
Boar fish	Ling	Lemon sole
Dab	Pollack	Megrim (female)
Dragonet	Saithe	Megrim (male)
Grey gurnard	Sole	Plaice
Herring	Spiny dogfish	Red gurnard
Horse mackerel	White anglerfish	Smallspotted catshark
Imperial sald fish		Tub gurnard
Long rough dab		Whiting
Mackerel		Witch flounder
Norway pout		
Octopus		
Poor-cod		
Squid		
	Cod (B&G)	Cod (N)
	Haddock (B)	Haddock (G&N)
	Forkbeard (N)	Forkbeard (B&G)
Nephrops (female) (G)		*Nephrops* (Female) (N)
Nephrops (male) (G)		*Nephrops* (Male) (B&N)
Pouting bib (B&N)		Pouting bib (G)
	Skates and rays (D&N)	Skates and rays (B)

"All landed" means that discards were negligible compared to landings (converse for "All discarded"). The bottom section is for species which were handled differently by each métier. For example cod was not discarded by benthic and Gadoid trawlers (B&G) but was partly discarded by *Nephrops* trawlers (N).

may be investigated by sampling several trips of a given vessel, which had not been done in the reported study. Hence the expected variability of discarded biomass across fishing trips will determine the number of trips to be included in the sample. A minimum number of hauls per trip has to be sampled in order to allow variance calculation at this level. Sampling five hauls per trip should be sufficient for this purpose. Sampling plans for estimating the numbers discarded by length group can be developed along the same lines.

Table 6. Comparison between the length at which 50% of the fish were discarded (DL_{50}) by each métier and the minimum landing size (MLS), in cm (*Nephrops*: mm).

Species	DL_{50} Benthic	DL_{50} Gadoid	DL_{50} *Nephrops*	MLS
Cod	28	27	35	35
Hake	31	34	37	30
Plaice	22	30	28	25
Witch flounder	27	30	25	28
Lemon sole	25	25	24	25
Whiting	30	32	36	27
Female megrim	28	29	29	25
Male megrim	28	28	27	25
Female *Nephrops*	NA	NA	35	25
Male *Nephrops*	NA	NA	34	25

NA: DL_{50} not estimated because benthic and Gadoid trawlers catch and discard very few *Nephrops*.

Based on the previous considerations, a sampling plan for estimating numbers of whiting, cod, anglerfish and *Nephrops* discarded by the French fleet operating in the Celtic Sea was elaborated (Table 10). The number of baskets per haul was estimated based on the average species proportion and the average variance of those proportions in the 1997 haul samples. For species proportions smaller than 0.1, a 10% chance for obtaining estimates which differ by more than 0.02 from the true value was aimed at. For proportions larger than 0.1 the acceptable absolute difference was set at 0.05. For calculating the required number of trips the average discarded biomass per trip and its variance in 1997 were used. Results are given for two levels of precision (20 and 40%) which are the relative difference between true and estimated weights which will not be exceeded with more than a 0.1 probability. Seasonal allocation of sampling effort might further improve the precision of discard estimates. Gadoid trawlers produced the majority of their discards during the first quarter in 1997 whereas *Nephrops* trawler discarding was spread throughout the year. Thus an appropriate temporal allocation of sampling effort could be implemented.

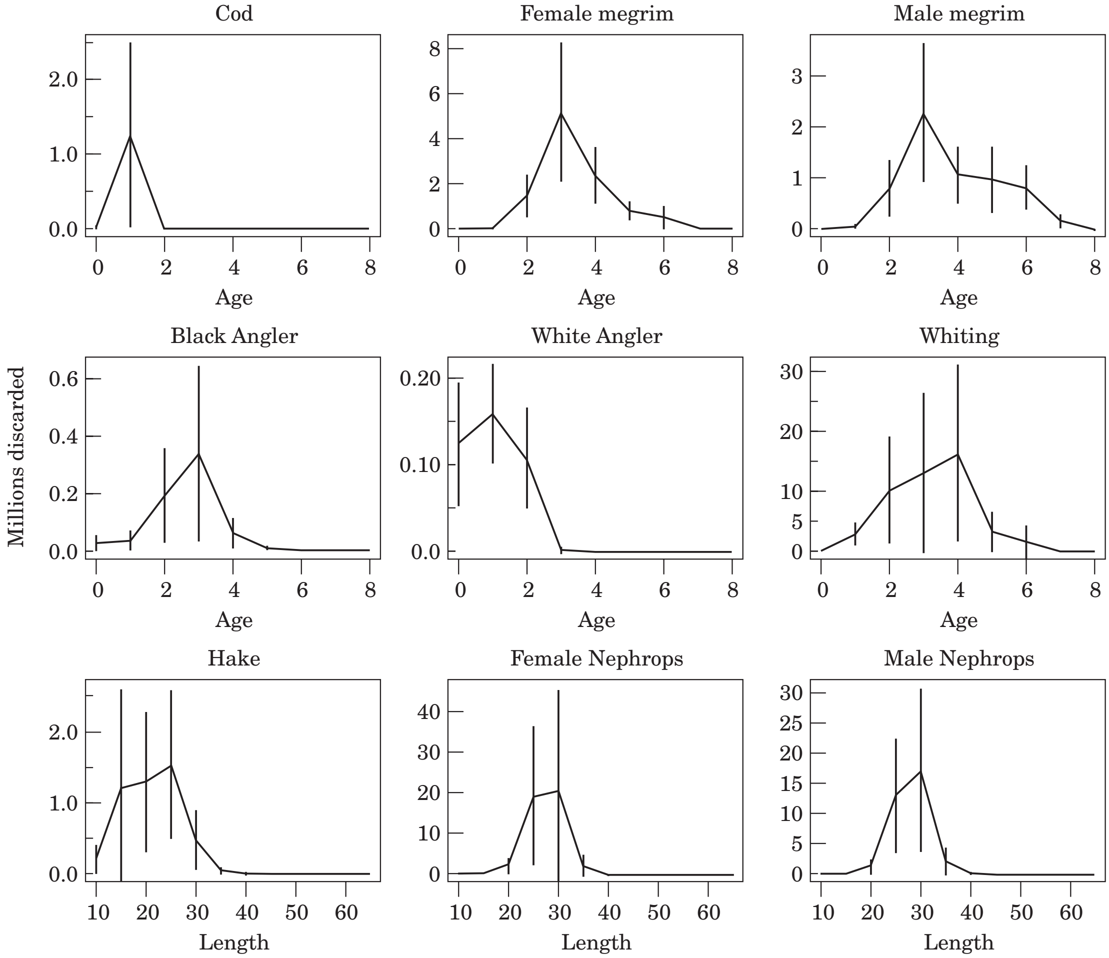

Figure 5. Estimated numbers discarded (in millions) at age (in years) and their 95% confidence interval for cod, male and female megrim, black anglerfish, white anglerfish and whiting. Estimated numbers discarded (in millions) at length and their 95% confidence interval for hake (TL in cm) and female and male *Nephrops* (CL in mm).

Discussion

It was estimated that, as a whole, the French fleet operating in the Celtic Sea discarded about one third of its catch in 1997. This proportion was similar for the three métiers operated by the fleet. It is not higher than proportions discarded in similar fisheries. Groundfish trawl fisheries have been reported to discard half their total catch or more in the North Sea (van Beek, 1998), German Bight (Weber, 1995), West of Scotland (Dupouy *et al*., 1998) and Celtic Sea (Spanish fleet: Perez *et al*., 1996). However, 30 000 tons of discarded fish per year justify further examination of what is discarded and why.

What is discarded varies among métiers. Benthic trawlers discarded mainly by-catch species. Ways of providing a market for these species may be sought. On the other hand, Gadoid and *Nephrops* trawlers discarded primarily their target species. For whiting and megrim, the estimated numbers discarded were twice the reported landings (Table 4). Discarded *Nephrops* were also more abundant than those landed. The estimated discards proportions by species are of the same order of magnitude as those reported for other groundfish trawl fisheries (Stewart and Newton, 1993; Stratoudakis *et al*., 1999; Tamsett and Janacek, 1999; Tamsett *et al*., 1999) and *Nephrops* trawl fisheries. In the latter, *Nephrops* discards are most often higher than half the catch (Hillis, 1981a, b; Briggs, 1985; Macer and Brown, 1987; Pope *et al*., 1991; Evans *et al*., 1994).

For most species, small fish account for a large proportion of discards. In order to reduce this component, progress in gear selectivity might be possible. In many cases fish larger than the minimum landing size were discarded. Hence for the studied fishery, minimum landing size does not seem to play an important role in resource conservation. Legal mesh size and minimum landing sizes may be better adjusted. However, this

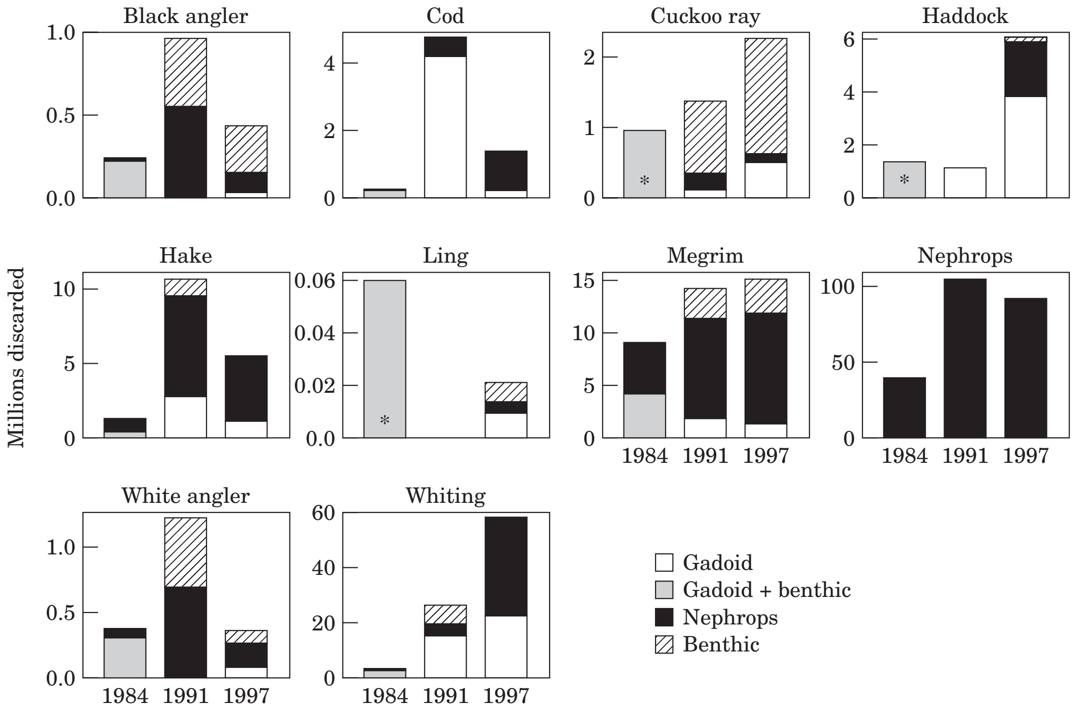

Figure 6. Comparison of the numbers discarded by métier in 1984, 1991 and 1997 (millions of fish). In 1984 benthic and Gadoid trawlers were considered a single métier. Stars: discards of these species by *Nephrops* trawlers were not counted in 1984.

Table 7. Analyses of variance of log-transformed total discarded weight. The factors métier and area × quarter were analysed separately due to the unbalanced design.

Source	d.f.	Sum of squares	Mean square	F	P(F)
Métier	2	0.144	0.072	0.077	0.926
Residuals	23	21.537	0.936		
Area	4	3.843	0.961	1.033	0.417
Quarter	3	1.105	0.368	0.396	0.757
Residuals	18	16.732	0.930		

might not always be possible as multispecies fisheries are considered here and optimal mesh size for one species will be unsuitable for other species. Furthermore, for hake, whiting, megrim and *Nephrops*, even large fish were discarded. With the data at hand it is impossible to find out which proportion of animals of marketable size were discarded because they were damaged, or due to low market prices, or for other unknown reasons.

Whether a species is discarded or not depends on its expected value and on the métier. However, explanations for the quantities discarded are not easily found. The present study gives weak evidence that year-class strength influences the numbers discarded. Weber (1995) reported that cod discards per unit effort were correlated with a recruitment index in a groundfish fishery exploiting a nursery area. Time series of both discards and recruitment estimates are needed to further explore the hypothesis.

The fishing methods also play a role in determining the quantities discarded, either summarized in the "métier" factor, or expressed explicitly by area, season, gear, mesh size, etc. Many parameters are involved, consistent with previous findings (Morizur *et al.*, 1996; Murawski, 1996; Perkins and Edwards, 1996; Blasdale and Newton, 1998; de Silva and Condrey, 1998). This means that discards need to be studied on a fishery basis and cannot be extrapolated from one fleet to another. In addition, large data sets will be needed to disentangle the effects of various factors. On a trip-by-trip basis, the most convincing factor found for explaining the weights discarded was the smallest size in the catch. Fishermen will discard more when they catch smaller fish. Reeves

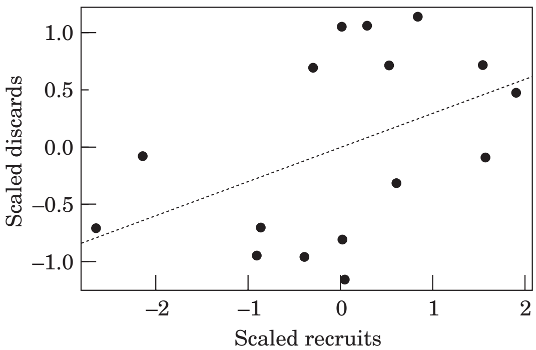

Figure 7. Estimated scaled numbers discarded versus scaled recruitment (as estimated by Anonymous, 2000) for eight commercial species, using pooled data from 1984, 1991 and 1997. Dashed line: linear regression (Intercept = − 0.002, s.e. = 0.19; slope = 0.30, s.e. = 0.16).

(1990) found that mean length-at-age in the catch was an important factor explaining numbers and proportions of haddock discarded by the Scottish fleet in the North Sea using a 12-year series. However, in the present study, no simple relationship that would help predicting discards from easily available data was found. In particular, discards were generally weakly linked to amounts landed. This observation was also reported by Reeves (1990) and Trujillo *et al*. (1997) for a Spanish trawler fleet. For some species, predictive models of discards incorporating various information were obtained. However, these models explain variability between trips (not years) for a limited sample. They need further validation before allowing us to predict discards when they are not sampled.

Since whiting, megrim and *Nephrops* were discarded in large numbers, including old ages, whether discards are taken into account or not, can have a significant impact on the results of the long-term predictions of VPA-based assessments, in particular when discard proportions vary between years; short term forecasts are less affected (Anonymous, 1986). For ICES assessment purposes, the French discards estimates were incorporated into catch estimates of megrim and *Nephrops* as follows. The 1984, 1991 and 1997 estimated discards-to-landings ratios were used for subsequent years until the next sampling survey. As the estimated ratios differed among sampling years, this created inconsistencies in the assessments that are not yet resolved (Anonymous, 1999; Anonymous, 2001).

We found that (i) the amounts discarded were highly variable between trips, and between the 1984, 1991 and 1997 studies. This is consistent with the available information: in most studies cited above, the coefficients of variation of the estimated amounts or proportions varied between 25 and 50%; this variability can be between trips, between months and years. (ii) There was no auxiliary variable sufficiently correlated with the amount discarded, to estimate discards without sampling them. Although most authors do not report explicitly on this point, this seems also consistent with previous studies, because the coefficients of variations of the estimated

Table 8. Automatically selected linear models of the weight of each species discarded per trip, with predictors describing the landings and fishing operations: multiple R-squared and coefficients of the selected predictors.

Species	R^2	Interc.	Métier B	Métier D	Nb small fish landed	Species weight landed	Total weight landed	Days at sea	Target weight landed	Min. length of landings	Other
Black angler	0.47	0.24	—	—	—	1.6E-3	—	—	—	—	
Catshark	0.14	3.78	—	—	5.7E-3	—	—	—	—	—	
Cod	0.43	− 1.35	0.50	1.51	—	—	0.21	—	—	—	
Cukoo ray	0.44	− 1.46	—	—	1.0E-3	—	—	0.43	—	—	
Dogfish	0.00	1.08	—	—	—	—	—	—	—	—	
Grey gurn.	0.76	2.84	—	—	6.8E-3	—	0.15	—	—	—	quarter
Haddock	0.50	3.04	1.35	0.46	—	5.7E-4	—	—	—	—	
Hake	0.71	− 6.26	1.05	1.77	—	—	—	0.81	—	—	
Lemon sole	0.89	1.11	—	—	—	—	0.11	—	—	—	gear
Ling	0.00	− 0.56	—	—	—	—	—	—	—	—	
Megrim F	0.57	8.58	—	—	3.1E-3	− 1.5E-3	—	− 0.34	—	—	
Megrim M	0.81	10.03	—	—	—	—	—	− 0.54	—	—	area
Nephrops F	0.66	23.00	—	—	—	—	—	− 1.70	7.0E-4	—	
Nephrops M	0.72	17.18	—	—	—	—	—	− 1.10	—	—	
Plaice	0.77	2.36	3.06	0.66	—	—	—	—	—	—	
Rays	0.15	2.81	—	—	1.6E-2	—	—	—	—	—	
Red gurnard	0.24	− 5.83	—	—	—	—	—	0.84	—	—	
Tub gurnard	0.57	3.51	—	—	—	—	—	—	—	− 0.14	
White angler	0.43	1.05	—	—	—	—	—	—	—	—	area
Whiting	0.71	5.32	3.15	1.27	—	—	—	—	—	—	
Witch flound	0.65	3.01	—	—	—	1.4E-2	—	—	—	− 0.13	

Table 9. Automatically selected linear models for the weight of each species discarded per trip, with predictors describing the landings, fishing operations and the catch: multiple R-squared and coefficients of the selected predictors.

Species	R^2	Intercept	Min. length of catch	Species weight landed	Max. length of catch	Total weight landed	Headline length	Mesh size
Black angler	0.70	2.72	− 0.14	1.4E-03	—	—	—	—
Catshark	0.57	5.80	− 0.14	—	—	0.12	—	—
Cod	0.50	6.99	− 0.17	—	—	—	—	—
Cukoo ray	0.55	6.37	− 0.13	4.7E-04	—	—	—	—
Dogfish	0.25	4.52	− 0.07	—	—	—	—	—
Grey gurnard	0.46	2.42	− 0.19	—	0.17	—	—	—
Haddock	0.65	10.45	− 0.35	6.6E-04	—	—	—	—
Hake	0.59	7.63	− 0.22	—	—	—	—	—
Lemon sole	0.44	5.67	− 0.22	—	—	0.14	—	—
Ling	0.13	3.42	− 0.09	—	—	—	—	—
Megrim F	0.55	6.73	− 0.26	− 1.5E-03	—	—	0.09	—
Megrim M	0.69	6.03	− 0.26	—	—	—	0.07	—
Nephrops F	0.61	− 9.06	—	—	0.35	—	—	—
Nephrops M	0.79	4.61	—	—	0.18	—	—	− 0.10
Plaice	0.69	15.14	− 0.61	—	—	—	—	—
Rays	0.42	− 6.55	− 0.08	—	—	—	—	0.12
Red gurnard	0.66	10.88	− 0.51	4.9E-02	—	—	—	—
Tub gurnard	0.50	9.75	− 0.30	—	—	—	—	—
White angler	0.52	5.06	− 0.22	—	—	—	—	—
Whiting	0.61	13.36	− 0.36	—	—	—	—	—
Witch flounder	0.56	8.72	− 0.30	—	—	—	—	—

Table 10. Annual sampling plan for estimating discarded numbers of whiting, cod, anglerfish and *Nephrops* by métier for the French fleet operating in the Celtic Sea.

Métier	Number of trips for 40% precision	Number of trips for 20% precision	Number of hauls per trip	Number of 10 kg baskets per haul
Benthic	3	13	5	4
Gadoid	10	35	5	5
Nephrops	15	56	5	5

For explanation see text.

discard rates were seldom lower than the ones of discarded quantities. As a consequence, discards should be sampled routinely. This would require a high sampling effort, implying high costs and the continued co-operation with fishermen, which is not always easy in the European context. For the present study, 14 tons of fish were measured, and this was not sufficient to achieve a reasonable precision for estimating the discards by age for whiting, the most discarded species.

Discarding the amounts estimated here potentially affects the dynamics of exploited stocks, as well as other species of the community (Rochet *et al.*, 2000). Fisheries scientists are urged to improve stock assessments, and to provide scientific basis for an ecosystem approach to fisheries management (Gislason *et al.*, 2000). Both require accurate knowledge of discarded quantities, and a better understanding of discarding practices. There is a strong need for increased sampling and research in this field.

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Appendix. List of species names.

Species name	English name	Species name	English name
Alosa spp.	Shad	*Pecten maximus*	Common scallop
Argentina spp.	Argentine	*Phycis blenoides*	Greater forkbeard
Arnoglossus imperialis	Imperial sald fish	*Platichtys flesus*	European flounder
Aspitrigla cuculus	Red gurnard	*Pleuronectes platessa*	Plaice
Callionymus lyra	Dragonet	*Pollachius pollachius*	Pollack
Capros aper	Boar fish	*Pollachius virens*	Saithe
Conger conger	Conger eel	*Raja batis*	Blue skate
Clupea harengus	Atlantic herring	*Raja brachyura*	White skate
Eledone cirrosa	Octopus	*Raja clavata*	Biscuit ray
Eutrigla gurnardus	Grey gurnard	*Raja fullonica*	Shagreen ray
Gadus morhua	Atlantic cod	*Raja microocellata*	Small-eyed ray
Gaidropsarus vulgaris	Three-beard rockling	*Raja montagui*	Spotted ray
Glyptocephalus cynoglossus	Witch flounder	*Raja naevus*	Cukoo ray
Hippoglossus platessoides	Long rough dab	*Raja undulata*	Undulate ray
Lepidorhombus boscii	Four-spotted megrim	*Coryphaenoides rupestris*	Roundnose grenadier
Lepidorhombus wiffiagonis	Megrim	*Sardina pilchardius*	European pilchard
Limanda limanda	Common dab	*Scomber scombrus*	Mackerel
Loligo spp.	Squid	*Scyliorhinus canicula*	Smallspotted catshark
Lophius budegassa	Black anglerfish	*Sepia officinalis*	Common cuttlefish
Lophius piscatorious	White anglerfish	*Solea vulgaris*	Sole
Merlangius merlangus	Whiting	*Sprattus sprattus*	Sprat
Melanogrammus aeglefinus	Haddock	*Squalus acanthias*	Spiny dogfish
Merlucius merlcius	Hake	*Torpedo nobiliana*	Electric ray
Microstomus kitt	Lemon sole	*Trachurus trachurus*	Horse mackerel
Micromesistius poutassou	Blue whiting	*Trigla luceran*	Tub gurnard
Phycids	Forkbeards	*Trisopterus esmarki*	Norway pout
Microchirus variegata	Thickback sole	*Trisopterus luscus*	Pouting bib
Molva molva	Ling	*Trisopterus minutus*	Poor-cod
Chelon labrosus	Grey mullet	*Zeugopterus punctatus*	Topknot
Mustelus mustelus	Smoothhound	*Zeus faber*	John Dory
Nephrops norvegicus	Norway lobster		