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A new optimal allocation sampling design to improve estimates and precision levels of discards from two different Fishery Units of Spanish trawlers in northeast Atlantic waters (ICES subareas VIIc,j,k)

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ABSTRACT

The present report discusses a new onboard sampling design for the Spanish trawlers in northeast Atlantic waters –International Council for the Exploration of the Sea (ICES) subareas VIIc,j,k–. This sampling design comprises three stages: i) number of vessels and trips per vessel to be sampled; ii) the minimum number of sampled hauls; and iii) a temporal distribution of those sampled hauls throughout the fishing trip to balance hauls sampling along the fishing trip. As a result, an optimal allocation sampling is suggested, comprising at least one vessel and one trip per vessel to be sampled monthly, between 30 to 50 sampled hauls within that fishing trip, and a time-division for hauls during the fishing trip, containing 8-15 sampled hauls at the beginning, middle and end of the trip.

Keywords: Hake, megrim, discards, Fishery Units, precision levels, sampling design.

RESUMEN

Nuevo diseño de muestreo de alocación óptima para mejorar las estimaciones y los niveles de precisión de los descartes en dos unidades pesqueras de arratreros españoles en el Atlántico nororiental (subáreas VIIc,j,k del CIEM)

Se aporta un nuevo diseño de muestreo de aplicación a bordo para los arrastreros españoles que faenan en las suáreas VIIc,j,k establecidas en el Atlántico noreste por el Consejo Internacional para la Exploracion del Mar (CIEM), diseño en cuyo desarrollo en tres etapas intervienen las siguientes variables: i) número de barcos y de las respectivas mareas a muestrear; ii) número mínimo de lances a muestrear; iii) distribución temporal del muestreo de lances a lo largo de la marea. Como conclusión, se recomienda un muestreo de alocación óptima consistente en el muestreado mensual de un barco y una marea, la elección de entre 30 y 50 lances a muestrear y, por último, que éstos estén distribuidos a lo largo de la marea de forma que al menos de 8 a 15 lances correspondan a cada uno de los periodos inicial, intermedio y final de la misma.

Palabras clave: *Merluza, gallo, descartes, unidades pesqueras, niveles de precisión, diseño de muestreo.*

INTRODUCTION

In many fisheries, discards constitute a major contribution to fishing mortality in younger ages of commercial species (Jennings and Kaiser, 1998; Hammond and Trenkel, 2005; Punt *et al.*, 2006). However, relatively few stock assessments in ICES working groups have taken discards into consideration (Hammond and Trenkel, 2005). This happens mostly due to the long time series of onboard observation needed, not available for all the fleets involved in the exploitation of most stocks, and to the large amount of research effort needed to obtain this kind of information (Kelleher, 2005; Alverson *et al.*, 1994).

Advances in multilevel modelling for measuring discards have been recently reported. Tamsett, Janacek and Emberton (1999) and Allen *et al.* (2001) showed comparisons of methods for onboard sampling of discards in commercial fishing and produced estimates using different methods. Stratoudakis *et al.* (2001) showed that collapsing the stratification into groups of strata with similar ratios and then applying a ratio estimator to each group of strata gives estimators of total discards that are less biased and more precise. Borges *et al.* (2004) reported optimum sampling levels in discard sampling programs by using total fish discard ratios. Their analysis took into account cost and precision objectives and explores dependence on both variables. Borges *et al.* (2005) also suggested a method for searching the best sampling unit and auxiliary variables for discards estimations. Their results showed that one fishing trip was the recommended sampling unit to estimate discards in most of the fleets studied.

One of the main problems when dealing with onboard observer data is the high variation they usually show over space and time. If the sampling design does not account for it, this high variation could hide some bias in the estimation, which will be transferred to the raising estimates for the whole fleet or strata (Allen *et al.*, 2001, 2002; Borges *et al.*, 2004; Apostolaki, Babcock and McAllister, 2006).

Fishing observer data are based on a multistage sampling design, with several stratified, cluster and random stages. These stages take into account Fishery Units, vessels, fishing trips, hauls and species sampling. Therefore, an adequate definition of number of vessels and trips per vessel to be sampled is crucial, both to optimise deployment resources and to achieve the most accurate estimates of total catch at sea.

The present paper reports on a three-stage sampling design. The first stage aims to determine the sample size for different vessels and fishing trips. The second stage is to establish a minimum number of hauls to be sampled during the fishing trip. The third focuses on how those sampled hauls should be distributed throughout the trip. Finally, an optimal allocation sampling design is suggested, which takes into account the multistage nature of onboard sampling.

MATERIALS AND METHODS

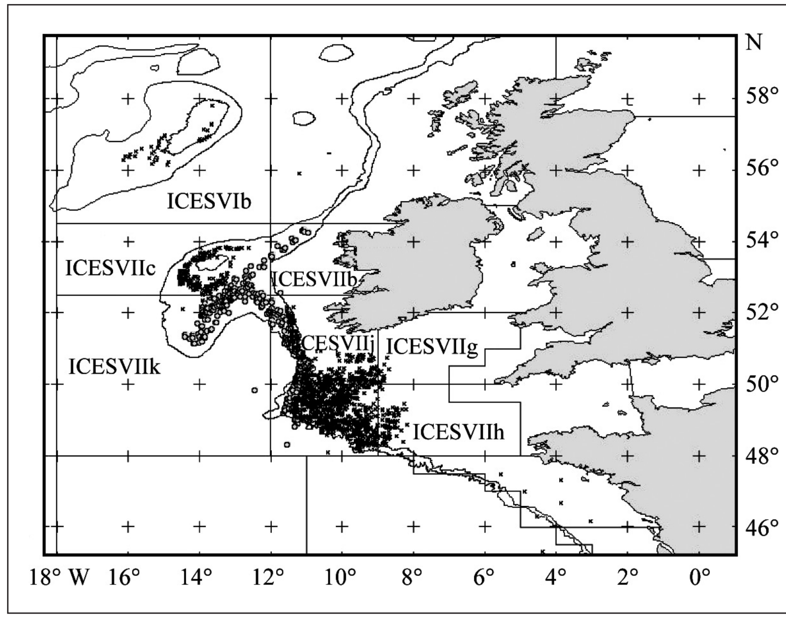
Reference fleet and data set

The reference fleet for this work comprised Spanish demersal trawlers that operate in the Grand Sole and Porcupine subareas (ICES subareas VIIc,j,k). This is a medium-distance fleet, which usually lands in northwest Spanish fishing ports. These fishing boats' campaigns last from 12 to 16 fishing days, comprising between 40 and 75 hauls for each trip (Bellido, Pérez and Lema, 2005).

Two different Fishery Units (also called *metiers*) can be distinguished in this fleet. The Spanish Otter Trawlers Targeting Megrim (hereafter referred as SOTTMeg) is based at the Vigo and Marín ports. It targets megrim *Lepidorhombus whiffiagonis* (Walbaum, 1792), but also anglerfishes *Lophius piscatorious* L., 1758 and *Lophius budegassa* Spinola, 1807 and hake *Merluccius merluccius* (L., 1758). The Spanish Otter Trawlers Targeting Hake (hereafter referred as SOTTHak) is based at the A Coruña and Celeiro ports. It targets mainly hake, but also anglerfishes, witch *Glyptocephalus cynoglossus* (L., 1758), Norway lobster *Nephrops norvegicus* (L., 1758) and megrim.

These metiers differ in the location of their fishing grounds and in their fishing operations. SOTTMeg operates in waters from the continental shelf around the 200 m isobath (figure 1). It makes short hauls, with trawls of 4 hours, comprising about 75 fishing hauls per trip. Whereas SOTTHak is more restricted to deeper waters around the slope (figure 1). It makes about 7-hour hauls, resulting in about 40 fishing hauls per trip.

Figure 1. Geographic location of main fishing grounds by Fishery Units. Circles represent SOTTHak and crosses represent SOTTMeg. The 200 m and 1 000 m isobaths are shown



This fleet has been monitored onboard since the late 1980s. However, it was not until 2003 that routine yearly sampling was achieved, through EU Data Collection Regulation 1639/2001. This EU Regulation also implies the need to provide fishery annual estimations which different precision levels. According the EU Regulation 1639/2001, "data related to annual estimates of discards must lead to a precision level that make possible to estimate a parameter with precision of plus or minus 25 % for a 95 % confidence level". This implies that the estimated Coefficient of Variance (CV) of the parameter is, at most, 12.5 % (ICES, 2004).

The ongoing data set comes from years 2003, 2004 and 2005. This comprises sampling on 29 vessels, 30 trips and 1 104 hauls. The sampling was conducted throughout the year, usually deploying an observer every month. The observer programme is based on a stratified random sampling per Fishery Unit, which comprises area, gear and target species. Observers record discards and retained catch by species and haul, both in weight and number.

Optimal sample size for vessels and fishing trips

Surveys to estimate the amount of fish discarded from commercial fishing vessels typically use multistage sampling, comprising up to six levels (i.e. vessels, trips, hauls, boxes, fish length and fish age), each of which contribute to the overall variability (Allen *et al.*, 2002). We consider here only three levels: V is the number of vessels in the fleet, T is the average number of trips per vessel, and H the average number of hauls per trip. These three parameters are constant across the study period (see table I for settings). The lower case equivalents (v, t, and h) are the corresponding numbers in the samples.

The data used for estimation of the variance components are the number for hake, megrim, and all species discarded at haul level. Previous analysis showed that results for discard in weight are quite similar to those of discard in number Thus, in order to gain in conciseness, this paper only reports results for discards in number. As the data are unbalanced, due to the different number of hauls per trip and trips per vessel, analysis of variance (anova) should not be applied (Allen *et al.*, 2002). Hence, the residual maximum likelihood method was used to analyse the data, assum-

Table I. Values of settings to estimate optimal size sample for vessels and fishing trips. V is the number of vessels in the fleet, T is the average number of trips per vessel, H the average number of hauls per trip, and h the average number of sampled hauls per trip

	SOTTMeg	SOTTHak
V	51	30
T	14	14
H	74.50	39.50
h	42.27	21.75

ing that the residual variation is greater than zero and the remaining variance parameters are greater than or equal to zero (Allen *et al.*, 2002).

The estimated variance components were used to calculate the optimal average number of trips per vessel that must be sampled to achieve the target precision, formula below (Allen *et al.*, 2002).

The mean discard is given by:

$$\bar{\bar{\bar{y}}} = \frac{\sum_{i=1}^{v} \sum_{j=1}^{t} \sum_{k=1}^{h} y_{ijk}}{vth}$$

and the variance is:

$$\mathrm{Var}(\bar{\bar{\bar{y}}}) = \left(1 - \frac{v}{V}\right)\frac{S_v^2}{v} + \left(1 - \frac{t}{T}\right)\frac{S_{VT}^2}{vt} + \left(1 - \frac{h}{H}\right)\frac{S_{VTH}^2}{vth}$$

The optimum values for the number of vessels to sample, v_{opt} are, for a target variance (Var_{tar}):

$$v_{opt} = \frac{S_V^2 + \left(1 - \frac{t}{T}\right)\frac{S_{VT}^2}{t} + \left(1 - \frac{h}{H}\right)\frac{S_{VTH}^2}{th}}{\mathrm{Var}_{tar} + \frac{S_V^2}{V}}$$

h was kept constant at the average value by Fishery Unit (see table I) and the number of sampled trip per vessel t was ranged from 1 to 6 and evaluated for CVs of 12.5, 25, 50 and 75 % (i.e. Var_{tar} of 0.12, 0.25, 0.50, 0.75) for discards of megrim, hake and all species.

Haul bootstraps

A re-sampling method with bootstrap techniques was applied to data to determine the minimum number of hauls to be sampled to reduce significantly intra-variance within a fishing trip –see Efron and Tibshirani (1993) and Davison, Hinkley and Young (2003) for a detailed review of bootstrap techniques–.

Bootstraps were applied to megrim, hake and total discard for both SOTTMeg and SOTTHak. Several groups of samples comprising 10, 20, 30,… up to 100 hauls were selected in each fishing trip and a mean and CV was estimated for each group. The 10-hauls group is considered the reference group beyond which improvement is estimated. This procedure was repeated 500 times for every haul group and trip. The percentiles 95 and 5 % of CV were used to identify the variance decrease, expressed as a percentage, when the number of hauls is increased within the fishing trip. Finally, the average percentage of variation of CV with confidence intervals across hauls groups for every fishing trip and Fishery Unit was plotted.

Retaining and discard behaviour throughout the fishing trip

On the other hand, fishermen may vary their retained catch and discard patterns as a fishing trip progresses. Particular targets, length and/or proportion of fish discarded/retained may change according to such factors as market prices, weather, occasional presence/absence of the main target, and storage space. To look into these plausible discarding differences within the same fishing trip, every fishing trip was divided into three groups –a beginning, middle and end– each group containing an equal number of hauls.

Each group comprised up to 10 hauls from the beginning, middle and end of the fishing trip. The minimum gathering group was by 6 hauls for every group. This was particularly important for SOTTHak, where the number of hauls by fishing trip was smaller than for SOTTMeg. The non-parametric anova Kruskal-Wallis analysis of ranks was used to look for differences in discarding pattern throughout the fishing trip. This was done by weight and number for the two Fishery Units and the specific target species, i.e. hake and megrim, but also for other important associated species such as witch, Norway lobster, four spot megrim *Lepidorhombus boscii* (Risso, 1810) and greater fork beard *Phycis blennoides* (Brünnich, 1768). Retaining and discarding pattern by length were also compared for the two main commercial species, based on the adjusted curve of retained/total catch by length.

RESULTS

Vessels and fishing trips, optimal sample size

Results on megrim discard CVs are quite similar for both Fishery Units (figure 2A). Achieving a CV of ± 12.5 % implies sampling 45 vessels with a fishing trip for each vessel, or about 35 vessels with 2 fishing trips each, for both SOTTMeg and SOTTHak. With a target of 25 % CV, sampling effort is greatly reduced, particularly for SOTTMeg, where 15 vessels are needed to get a 25 % CV target with one fishing trip. It is important to highlight that there is no a great gain when increasing the sampling to more that one fishing trip for the same CV target (figure 2A).

Hake discards require more sampling effort to achieve specific CV targets (figure 2B). To achieve a 12.5 % CV target for SOTTMeg, more than 60 vessels are necessary, with one sampled fishing trip. Sampling effort is also halved for 25 % CV target in SOTTMeg. However, the figures are lower in SOTTHak and rather similar to those estimated for megrim (figure 2A), i.e., 45 vessels with one trip to achieve a CV of 12.5 %.

Regarding total discards, a target CV of 12.5 % is achieved by sampling 30 vessels once for SOTTMeg (figure 2C). When the target CV is 25 %, sampling is reduced to 10 vessels. As mentioned above, there is no apparent improvement when the sampling takes into account more than one fishing trip, particularly for target CV of 25, 50 and 75 %. The estimates obtained for SOTTHak are slightly higher than those of SOTTMeg.

Haul bootstraps

Results for megrim discard at the haul level are shown in figure 3. A 50 % CV improvement is achieved with 40 sampled hauls for SOTTMeg (figure 3A), whereas for SOTTHak about 50 sampled hauls are required. It should be noted that the confidence interval, 5-95 %, is wider for SOTTHak. Regarding hake discards, the 50 % CV improvement is achieved with about 70-75 sampled hauls for SOTTMeg (figure 3B). SOTTHak hake discard requires a higher sampling effort, about 95 sampled hauls. The figures for hake discards are notable higher than those for megrim (see figure 3 versus figure 2). This could be explained by the highly skewed nature of hake discard data, which includes many zeros. Discarding hake is not as usual as discarding megrim, and therefore it becomes harder to produce a robust estimate for hake discards.

Figure 3C show the results for total discard in number, considering all fish. The estimate of sampled hauls is smaller for SOTTHak than for SOTTMeg. Regarding SOTTMeg, the 50 % CV improvement occurs at 100 sampled hauls, and around 45 sampled hauls for SOTTHak (figure 3c). It is important to note that the results for total discards seem to be quite high, particularly for SOTTMeg. This could be explained by the highly skewed data, in this case due to occasional catching and discarding of important schools of small fish, mainly boarfish *Capros aper* (L., 1758), but also small horse mackerel *Trachurus trachurus* (L., 1758), with very low catch weight but very high catch numbers.

Retaining and discard behaviour throughout the fishing trip

A slight increase of L_{50} (length at which 50 % is retained) occurred during the fishing trip in both metiers, especially for hake (table II). This shows an opportunistic pattern at the beginning of the trip, and a slightly increasing selective pattern, retaining larger and larger hake as the fishing trip progresses, particularly in SOTTMeg (table II). This agrees with results from table III for hake, where the hake discarding pattern was found to be significantly different among the different SOTTMeg hauls periods that were analysed. However, results for megrim suggest that fish length is not a key factor for retaining or discarding megrim (table III).

There were no statistical differences regarding megrim discarding behaviour among the three time groups during the fishing trip for SOTTMeg (see table III). However, discarding behaviour for hake changed as fishing trips progressed, particularly from the beginning to the end. Significant differences in the discarding pattern were also found

Table II. L_{50} values for hake and megrim in the different Fishery Units over the three periods in a fishing trip, i.e. beginning, middle and end

Species	Fishery Unit	L_{50} (cm)		
		Beginning	Middle	End
Hake	SOTTMeg	31.6	33.4	34.3
Hake	SOTTHak	33.0	34.5	34.9
Megrim	SOTTMeg	23.0	23.1	22.4
Megrim	SOTTHak	24.2	24.7	27.5

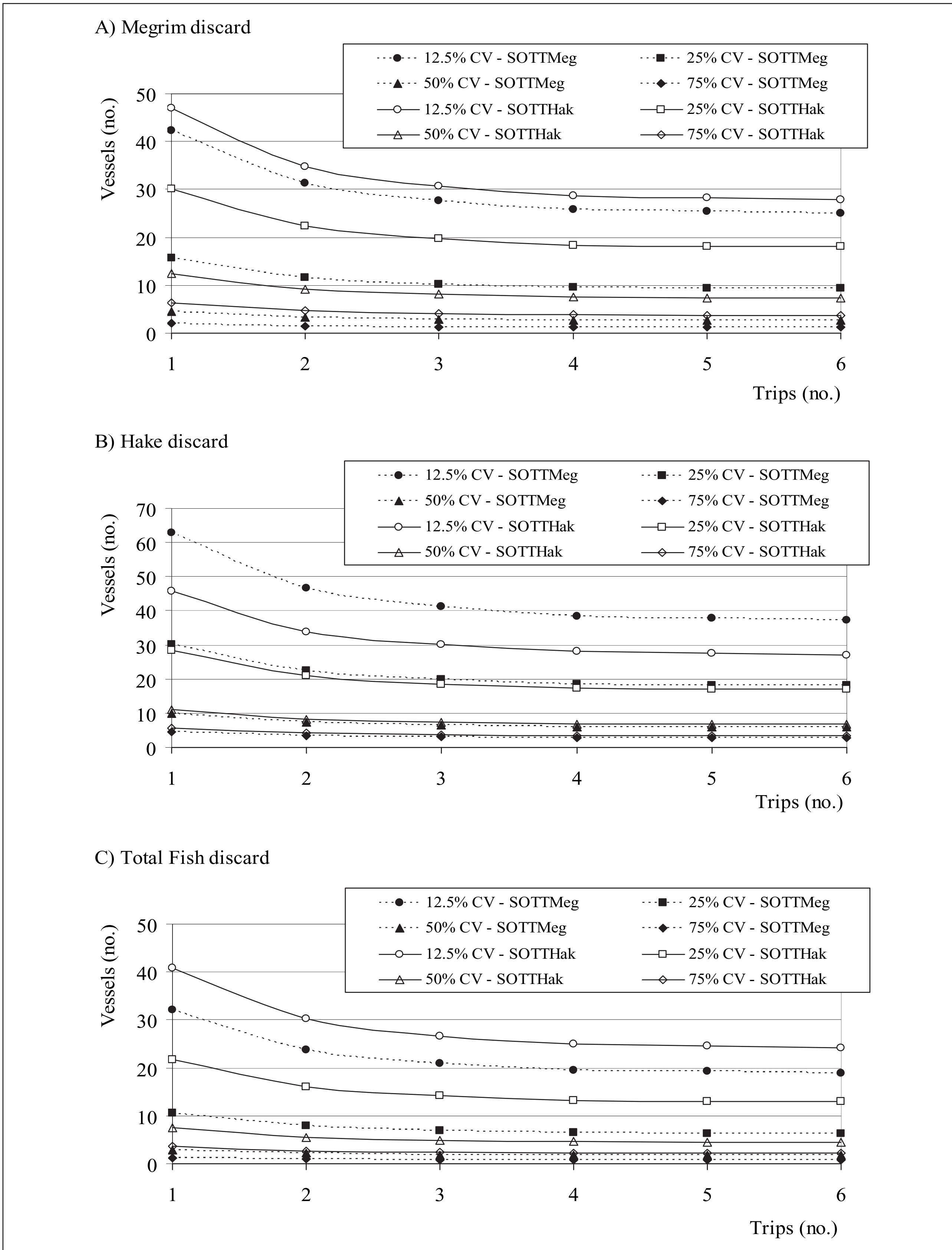


Figure 2. Number of vessels and fishing trips needed to obtain a specific CV for megrim (A), hake (B), and total (C) discards numbers for both Fishery Units

for four-spot megrim, witch and Norway lobster for SOTTMeg.

Regarding SOTTHak, significant differences were found only for discards of Norway lobster (table III). Results suggest SOTTMeg is more variable in its discarding pattern during fishing trips in practically all of the species analysed, whereas SOTTHak is more stable across fishing trip duration, and there is no important variation in discarding practices, except those for Norway lobster.

DISCUSSION

Onboard sampling is one of the most important direct sources of information in fisheries research, both to produce estimates of total extracted biomass and to study fishing patterns of specific fleets, as well as the impact of fishing on the ecosystem. Recently, the international literature has reflected this, highlighting the increasing importance of such applied research in different parts of the world (Kumar and Deepthi, 2006; Hall and Mainprize, 2005; Zeller and Pauly, 2005; Rochet and Trenkel, 2005; O'Brien, Pilling and Brown, 2004; Pitcher *et al.*, 2002). In a European context, the importance of an onboard sampling methodology was further increased when EU Data Collection Regulation (DCR) 1639/2001 and EU Regulation 1581/2004 required that "data related to annual estimates of discards must lead to a precision level that make possible to estimate a parameter with precision of plus or minus 25 % for a 95 % confidence level". The ICES Workshop on Sampling and Calculation Methodology for Fisheries data agreed this precision level is equivalent to a CV of ± 12.5 % (ICES, 2004).

The present paper also deals with sampling design related to specific-species discard data, differing from other authors who have traditionally suggested sampling designs based on total discard data (Allen *et al.*, 2001, 2002; Borges *et al.*, 2004; Borges, Rogan and Officer, 2005). If the final sampling results are thought to be used in fishery assessment or management, then the sampling design ought to make it possible to calculate robust estimates for individual species. In such a multispecies fishery, the sampling design could vary greatly, depending on the species of focus. Thus, it is important to know all the options and sampling needs to achieve good quality estimates for at least the most important species of the fishery, in this case, megrim and hake. Our sampling design aims to compromise among the main species, while being efficient and effective.

Our results show that the optimal sample size for vessels and fishing trips are far from those required to meet EU Data Collection Regulations (DCR). To increase the sampling level to that suggested by DCR requirements would imply a very expensive onboard data collection program. We consider the EU DCR level to be unrealistic, and such a DCR level is very hard to obtain in a fishery observation programme. Our results show this contradiction between funding and requirements of the current EU DCR.

As mentioned before, the current sampling effort is monthly, i.e., it consists of 12 vessels and one trip per vessel. This implies a CV of around 25 % for total discard in weight, and more than 50 % for total discard in number. We consider that a reasonable indicator CV would be about ± 25 %. Therefore, if specific species estimates are needed, for instance to include total catch in stock assessment, the EU DCR compulsory sampling should be extended to reach at least that ± 25 % CV level.

Eventually, sampling design becomes increasingly complicated when different target species are to be considered. For example, sampling levels for megrim are easier to obtain, perhaps because megrim discards are relatively homogeneous. However, estimation of robust sampling levels required for hake discards are much harder to obtain, due to the variable discarding pattern, both inter- and intra-metier.

One way to reduce all of this variability is using total discard rates. Total discard sampling levels could be used as a compromise to balance the sampling design within a multispecies fleet. To achieve a ± 25 % CV level on total discards, it would necessary to sample 10 vessels and one fishing trip for SOTTMeg and 20 vessels and one fishing trip for SOTTHak. Therefore, we suggest a sampling design of at least 10 vessels and one fishing trip for both metiers. SOTTHak sampling would be improved by implementing specific surveys for particular species of high commercial (or ecological) interest. These specific surveys could be biennial or even triennial, and they would be focused on a particular Fishery Unit.

Regarding haul sampling, once again a compromise of balance should be made, and we must use total discard rates, as we did in the first sampling stage. For SOTTMeg, variability is halved, with 40 to 50 hauls sampled, which is an appropriate sampling effort. For SOTTHak, we believe that sampling should be around 20 to 30 hauls per fishing trip. A higher sampling level for SOTTHak could be inefficient for the observer, as it would involve sampling almost all hauls. Our suggested sampling

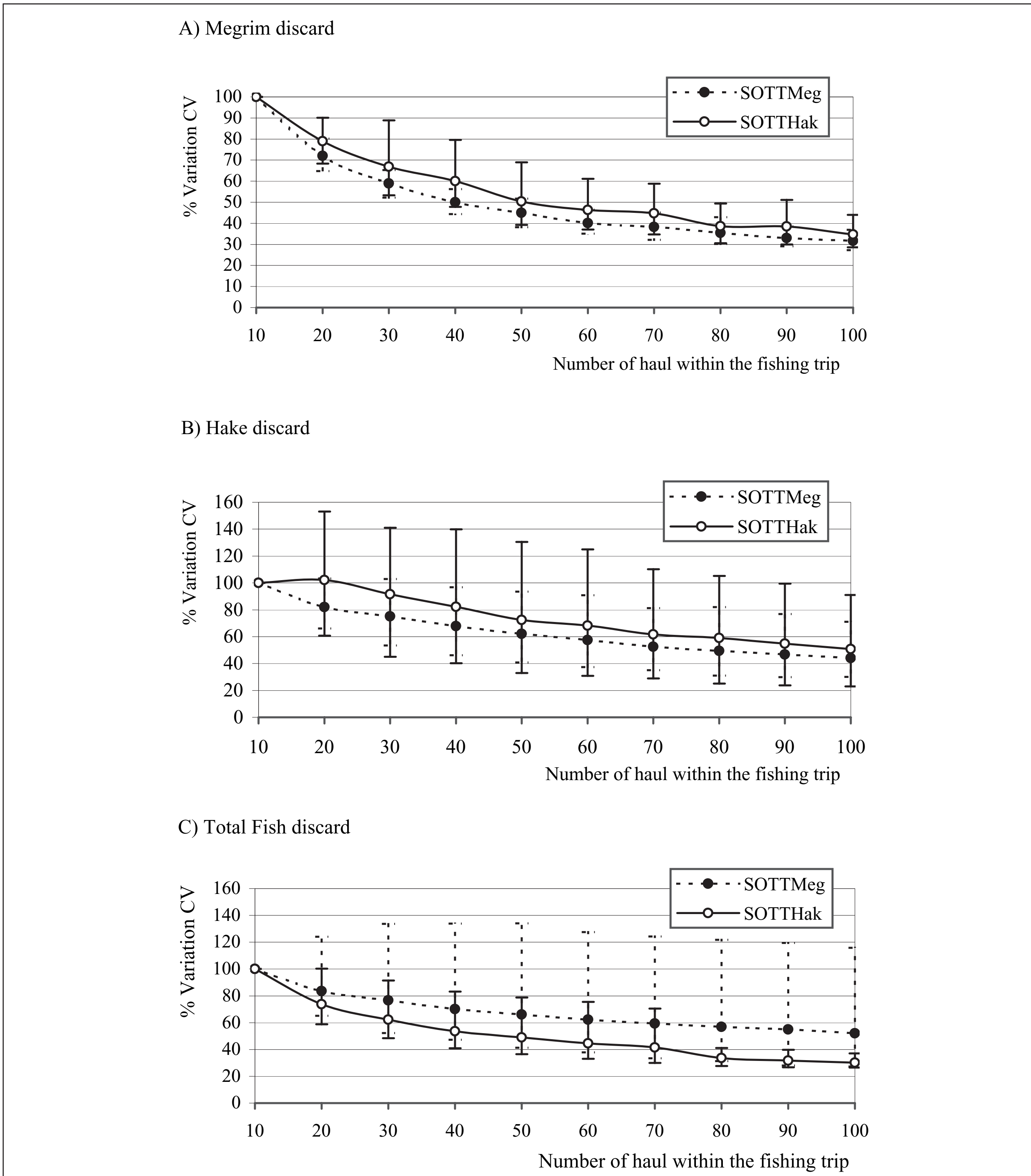


Figure 3. Bootstraps for CV simulation and CV improvement estimation across haul groups for megrim (A), hake (B) and total (C) discards numbers for both Fishery Units. X-axis shows number of hauls in the fishing trip. The dashed line and black line represent the mean 50 % for SOTTMeg and SOTTHak, respectively. Bars show confidence intervals 5 and 95 % for every Fishery Unit

Table III. Results from nonparametric Kruskal-Wallis test for SOTTMeg and SOTTHak. Analysis of discard by weight and number per hauls' groups and species. Differences are significant at $p < 0.05$ (in bold)

Species and Groups	SOTTMeg		SOTTHak	
	Discard by Weight	Discard by Number	Discard by Weight	Discard by Number
Four spot megrim				
First Group/Intermediate Group	0.194	0.100	0.264	0.264
First Group/Last Group	**0.020**	**0.015**	0.807	0.788
Intermediate Group/Last Group	0.327	0.426	0.323	0.184
Greater fork beard				
First Group/Intermediate Group	0.801	0.686	0.957	0.939
First Group/Last Group	0.521	0.908	0.053	0.142
Intermediate Group/Last Group	0.850	0.610	0.060	0.250
Hake				
First Group/Intermediate Group	**<0.001**	**<0.001**	0.133	0.130
First Group/Last Group	**<0.001**	**<0.001**	0.952	0.841
Intermediate Group/Last Group	0.374	0.796	0.174	0.174
Megrim				
First Group/Intermediate Group	0.700	0.165	0.285	0.283
First Group/Last Group	0.581	0.854	0.788	0.841
Intermediate Group/Last Group	0.374	0.153	0.469	0.443
Witch				
First Group/Intermediate Group	0.447	0.465	0.138	0.151
First Group/Last Group	**0.001**	**0.001**	0.586	0.601
Intermediate Group/Last Group	**<0.001**	**<0.001**	0.263	0.277
Norway Lobster				
First Group/Intermediate Group	0.005	**0.002**	**<0.001**	**<0.001**
First Group/Last Group	0.003	**0.002**	0.188	0.123
Intermediate Group/Last Group	0.860	0.966	**<0.001**	**0.030**

effort would make it possible to produce reasonable estimates for both total discard and total catch for most of the main target species. If estimates are needed for a particular species, we recommend carrying out specific pilot surveys.

Finally, the third and last sampling stage is allocation of sampling throughout the fishing trip. This is fascinating topic, but one not commonly dealt with in the scientific literature. Gray *et al.* (2005) reported seasonal differences for discard rates in an estuarine commercial gillnet fishery. Faere, Kirkley and Walden (2006) examined differences in discards between efficient and inefficient tows off a multi-species otter-trawl fishery from George Bank, off the US coast. However, this is a very wide-ranging topic, and no papers were found in the literature analysing possible differences in discarding pattern within the same fishing trip. Discards and total catch estimates may be biased as to whether sampling effort focuses on one particular period of the fishing trip, since the discarding pattern may change as the fishing trip progresses.

This is particularly important in long-distance fleets, which tend to make many hauls in the same fishing trip. Characteristics of fishing hauls such as haul duration, depth, and location may affect discards. However, discard behaviour may also be altered by such factors as storage space and changes in market price during the fishing trip. In this case, the number of discarded fish usually increases throughout the fishing trip's duration, with higher discard rates at the end for most of the species. This increasingly selective discarding pattern must be considered when sampling discards.

Our results show that there are significant differences in the discarding pattern for hake, four spot megrim, witch, and Norway lobster during the three periods of a fishing trip. Megrim discarding patterns do not present significant differences. This pattern is opposite to the findings of ICES (2004) with information from the same area from 1999 and 2000, where a selective pattern for larger megrims was apparent. This could be explained by the high recruitment of megrim in 2000, when many small fish were available and easily discarded at the beginning of the fishing trip (ICES, 2006). Once that high recruitment was not so present, megrim discarding showed no differences over the course of fishing trips.

Therefore, our results confirm the importance of distributing the sampling effort throughout the fishing trip, with similar sample sizes for every period, to avoid possible bias from changes in discard pattern over time. We suggest an optimal allocation sampling design of at least 10 vessels and one fishing trip for both metiers. Sampling effort will be increased for particular species of high commercial (or ecological) interest by implementing specific biennial or triennial surveys. The number of sampled hauls within a fishing trip should be about 2/3 of the total trawl hauls. This comprises between 40-50 hauls for SOTTMeg and 20-30 hauls for SOTTHak. The sampled hauls should be distributed proportionally over the three periods of the fishing trip (beginning, middle, and end), i.e. not less than 15 hauls during each of the three periods for SOTTMeg, and about 8 hauls during each of the three periods for SOTTHak.

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