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Uncertainties in sampling procedures for age composition of hake and sardine in Iberian Atlantic waters*

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SUMMARY: Estimates of the age composition of hake (demersal) and sardine (pelagic) in Iberian Atlantic waters in 1999 are analysed, paying specific attention to sampling variability. Two methods are applied, one based on an analytical approach and the other on simulation using a non-parametric bootstrap technique. The methods were used to estimate the catch at age by numbers per species for 1999, and the associated variability. They provide a useful means of analysing the precision of the estimates, of assessing data quality, and of optimising different sampling schemes. The estimates are precise for the reference ages used in assessment (CV <13% for both species). The bootstrap method is considered better owing to its non-parametric nature, despite its more complicated implementation and greater need of computational resources.

Key words: age composition, hake, sampling variance, sardine.

RESUMEN: INCERTIDUMBRES EN EL MUESTREO Y COMPOSICIÓN POR EDAD DE LA ,MERLUZA Y LA SARDINA EN AGUAS IBERO-ATLÁNTICAS. – Se analizan las estimaciones de la composición por edad y su variabilidad en el muestreo para la merluza (demersal) y sardina (pelágica) en aguas Ibero-Atlánticas de 1999. Se han aplicado dos métodos: uno basado en un desarrollo analítico y el otro basado en una técnica por simulación utilizando un bootstrap no-paramétrico. Estos métodos se utilizaron para estimar la captura por clase de edad en número por especie para el año 1999 y la variabilidad asociada. Ambos métodos son herramientas útiles: para analizar la precisión de las estimas, evaluar la calidad de los datos, y para optimizar los diferentes esquemas de muestreo. Las estimas obtenidas son precisas para las edades de referencia empleadas en la evaluación (CV <13% para ambas especies). El método bootstrap se considera mejor debido a que es una aproximación no-paramétrica, aunque sea más complicada su implementación y tenga una mayor demanda de computación.

Palabras clave: composición por edades, merluza, sardina, variabilidad de muestreo.

INTRODUCTION

Catch numbers at age (N_a) are the basis of stock assessment models such as XSA (Shepherd, 1999) and ICA (Patterson and Melvin, 1996), which are respectively used in Europe to assess hake (*Merluccius merluccius*) and sardine (*Sardina pilchardus*) stocks. Unbiased, low estimates of variance of estimates are crucial in order to guarantee a reliable cohort analysis and subsequent projection for management advice. Several methods have been used to analyse the sampling error inherent in N_a estimation, generally measuring it on the basis of coefficients of variation (CV). A CV is non-dimensional and allows comparison of the dispersion of variables with different magnitudes. Numbers at age are such a variable, because of the differences by country in terms of data provision by age and by species.

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National Sampling Programme (NSP) variability has been addressed by implementing several projects funded by the European Commission (Pestana *et al.*, 1998; EMAS, 2000; FIEFA, 2000; SAMFISH, 2002). The variance of each country's estimates contributing to the international catch-at-age information allow an NSP's problems to be identified and addressed with a view to their improvement. CV analysis is therefore a powerful means of evaluating and improving sampling designs. However, analysis of CVs fails to take into account errors in official catch statistics (through misreporting or discarding) or basic age determination.

Scientists are acutely aware of the importance of accurate estimates of fish catch and age in their stock assessments, inaccurate material from either source undermining confidence in the predictions that underpin management advice. CVs measure internal error (the variability between samples), and a full NSP investigation needs also to include an analysis of sampling coverage in space and time and by gear, to ensure adequate coverage of all relevant strata and gear types. A low CV does not necessarily mean that the NSP yields accurate data, but rather that the variability between samples is low. In the case of southern European hake and Iberian sardine, sampling coverage was analysed during the SAMFISH project (SAMFISH, 2002), which revealed that all major strata were sampled. The methods used most commonly to estimate the CVs for number at age are the analytical method described by Flatman (1990), and a non-parametric simulation method that uses bootstrapping (Efron and Tibshirani, 1993; EMAS, 2000; FIEFA, 2000; SAMFISH, 2002). The analytical method has been used, *inter alia*, to evaluate sampling precision in terms of numbers at age (Flatman, 1990), to obtain an optimum sampling level for cod otoliths (Baird, 1983), to estimate cod catch at age and its variance (Gavaris and Gavaris, 1983; Smith and Maguire, 1983), and to analyse the effectiveness of commercial sampling of sardine in Portuguese waters (Jardim, 1999). The bootstrap method has been applied to estimate catch at age and its variance for several stocks (Pelletier and Gros, 1991; ICES, 2000; EMAS, 2000; FIEFA, 2000; SAMFISH, 2002).

This work investigates the reliability of catch-at-age estimates of southern European hake and Iberian sardine in 1999 for ICES (International Council for the Exploration of the Sea) statistical areas VIIIc and IXa.

TABLE 1. – Types and sources of information on hake and sardine (SRS: Stratified random sampling).

Species	Information	National Sampling Programme Spain	Portugal	Survey Spain
Sardine	Age	SRS	SRS	
	Length	SRS	SRS	
Hake	Age	SRS		SRS
	Length	SRS	SRS	

MATERIAL AND METHODS

The length and age data used were collected by Spain and Portugal in their National Sampling Programmes (FIEFA, 2000). The Portuguese NSP is conducted by the Instituto de Investigação das Pescas e do Mar (IPIMAR) and the Spanish NSP by the Instituto Español de Oceanografía (IEO) and the Instituto Tecnólogico Pesquero y Alimentario (AZTI). Length information is collected following a stratified random sampling scheme (SRS) by gear, zone and quarter, and the sampling unit is the vessel. Age sampling is also through an SRS, applied by zone and length, and the sampling unit is the individual fish. Table 1 summarises the type and source of information used. The basic information collected is:

– length: number of individuals per length l, vessel v and strata s, n_{lvs}, i.e. the length composition;

– age: number of individuals per length l and age a, n_{la}, i.e. the age-length key (ALK); with $l = 1, \ldots, L$; $v = 1, \ldots, V$; $s = 1, \ldots, S$; and $a = 1, \ldots, A$.

For this analysis, 1999 data were selected on the basis of data availability and previous work (see Table 2), and the methods were applied to hake and sardine in Iberian waters. In the case of hake the analysis was for the whole stock and the fleet-disaggregated stock (trawl and artisanal). For sardine the CVs were computed for the entire stock and for the stock separated by zones (VIIIc east, VIIIc west, IXa north, IXa north–centre, IXa south–centre, IXa south).

Analytical method

This method is described in detail by Flatman (1990), but for reasons of completeness, a general overview is given here.

The numbers-at-age estimator is

$$\hat{N}_a = \sum_{l=1}^{L} \hat{P}_{la} \times \hat{N}_l \qquad a = 1, \ldots, A \qquad (1)$$

TABLE 2. – Sampling of hake and sardine during 1999.

Species	National Sampling Programme	Level of sampling Boats (n)	Measurements of length (n)	Ages determined (n)	Landings (t)
Hake	Spain	562	37 084	1 494	4 247
	Portugal	1 259	182 789	0	2 918
	Both countries	1 821	219 873	1 494	7 165
Sardine	Spain	336	36 422	2 532	22 271
	Portugal	412	46 558	4 102	71 820
	Both countries	748	82 980	6 634	94 091

where $\hat{N}_l$ is the estimator of the number of individual fish per length, based on the stratified estimator for the population (Thompson, 1992) applied to n_{lvs}, with variance $v\hat{a}r(\hat{N}_l)$, and $\hat{P}_{la}$ is the estimator of the percentage of individuals of age a and length l, based on the proportion estimator (Cochran, 1960) applied to n_{la}, with variance $v\hat{a}r(\hat{P}_{la})$.

Mood *et al.* (1974) show that the variance of the product of two random variables $var[XY] = var[X]Y^2 + var[Y]X^2 + var[X]var[Y]$, but for this analysis we considered the last term to be negligible owing to the relatively small value of $v\hat{a}r(\hat{N}_l)$ in comparison with $\hat{N}^2$. The variance of $\hat{N}_a$ is obtained from

$$\text{vâr}(\hat{N}_a) = \sum_{l=1}^{L} \text{vâr}(\hat{N}_l) \times \hat{P}_{la}^2 + \sum_{l=1}^{L} \text{vâr}(\hat{P}_{la}) \times \hat{N}_l^2 \quad (2)$$

The CV at age (CV_a) was obtained from

$$CV_a = \frac{\sqrt{\text{vâr}(\hat{N}_a)}}{\hat{N}_a} \quad (3)$$

In the case of sardine, the overall CV at age was obtained by combining data by zone ($\hat{N}_{az} z = 1,...,6$), i.e. CV_{az},, from

$$CV_{az} = \frac{\sqrt{\sum_{z=1}^{6} \text{vâr}(\hat{N}_{az})}}{\sum_{z=1}^{6} \hat{N}_{az}} \quad (4)$$

Bootstrap method

To produce bootstrap replicates of the catch numbers at age, N^b_a:

- the n_{lvs} are sampled with replacement within each stratum, creating a single bootstrap replicate of the length composition, N^b_l;

- this procedure is repeated m times;

- the n_{la} are sampled with replacement, creating a bootstrap replicate of the ALK, P^b_{la};

- this procedure is repeated m times;

- N^b_a is computed by combining each length composition with each ALK, producing $m.m = m^2$ bootstrap replicates.

The bootstrap estimator for N_a is

$$N_a^B = \frac{\sum_{b=1}^{m^2} N_a^b}{m^2} \quad (5)$$

$$\text{var}(N_a^B) = \frac{\sum_{b=1}^{m^2} [N_a^b - N_a^B]^2}{m^2} \quad (6)$$

$$CV_a^B = \frac{\sqrt{\text{var}(N_a^B)}}{N_a^B} \quad (7)$$

The procedure used to compute N^B_a is distinct from the "common" bootstrap, which combines the m^{th} replicates of N^b_l and P^b_{la} to compute N^b_a. Our concern with that procedure is that the Portuguese and Spanish NSPs dictate independent sampling schemes for length and age, so it is not possible to define which length composition replicate combines with which ALK replicate. To mimic the sampling procedures, we used a full combination of length composition replicates (N^b_l) and ALK replicates (P^b_{la}) to obtain m^2 bootstrap replicates of N_a, the N^b_a. The main drawback of this procedure is the possible introduction of covariance, because each replicate would be used m times.

To investigate the validity of the method, a simulation study was carried out. The complete results are not presented, but are available. The most important conclusions are:

- the variance obtained by the "common" procedure is dependent on the combination used (Fig. 1);

- the variance obtained by the full combination procedure is unbiased;

- the covariance introduced by use of the same replicates several times was trivial (Fig. 1).

Another important consideration for all bootstrap procedures is the number of replicates needed. Data from the artisanal fleet on hake aged 2 were used in an exploratory analysis to investigate this parameter (Fig. 2). The variance seems to stabilise at around 400 replicates for both methods, but the "common" bootstrap procedure showed two outliers at 550 and 800 replicates. Conversely, the full combination of

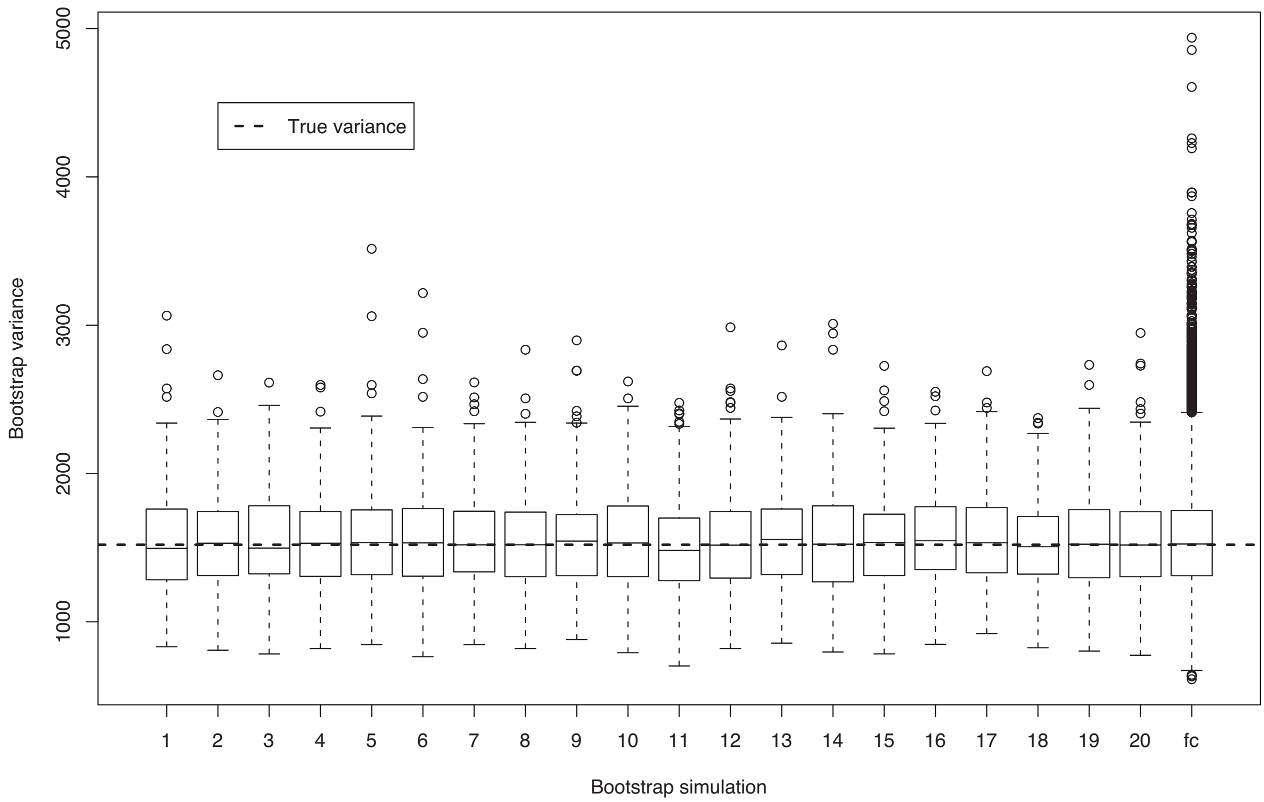

FIG. 1. – Results of 20 common bootstraps and a full combination of bootstrap simulations.

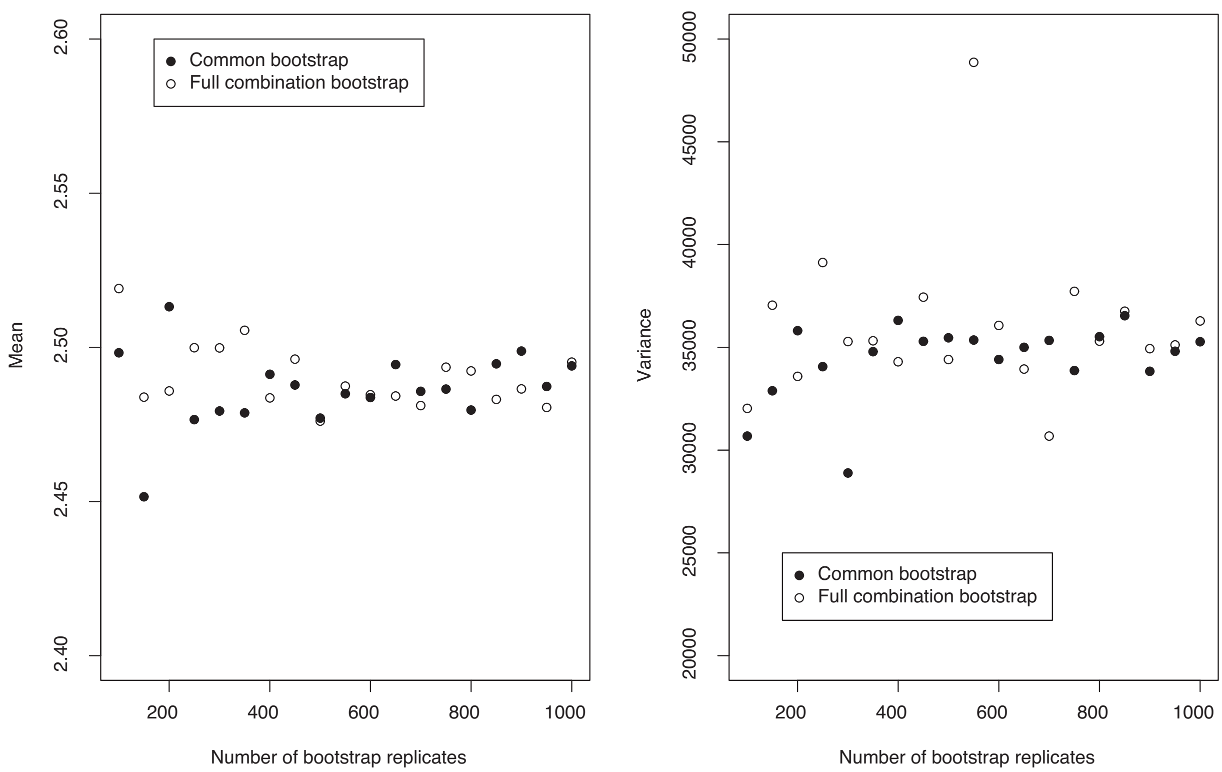

FIG. 2. – Analysis of the number of replicate bootstraps needed to stabilise the mean and variance of hake aged 2 caught by the artisanal fleet during 1999.

TABLE 3. – Numbers at age (N_a) and CVs of the two methods applied, bootstrap and analytical. Reference ages 2-5 emboldened.

Species	Method	Para-meter	Value at age 0	1	2	3	4	5	6	7	8	9	10
Hake	Bootstrap	$N_a(10^6)$	0	2.55	**8.10**	**12.48**	**2.83**	**0.73**	0.35	0.17	0.04	0.02	0
		CV	0.84	0.10	**0.07**	**0.04**	**0.07**	**0.10**	0.15	0.21	0.3	0.29	0.39
	Analytical	$N_a(10^6)$	0	2.6	**10.6**	**10.3**	**3.0**	**1.0**	0.4	0.2	0.04	0.02	0/02
		CV	6.87	0.14	**0.06**	**0.06**	**0.13**	**0.13**	0.16	0.23	0.44	0.70	3.52
Sardine	Bootstrap	$N_a(10^6)$	289.3	531.1	**472.5**	**328.2**	**248.7**	**112.6**	58.0	16.0	2.2	0.3	0.2
		CV	0.13	0.05	**0.03**	**0.03**	**0.04**	**0.05**	0.06	0.1	0.23	0.58	0.61
	Analytical	$N_a(10^6)$	182.5	308.9	**391.0**	**350.9**	**266.8**	**110.2**	57.7	16.6	2.4	0.2	0.2
		CV	0.13	0.05	**0.04**	**0.04**	**0.04**	**0.07**	0.10	0.15	0.43	0.62	0.70

replicates revealed a tendency to underestimate variance when the number of replicates was small.

In this analysis, 400 N^b_l and 400 P^b_{la} were simulated, a total of 160,000 N^b_a. The analyses were performed in the R environment (Ihaka and Gentleman, 1996), using code developed personally.

RESULTS

The results of the two methods applied to both species to estimate the total numbers at age and their dispersion are shown in Table 3, and in Figure 3 for hake and Figure 4 for sardine. Both methods were also used for hake to estimate the numbers at age by fleet, and the results of that analysis are presented in Figures 5 (artisanal) and 6 (trawl). The results of applying the bootstrap method to sardine by zone are shown in Figure 7. In general, CVs are <25%, an acceptable level. However, at ages 0, 8, 9 and 10 for hake, and at ages 8 and 10 for sardine, the level of CV is >25%. Nevertheless, for the reference ages of both species (ICES, 2001a, b), the CVs are <13%, indicating that the error attributable to sampling is low. The two methods give similar values of CV at age, but in the case of hake there are some differences at ages 0 and 10, where higher CVs were estimated by the analytical method.

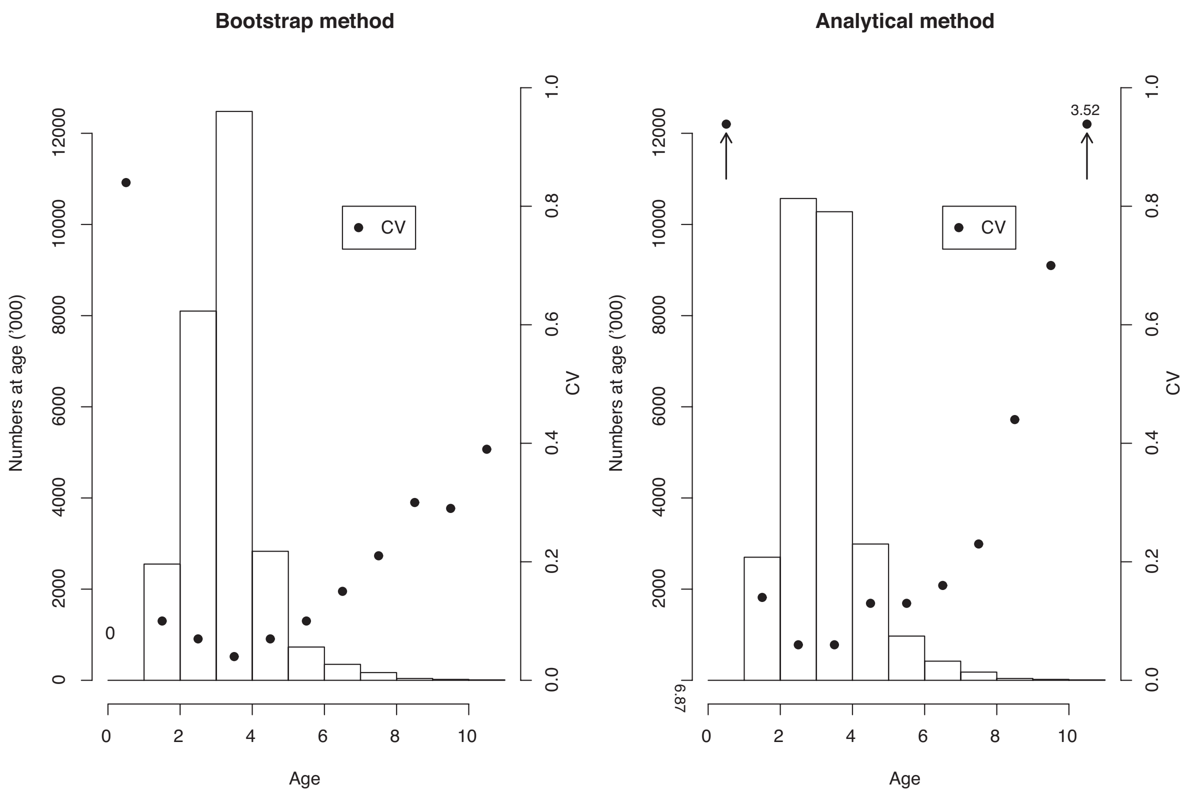

FIG. 3. – Hake catch (numbers) at age and CVs estimated by the bootstrap and analytical methods for 1999.

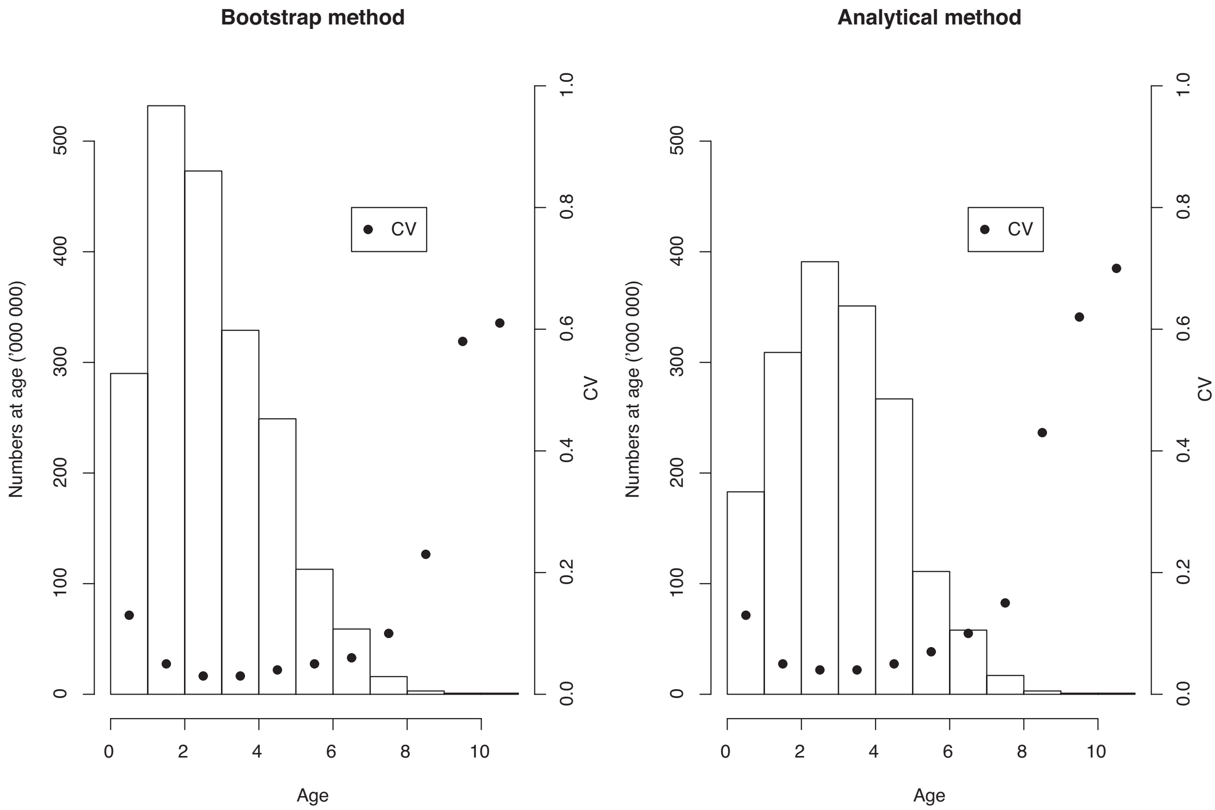

FIG. 4. – Sardine catch (numbers) at age and CVs estimated by the bootstrap and analytical methods for 1999.

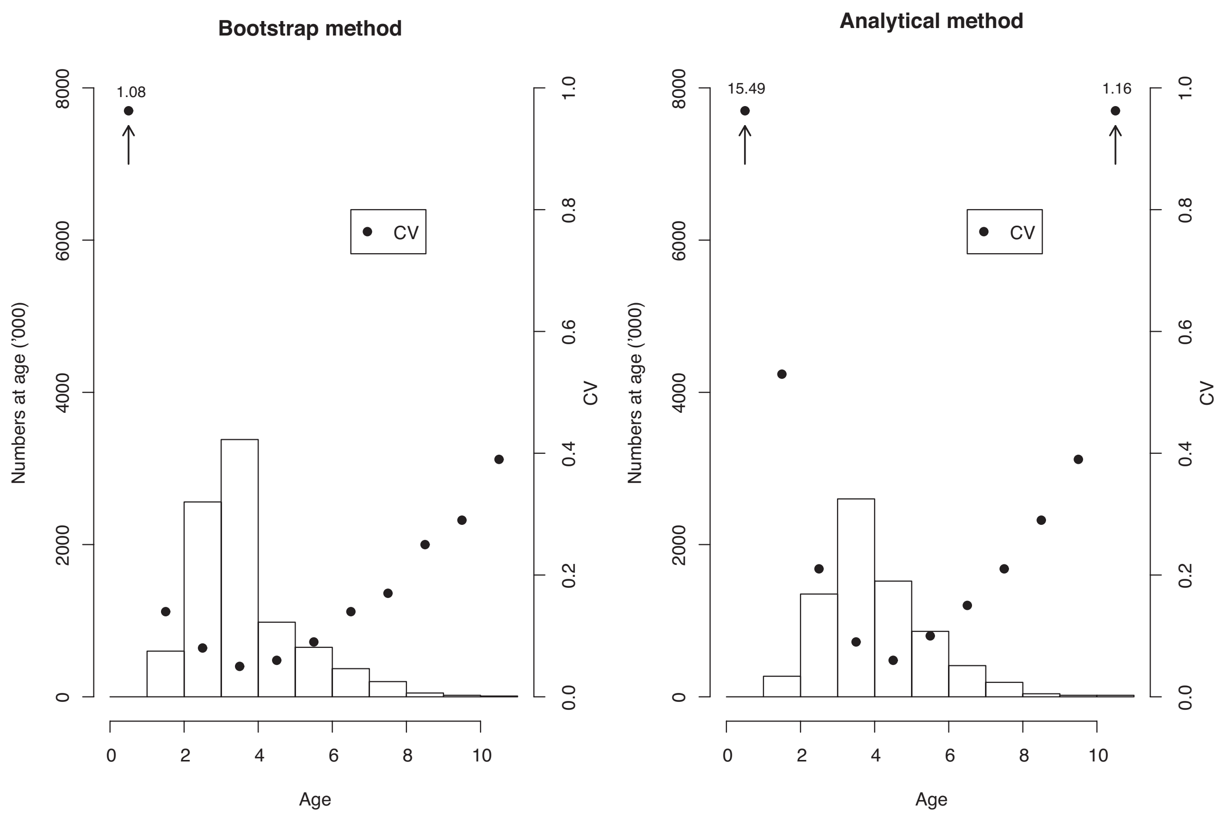

FIG. 5. – Artisanal fleet hake catch (numbers) at age and CVs estimated by the bootstrap and analytical methods for 1999.

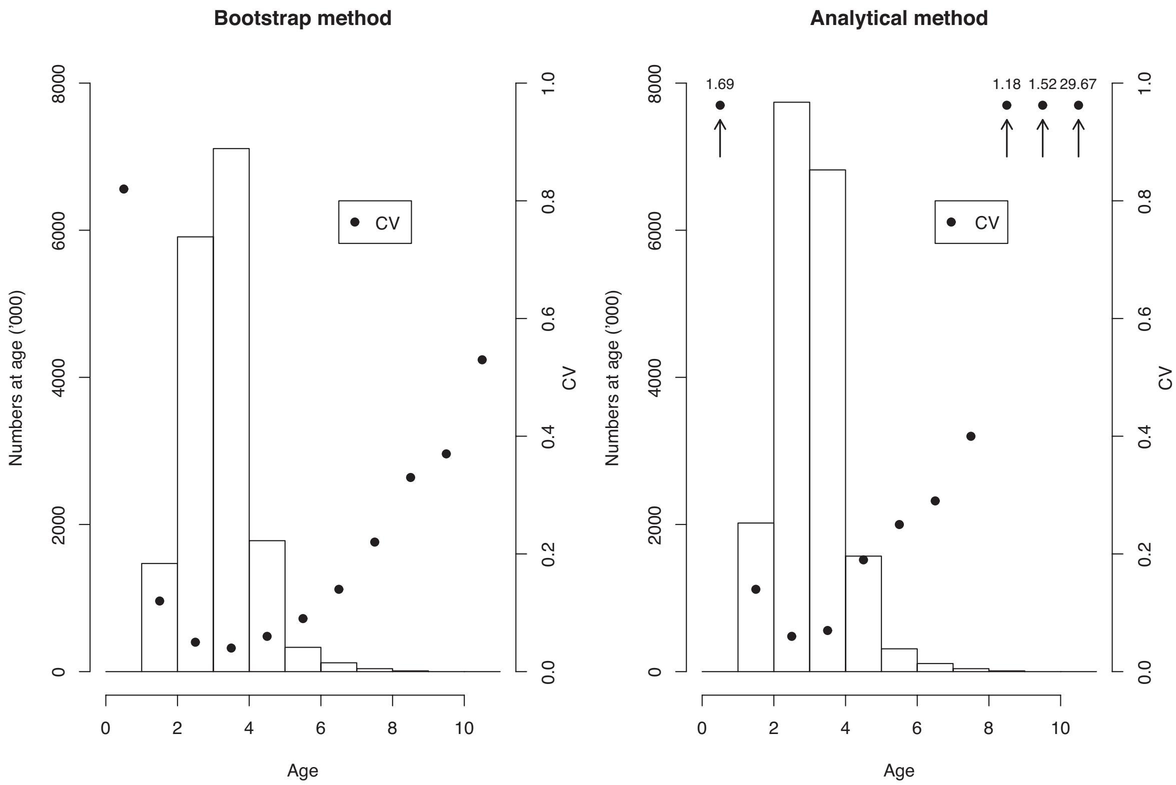

FIG. 6. – Trawled hake catch (numbers) at age and CVs estimated by the bootstrap and analytical methods for 1999.

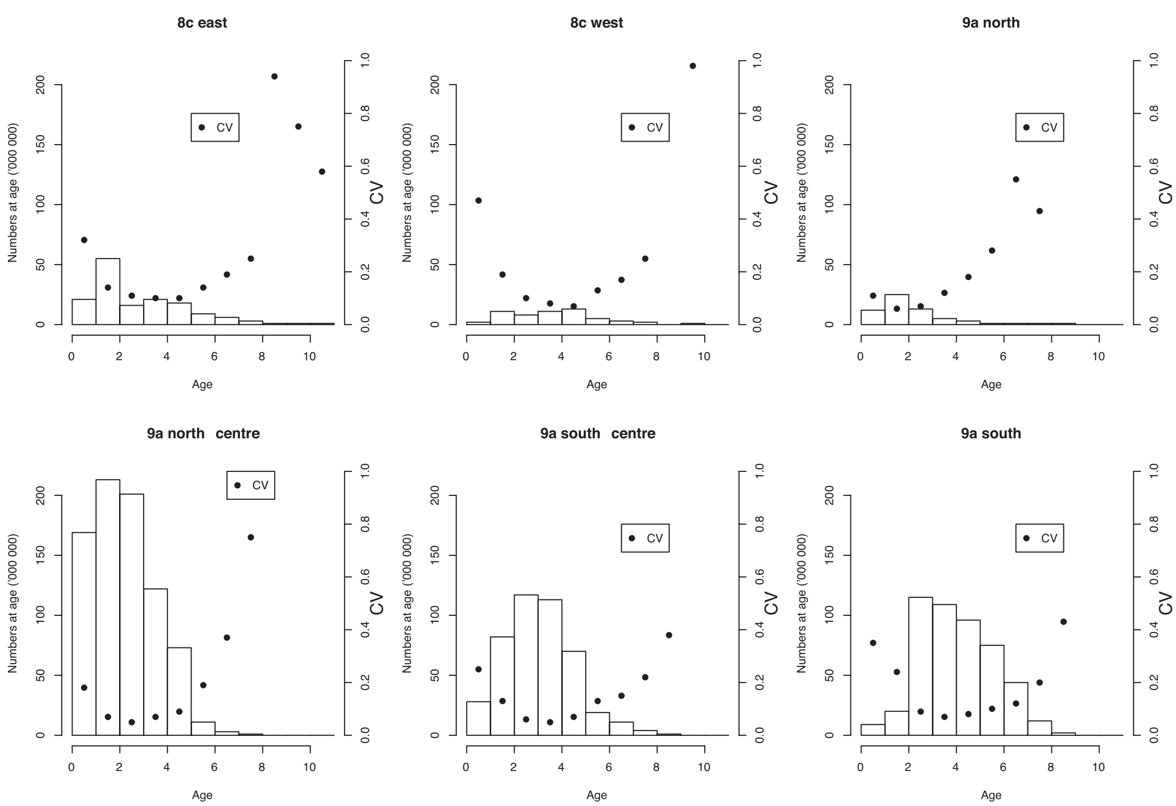

FIG. 7. – Sardine by zone catch (numbers) at age and CVs estimated by the bootstrap method for 1999.

In terms of the numbers at age and CVs for hake by fleet (Figs 5, 6), the bootstrap method applied to the artisanal fleet gave higher estimates at ages 2 and 3, and lower at other ages. For that fleet, bootstrap CV estimates are <20% for ages 1–7, whereas the analytical model CV estimates are >20% for ages 1, 2, 7, 8 and 9. The trawl estimates reveal some inconsistencies between methods, in particular in terms of CVs for ages greater than 4 years. For ages 4, 5, 6 and 7, the CVs estimated by the analytical method were 19, 25, 29 and 40% respectively, whereas those of the bootstrap method were 6, 8, 13 and 21%.

Estimates of sardine numbers at age and CVs by zone (ICES, 2001a; Fig. 7) reveal low CVs in all areas for ages up to 5 years. However, as would be expected, the CVs were higher in zones and for ages where the numbers at age were fewer.

DISCUSSION

The analyses presented here are conditional on good sampling coverage of the main areas and fleets that target hake and sardine in Iberian waters. This would mean a lack of noticeable bias in the estimates of numbers at age. However, the analyses do not take age determination errors—probably significant for hake—or errors in total catch caused by misreporting, discarding, etc. into consideration. Further research is needed to develop a procedure and statistics that include such errors along with sampling variability. Notwithstanding the limitation just referred to, the results do seem to corroborate the belief that the NSPs provide good estimates of numbers at age for the most important age classes in the catches (2-5 for both species).

The high CVs obtained for some ages (8-10 for both species) are the consequence of the scarcity of hake or sardine of those ages in the populations. For assessment purposes, fish of those ages are grouped as a plus-group, but this situation would have to change if such older fish assumed greater importance in terms of their contribution to the spawning stock biomass (SSB) of either species. In the case of hake, the contribution by weight of the plus-group to the SSB in 2002 was just 9.5%, the reference ages of 2-5 contributing 65.5% of the SSB (ICES, 2004).

Given the minimum landing size of hake (27 cm), 0-group hake are not landed by the commercial fleet. Therefore, the catch in numbers at age of that age class are and will probably always be poorly estimated, making discards a significant source of error. As stated earlier, this source of error is not considered here.

The analytical method is easier to implement and requires less computational resources, but it makes some assumptions about the estimators $\hat{N}_l$ and $\hat{P}_{la}$ that are open to question. In contrast, the bootstrap method makes no assumptions about the statistical distribution of the estimators, but is more difficult to implement and requires greater computational power. However, to combine data at an international level, the non-parametric bootstrap procedure would be the best choice because it by-passes the problem of developing analytical statistics in complex situations, such as in estimating the numbers at age and the variance, by combining data collected under different sampling regimes at national levels.

In conclusion, comparison of the estimates from both methods reveals some similarities but also some differences in hake CVs at ages 0, 8, 9 and 10 (Table 3). Such inconsistencies can result from the scarceness of fish of those ages in the data and therefore in the estimates, opening any results for those ages to criticism. The analytical method tends to overestimate and the bootstrap method to underestimate variance, so analysis of each country's NSP by just one of these methods could lead to erroneous conclusions on over- or undersampling.

Analysis of the CVs permits comparison between strata over years and among different sampling schemes. In our opinion, such characteristics make the analysis presented here a useful tool for monitoring the sampling error inherent in estimates of numbers at age of hake and sardine, hopefully leading to enhanced NSPs and ultimately to improved stock assessment. If such analyses were to be implemented routinely, decision-makers and managers could be presented with advice that stipulates more clearly the uncertainty or even the possible error based on data quality that underpins each annual assessment.

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