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A REVIEW OF TWO METHODS FOR BIOMASS ASSESSMENT OF LONG TAIL HAKE FROM THE SOUTH WESTERN ATLANTIC (45°- 55° S) BASED ON SWEPT AREA DATA [1]

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SUMMARY: The distribution of long tail hake *(Macruronus magellanicus)* density (t/nm²) as estimated from stratified, swept area surveys are reviewed. The surveys were carried out on the SW Atlantic (45°- 55° S) during the years 1992 - 1995. The performance of the arithmetic mean and the delta-based estimator of population mean density were compared by a series of simulations. When the sample size was set as small as that currently allocated during the surveys, no estimator was accurate enough to evaluate mean density by stratum. The results corresponding to sample sizes of over 30-40 tows indicated a better performance of the delta- based estimators. Accordingly, a delta-based approach is recommended to assess long tail hake biomass in the future, based on an allocation of tows proportional to strata area.

Key Words: Fish biomass estimation; Trawl surveys; Delta distribution; *Macruronus magellanicus.*

RESUMEN: REVISION DE DOS METODOS PARA LA EVALUACION DE BIOMASA DE LA MERLUZA DE COLA DEL ATLANTICO SUDOCCIDENTAL (45° - 55°S) BASADAS EN DATOS DE AREA BARRIDA. Se revisan las distribuciones de datos de densidad (t/mn²) de merluza de cola *(Macruronus magellanicus)* obtenidas en campañas donde se aplicó el método de área barrida y un diseño aleatorio prestratificado. Estas campañas se llevaron a cabo en el Atlántico Sudoccidental (45°- 55° S) durante los años de 1992 a 1995. La calidad de la media aritmética de los valores de densidad se comparó con aquella de un estimador de la densidad media basado en la distribución delta, por medio de una serie de simulaciones. Cuando el tamaño muestral establecido por estrato fue tan pequeño como el que se aplicó en las campañas, ninguno de los estimadores fue suficientemente confiable para evaluar la densidad media. Los resultados correspondientes a tamaños muestrales mayores de 30-40 lances indicaron una mejor calidad del estimador basado en la distribución delta. En consecuencia, un enfoque basado en un modelo, el delta, se recomienda para evaluar la biomasa de merluza de cola en el futuro. También se sugiere usar solamente el área del estrato para distribuir el número total de lances posibles.

Palabras clave: Estimación de biomasa íctica; Campañas de investigación; Distribución Delta; *Macruronus magellanicus.*

INTRODUCTION

Accurate estimates of abundance, either relative or absolute, are required to provide scientific advice on fishery resources management. Research trawl surveys are often used as sources of information on stock size, as well as to estimate other population parameters.

The statistical techniques involved in biomass assessment are often based on the assumption that sample size is large enough so that the central limit effect is valid, i.e., the distribution of the estimators is approximately normal. Nevertheless, survey indices of abundance, typically catch- per- tow or catch per square nautical mile, even from relatively small marine areas, usually exhibit some kind of skewed distribution. That skewness is a result of a trend for the fish to over-aggregate in a way that depends on the species, season, area, physiological status, etc. For sample sizes currently used for marine surveys, the sample statistics for these skewed distributions can be far from normally distributed. Positive (greater than zero) density values included in samples from those populations often conform to a log-normal distribution, and some proportion of zero densities may occur. Therefore, it is difficult to estimate stock size by using conventional methods (McConnaughey & Conquest, 1993) and statistical techniques based on the so-called delta distribution (Aitchison & Brown, 1957), or delta-lognormal distribution (Stefánsson, 1996) have been suggested (Pennington, 1983 and 1986; Smith, 1988; Warren, 1990; Caverivière, 1993).

Conventional methods have been, and still are used to evaluate the biomass of many groundfish species from the Argentine Sea. This paper aims to review the techniques used to assess the abundance of one of those species, the long tail hake *(Macruronus magellanicus* Lönnberg, 1907) in order to produce the most reliable estimation.

Long tail hake is a gadifom widely distributed within the SW Atlantic from 35°S Southwards. The main concentrations occur south of 45°S, not deeper than 200 m. It is one of the most abundant finfish resources in the region. Annual yields reached a maximum of about 145,000 tons. during 1988, mainly because of fishing by vessels from the former Soviet Union operating under joint-ventures with Argentine enterprises. After that, between 1991 and 1995, annual yields averaged about 33,000 tons.

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Since 1992, the National Institute for Fisheries Research and Development (INIDEP) of Argentina has been carrying out a systematic series of trawl surveys for biomass assessment of groundfish inhabiting South of 45° S. A stratified random sampling design (Cochran, 1977) has been adopted for every cruise, and the swept area method (Alverson & Pereira, 1969) has been used. The area under study is limited by the depth lines of 50 and 400 m and the latitudes of 45° and 55°S. It is a very large region (more than 100,000 nm²), and no more than 150 trawl hauls can be performed during each survey, mainly because of vessel availability and weather or bottom adverse conditions.

As a result of both the low number of hauls and the high catch variability observed within each stratum, the lower limit of the normal confidence interval for the mean biomass by stratum has several times had a negative value, which obviously have no biological sense. There were reasons to suspect that the normality assumption was not met, so the survey data were re- examined in order to test the observed density distributions by strata. After that, a series of simulations were conducted to compare the performance of the arithmetic mean estimator against that of an unbiased estimate of a population mean corresponding to a delta distribution. The objective of performing these simulations was to identify both the best estimator of the mean density and the best sampling design for the species.

2. Data and methods

The basic data came from annual biomass assessment surveys carried out by the R/V "Dr. E.L.Holmberg" and/or the R/V "Capitán Oca Balda" during the years 1992 to 1995. Both vessels are stern trawlers and used ENGEL bottom nets, with 103 mm mesh-sized codends and a 20 mm mesh-sized cover.

Even though the original survey design consisted of a larger number of strata, in this paper the data were grouped according to the stratification used during the 1995 cruise, while discarding those strata where long tail hake abundance was found to be negligible (Fig. 1). As a whole, the resulting 9 strata represent a total area of 99,597 nm². There was no long tail hake cruise in 1996, and the following ones were designed according to the results commented in the present paper. The species densities, both by strata and for the whole area, were estimated according to two different statistical techniques:

(a) by using the arithmetic mean of the densities (including density equal zero), i.e.:

$$\bar{d}=\frac{1}{n}\sum_{i=1}^{n} d_i \qquad (1)$$

and:

(b) by using an unbiased estimate of the population mean under the assumption of a delta distribution (what we called hereafter "delta estimator"). The delta distribution consists of a log-normal distribution for the non-zero values of a population also including a probability d for the zero value. That statistic and its corresponding variance were obtained by the following equations (Aitchison, 1955; Aitchison & Brown, 1957; Pennington, 1983):

$$c = \frac{m}{n}\ e^{\bar{y}}\ G_m\left(\frac{S^2}{2}\right) \qquad (2)$$

where n is the size of a sample including m nonzero values (m>1) of log transformed numbers or weight caught (y = ln (d), d>0) have a mean $\bar{y}$ and variance S^2, and:

$$G_m(t)=1+(m-1)\frac{t}{m}+\sum_{j=2}^{\infty}\frac{(m-1)^{(2j-1)}}{m^j(m+1)(m+3)...(m+2j-3)}\frac{t^j}{j!} \qquad (3)$$

$$Var_{est}(c)=\frac{m}{n}e^{(2\bar{y})}\left[\frac{m}{n}G_m^{\ 2}\left(\frac{S^2}{2}\right)-\frac{m-1}{n-1}G_m\left(\frac{m-2}{m-1}S^2\right)\right] \qquad (4)$$

Asymptotic confidence intervals on the population mean were found as the roots of the following function (De la Mare, 1994), which may be derived by using the likelihood ratio (Kendall & Stuart, 1967):

$$CI(c)=\left[\ln L(\bar{d};p,\lambda,k^2)\,\middle|\,p=\frac{m}{n},\lambda=\frac{1}{m}\sum_{i=1}^{m}\ln d_i,k^2=\frac{1}{m}\sum_{i=1}^{m}(\ln d_i-\lambda)^2\right]-$$

$$\sup[\ln L(d;p,\lambda,k^2)|0<p\le 1,\lambda=\ln\left(\frac{c}{pG_m(\frac{1}{2}k^2)}\right)0<k^2<\infty]-\frac{1}{2}\chi^2_{(1,\alpha)} \qquad (5)$$

where the log-likelihood of a vector of observations d_1, ..., d_n from a delta distribution is given by:

$$\ln L(\bar{d};p,\lambda,k^2) = (N-m)\ln(1-p) + m\ln p - \frac{m}{2}\ln k^2 - \frac{1}{2k^2}\sum_{i=1}^{m}(\ln d_i - \lambda)^2 - \sum_{i=1}^{m}\ln d_i - \frac{m}{2}\ln 2\pi \quad (6)$$

and χ^2 (1, α) is the critical value of the chi-square distribution with one degree of freedom at the alpha probability level.

In the present paper, equations (2) and (4) have been solved by an algorithm which includes the Powell's optimization routine (Powell, 1964) for approximating the supremum of equation (5). It also includes a secant algorithm for finding the equation's roots.

In order to test the normal distribution of the logarithms of the observed long tail hake densities (t/nm²), the data from the four research surveys were pooled by stratum, and a Kolmogorov-Smirnov test was conducted.

By assuming a delta distribution, the mean and variance of densities for each stratum, as well as for the whole area, were calculated as follows (Pennington, 1983; Brownlee, 1965):

$$E(d) = p\, e^{\left[E(y)+S^2(y)/2\right]} \quad (7)$$

$$S^2(d) = p(1-p)\, e^{\left[2E(y)+S^2(y)\right]} + p\, e^{\left[2E(y)+S^2(y)\right]} e^{\left[S^2(y)-1\right]} \quad (8)$$

Taking these "population" values as starting points, some simulation exercises were conducted to compare the performance of the two estimators, arithmetic (equation 1) and delta (equation 2). Sets of 150 thousand samples of a given size were generated. Increasing sizes were chosen to simulate 10, 15, 20, 30, 50 and 100 trawl hauls by stratum (10, 50, 90, 125, 175, 250, 400 and 500 for the whole area). From the density values randomly extracted in each run mean fish density was estimated, as well as three indices defined to evaluate the quality of the estimators, i.e.:

A.- Relative efficiency of the estimators (RE), which was calculated as:

$$RE = \frac{\sum(Sc/N) - \sum(S\bar{d}/N)}{\sum(S\bar{d}/N)} \cdot 100 \quad (9)$$

where

N: number of samples by run;

$$Sc = \sqrt{Var_{est}(c)} \quad \text{; and}$$

$$S\bar{d} = \sqrt{\sum_{i=1}^{N}(d_i - \bar{d})^2 / (N-1)} \,/\, \sqrt{N}$$

The RE is an index of the relative precision of both estimates, as the efficiency of a given estimate is usually evaluated by the magnitude of its variance. In the present paper, the comparison was based upon the **estimated** variances of both estimates of the population mean, because those are the statistics that one has to deal with in practice. On the other hand, the **population** values, i.e., Var (c) and Var *($\bar{d}$)*, where always Var (c) and Var *($\bar{d}$)*, were used in the comparisons presented by Smith (1988). Our relative measure of the estimated standard deviation of both estimates (as an average of every runs) mean, for instance, that whenever the value of RE was greater than zero, it would indicate a larger estimated standard deviation of the delta-based estimator in the average. This would be a unreal result indicating a bad performance in estimating the variances under a given, too small sample size.

B.- Risk $R_{0.25}$, i.e., probability of evaluating the mean with a percentage of error (or inexactitude) equal to or greater than 25 % of the population mean. Being both unbiased estimates of the mean, this is a measure of the uncertainty about the estimations for a given sample size.

$$R_{0.25} = \text{Prob}\left(\frac{|\bar{d}_{est} - \mu|}{\mu} \geq 0.25\right) \quad (10)$$

where μ : population mean density; and

$\bar{d}_{est}$ is a single estimation of that mean density ($\bar{d}$ or c).

C.- Percentage of error in estimating mean density (PED) with a risk of 0.05. It may be seen as an indicator of the length of the confidence interval of the mean (at α a= 0.05).

$$\text{Prob}\left(\frac{|\bar{d}_{est} - \mu|}{\mu} \geq \text{PED}\right) = 0.05 \quad (11)$$

3. Results

When pooled by strata, the frequency distributions of long tail hake densities corresponding to the surveys from 1992 to 1995 clearly depart from normal distributions (Fig. 2). For every stratum, positive density values showed no significant differences from the log-normal distribution when tested by the Kolmogorov - Smirnov (K-S) test (Table 1). Therefore, it can be accepted that delta distributions fit the data well (zero and positive densities) within each stratum. The proportion of zeros was very variable among strata (0 - 33 %), and they represented about 14 % of the hauls trawled within the whole area. Table 1 also shows that the K-S test detected significant differences in fitting of the log-normal distribution to the whole area data. However, this result might be due to the original random sampling design, which allocated a higher sampling effort within the strata having the largest mean densities (and largest variances). Nevertheless, it was evident that the fit of the delta distribution to the data was clearly better than that of the normal distribution.

The long tail hake biomass assessments by survey were rather different, depending on the estimator (arithmetic mean or delta estimator) used to evaluate mean densities (Table 2). There was also a great inter-annual variation in the mean estimate and dispersion for a given stratum (some examples: stratum 7; strata 3 and 6 in year 1995). Generally speaking, the biomass estimations both by strata and for the whole area were higher when based on the delta estimator. Those differences widely varied among strata and surveys, reaching a maximum of 142% (stratum 7, year 1992). They ranged between 20-40% for the whole area.

The most relevant results from the simulation runs were related to the following indicators:

A.- Relative efficiency of the estimators, RE (Fig. 3).

Because a delta distribution was assumed to generate simulated values, the Var(c) is less or equal Var $(\bar{d})$, and the expected result was that the estimated variances verified that condition, i.e., that RE was always negative. Nevertheless, these values became negatives only for sampling sizes above 20, or more frequently 30 - 40 observations, i.e., trawl hauls by stratum. Beyond that limit, the delta estimator showed to be more efficient. But at smaller sample sizes, the average estimated standard deviation from the means associated with the delta estimators were larger than those of the arithmetic - based. Dealing with population variances and small sampling sizes (n= 3, 4, 8 and 15), Smith (1988) showed that the efficiency of $\bar{d}$ with respect to c decreased considerably as the sampling size increased, provided that $\sigma^2 \geq 3$.

B. - Risk $R_{0.25}$, i.e., probability of evaluating the mean with a percentage of error equal to or greater than 25 % of the population mean (Fig. 4).

The risks of erroneously estimating the mean density by stratum were also very high for both the arithmetic mean and the delta estimator. A subjectively fixed value of ± 25% departure from the population mean was used to define an "erroneous estimation".

Even though the delta estimator generally resulted in lower levels of risk, they were too high in almost every stratum. When the simulations were performed by using for each stratum samples of equal size to the number of hauls effectively trawled during the surveys, the $R_{0.25}$ ranged between 0.53 - 0.83, with a mean about 0.70 (Fig. 5). Under these circumstances, it is clear that the mean density estimations by strata are too inaccurate. However, when the density data were pooled within the whole area (number of tows = 125) the $R_{0.25}$ noticeably decreased, especially when the delta estimator was used ($R_{0.25} = 0.36$).

C.- Percentage of error in estimating mean density (PED) with a risk of 0.05.

In order to investigate the accuracy of long tail hake biomass assessments based on both estimators, the corresponding errors (as percentages of the true density) having a probability of 0.05 to be matched or surpassed were calculated. The errors produced by both estimators were found to be very large (PED greater than 0.8) for every stratum when the effectively performed amount of trawling hauls were used as input. In other words, both estimators under or overestimate the "true" mean densities (and then biomass) by more than 80% in one out of 20 surveys.

When the number of 125 hauls towed within the whole area were used (Fig. 6), the results also suggested that high levels of uncertainty arose from the delta - based estimator (PED = 0.54). Nevertheless, what is more interesting is that the expected value of PED from the arithmetic mean - based estimator under the assumption of normality should have been about

0.7 (70% of the mean), which was the value obtained by simulation. Instead, the calculations of the PEDs corresponding to the four surveys as PED=$tS\bar{d}/\bar{d}$ ranged between 0.17-0.28 (Table 3). That would mean a great underestimation of the length of the confidence intervals, because of the departure of the sample mean from normality. It leads to an over optimistic, but unreal view about the accuracy of the estimates.

The same line of reasoning is difficult to use for the confidence intervals corresponding to the delta estimators, because they are asymmetric. Notice that the lower limits in Table 2 are close to c- 0.54 c (being PED= 0.54), whereas upper limits are far above c+ 0.54 c.

4. Discussion

Some of the results presented above agree with those of other authors: Pennington (1983) and Caverivière (1993) showed that the mean estimates, as well as the coefficient of variations, when obtained from the delta distribution were often higher than those coming from the arithmetic mean. Both authors also stressed that the normal distribution underestimated the true mean variability, giving a too optimistic picture on the accuracy of a given survey.

Nevertheless, the validity of using the delta distribution as a model-based abundance assessment (as opposite to the so-called design-based estimations) has been placed in doubt (Smith, 1990; Warren, 1990). On the other hand, the small sample size currently used in trawl surveys make the application of the theory for large samples suspicious (McConnaughey & Conquest, 1993), so both methods have a poor perfomance.

In any case, little gain would be expected as a result of changing the normal model to a delta model if the sample size is not large enough (Smith, 1988) or the log-normal distribution of nonzero values does not apply (Myers & Pepin, 1990). As to the long tail hake, the efficiency of the arithmetic mean estimate had not been checked before. Our study demonstrates that the stability of the indicators was not met with sample sizes below 30-40 trawl hauls by stratum. Myers & Pepin (1990) have also noted that "deviations from the model assumptions, which greatly reduce the efficiency of the lognormal-based estimators, have a low probability of being detected for small sample sizes (less than 40)". Provided a large sampling size, it is clear (at least for the long tail hake stock) that positive density values would follow a log-normal distribution, and the delta estimator would be better than the arithmetic mean to assess the population mean. Unfortunately, a 360-haul survey (40 trawls x 9 strata) is impracticable, because economic reasons and the loss of the synoptic nature that an assessment survey is expected to achieve. Moreover, the results indicate that doubling the current sampling effort would not decrease at less than 20% the risk of evaluating the mean density with an error of 25% or more. In practice, it is no possible to thing of more than 125-140 tows for this fish stock. As a consequence, no strata would be represented by the minimum number of hauls indicated by our results. Then the statistical advantages of a pre-stratified design would decrease, and a simple random design might be better. Nevertheless, the interannual variation in both the mean density and variance estimates by strata, sugges t that assuring a coverage of every one of them is important. For this species, the current survey strategy could be improved by performing a proportional random design within the whole area, taking the strata into account just to allocate the total trawl hauls according to its surface.

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Table 1. Results of Kolmogorov-Smirnov test for normality of long tail hake density distributions (as logarithm of nonzero values) and theoretical delta distribution parameters by stratum.

Stratum	(Area) (nm^2)	Tows	K-S Test	prob.	Mean $\bar{d}$	Standard Deviation	Proportion of zeros (δ=1-p)
1	15157	59	0.094	0.999	2.479	10.153	0.337
2	18723	103	0.108	0.182	9.070	38.958	0.169
3	3752	20	0.118	0.999	7.766	32.600	0.130
4	13237	51	0.069	0.999	8.747	20.800	0.038
5	13611	70	0.148	0.094	15.523	29.429	0.125
6	3206	32	0.140	0.998	64.412	197.722	0.086
7	4793	28	0.127	0.999	40.530	227.850	0.000
8	19666	110	0.099	0.284	43.231	254.161	0.056
9	7452	26	0.167	0.463	14.342	73.488	0.161
Total area	99597	499	0.069	0.020	19.292	135.397	0.141

Table 2. Estimated mean density (t/nm^2) and 95% confidence intervals by survey, according to both estimators (arithmetic mean and delta estimator). Differences among mean estimates are showed as percentages.

Year	Stratum	Tows Mean	Arith.	C.i.(±)	Delta est.	L.l.c.i.	U.l.c.i.	Mean diff.
1992	1	14	4.33	3.56	5.00	1.77	32.62	+15.5
	2	25	4.73	2.48	8.17	3.30	35.11	+72.6
	3	5	2.60	1.97	2.69	1.39	9.16	+3.6
	4	12	6.03	4.82	7.50	2.90	40.40	+24.4
	5	17	14.54	5.32	15.14	10.31	25.20	+4.1
	6	7	106.19	141.60	105.97	32.04	1112.47	-0.2
	7	6	35.68	31.81	86.30	14.07	3753.60	+141.9
	8	26	27.10	18.81	37.29	12.87	235.83	+37.6
	9	6	7.79	4.74	12.37	4.33	88.72	+58.8
	TOTAL	118	15.51	5.82	21.33	12.46	85.28	+37.5
1993	1	14	5.80	6.34	5.83	1.94	38.46	+0.5
	2	24	8.61	3.96	11.25	5.67	32.02	+30.5
	3	5	3.22	4.07	4.20	0.88	138.52	+30.6
	4	13	3.96	2.22	4.20	2.25	11.26	+6.0
	5	16	12.32	6.26	12.80	7.52	25.48	+3.9
	6	8	51.64	52.83	51.94	22.04	192.84	+0.6
	7	7	3.19	4.66	3.38	1.24	33.75	+5.8
	8	26	31.31	12.54	55.69	25.80	181.16	+77.9
	9	7	5.98	0.52	5.98	2.29	6.09	0.0
	TOTAL	120	13.28	3.18	18.75	12.17	43.59	+41.2
1994	1	17	0.34	0.23	0.35	0.17	0.84	+2.6
	2	29	5.58	2.64	6.79	3.59	17.41	+21.7
	3	5	1.48	1.88	1.50	0.49	11.68	+1.5
	4	14	11.86	8.44	12.29	6.23	39.67	+3.6
	5	20	10.65	8.38	11.93	5.33	45.05	+12.1
	6	9	30.74	15.59	43.91	17.60	236.42	+42.8
	7	8	14.16	6.82	19.53	8.19	100.13	+38.0
	8	31	12.44	5.86	18.58	8.30	64.20	+49.3
	9	7	13.15	21.68	21.34	1.07	5329.51	+62.3
	TOTAL	140	9.30	2.44	12.27	7.96	312.90	+31.9
1995	1	14	1.64	1.32	1.44	0.75	3.76	-12.1
	2	25	5.69	3.80	5.83	2.51	21.11	+2.5
	3	5	33.70	60.85	36.33	11.96	584.99	+7.8
	4	12	9.24	6.71	9.61	4.31	38.61	+4.0
	5	17	12.83	6.24	15.22	7.68	43.30	+18.7
	6	8	18.45	19.04	19.11	8.06	106.70	+3.5
	7	7	34.18	54.47	36.29	10.19	819.96	+6.2
	8	27	28.57	20.23	40.85	14.45	233.26	+43.0
	9	6	11.48	20.87	6.86	2.52	45.56	-40.2
	TOTAL	121	14.31	4.82	16.99	10.41	54.18	+18.7

Table 3. Long tail hake biomass (tons) and 95% Confidence Intervals by year as estimated from arithmetic mean and PED. The value of is that from Table 1.

YEAR	ESTIMATED BIOMASS	C. I. (±)	PED=$tSd/\bar{d}$
1992	1,544,430	579,399	0.273
1993	1,322,665	316,723	0.170
1994	926,089	243,046	0.199
1995	1,425,022	479,767	0.284

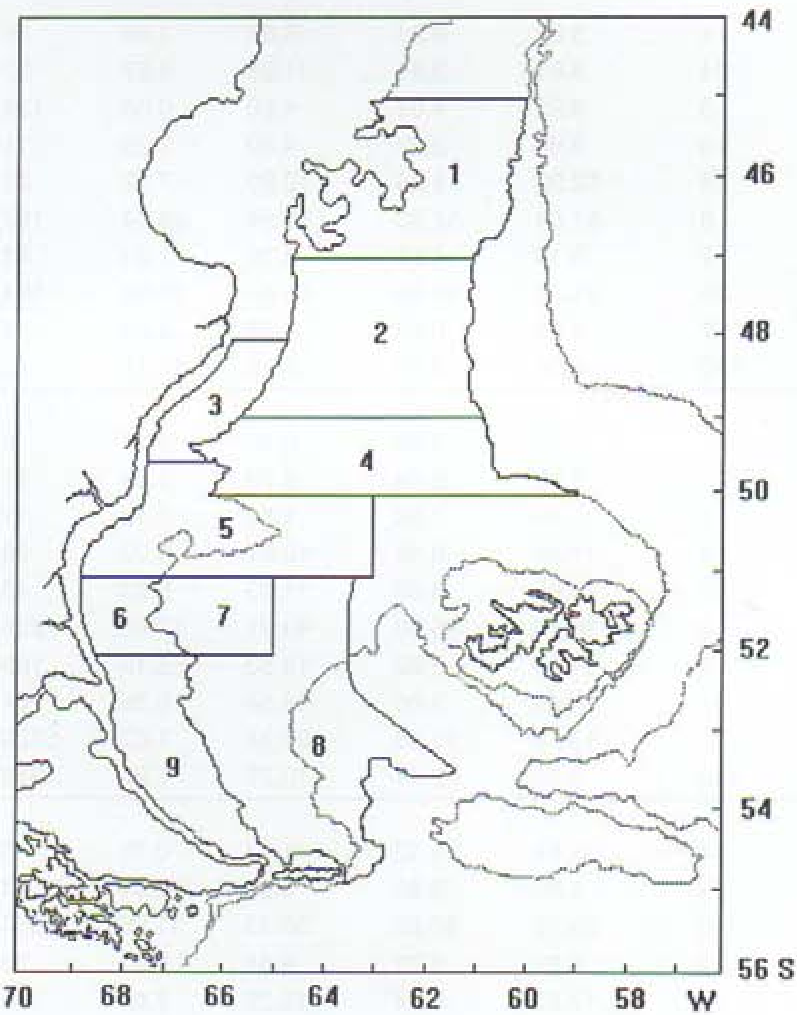

Figure 1. Strata used during the long tail hake surveys (years 1992-1995).

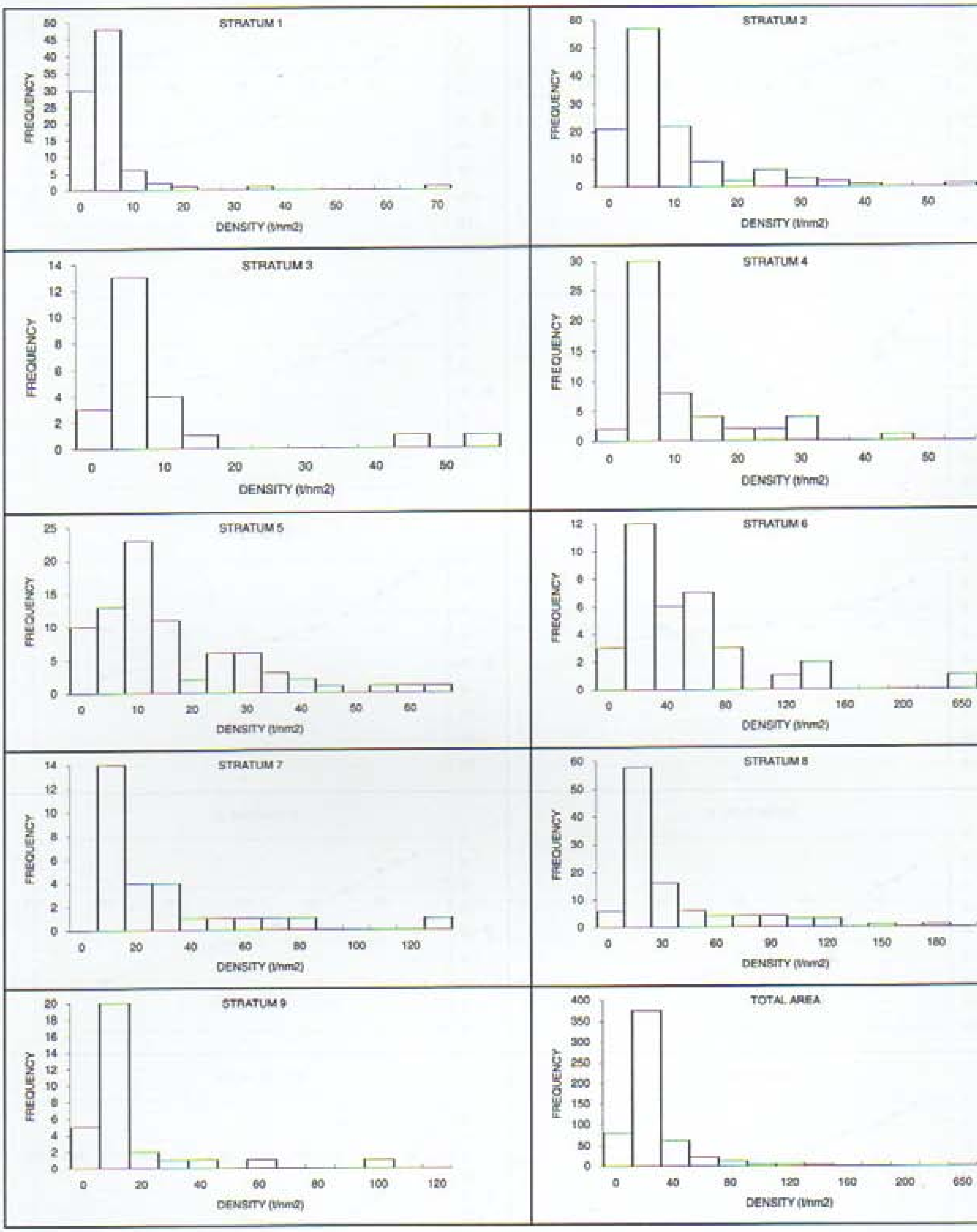

Figure 2. Long tail hake density (t/nm²) frequency distributions, both by stratum and for the total area. The years 1992 to 1995 have been pooled.

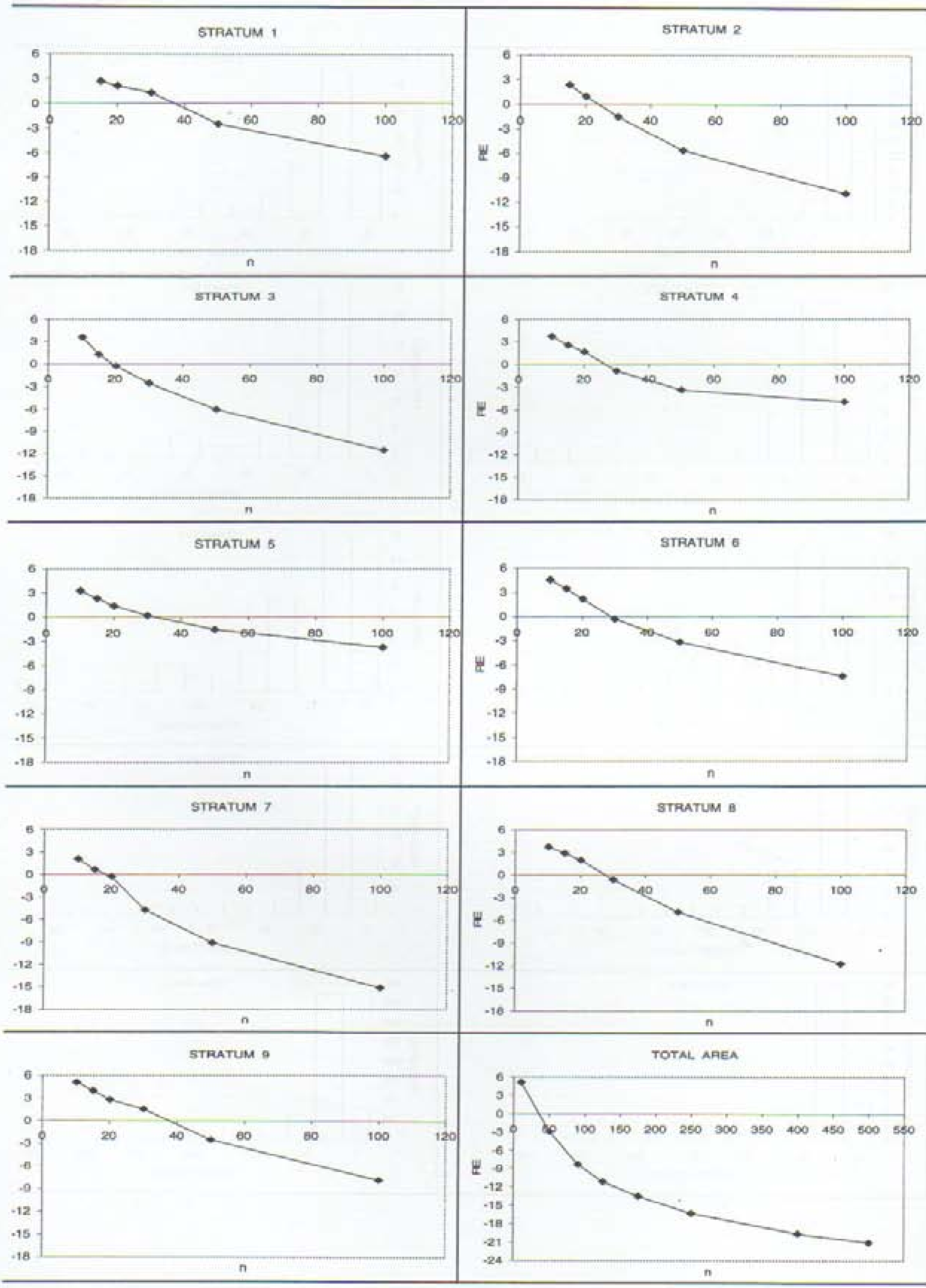

Figure 3. Relative efficiency of the estimators, RE.

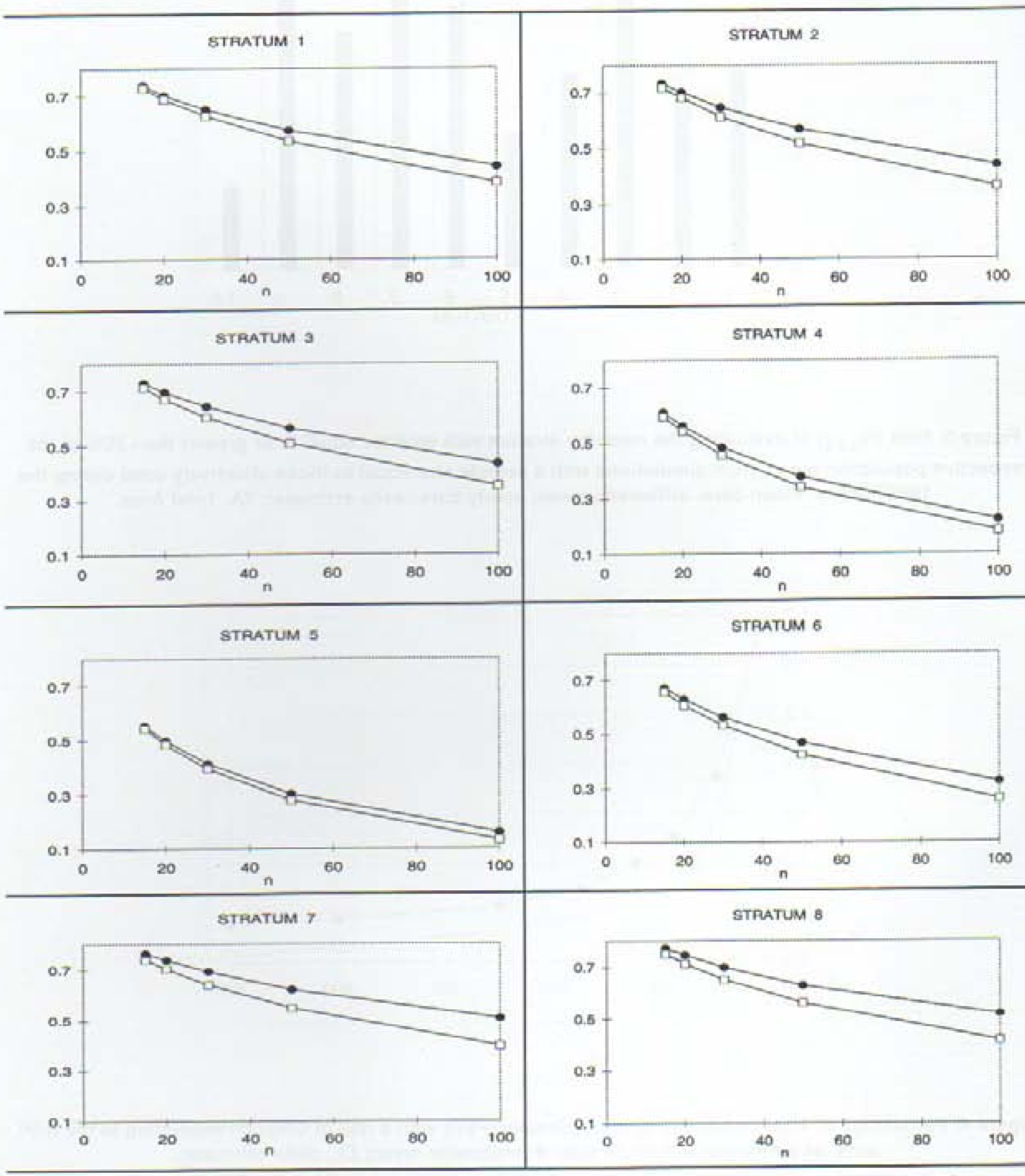

Figure 4. Risk, i.e., probability of evaluating the mean with a percentage of error equal to or greater than 25 % of the population mean ($R_{0.25}$).
●: arithmetic mean; □: delta estimator.

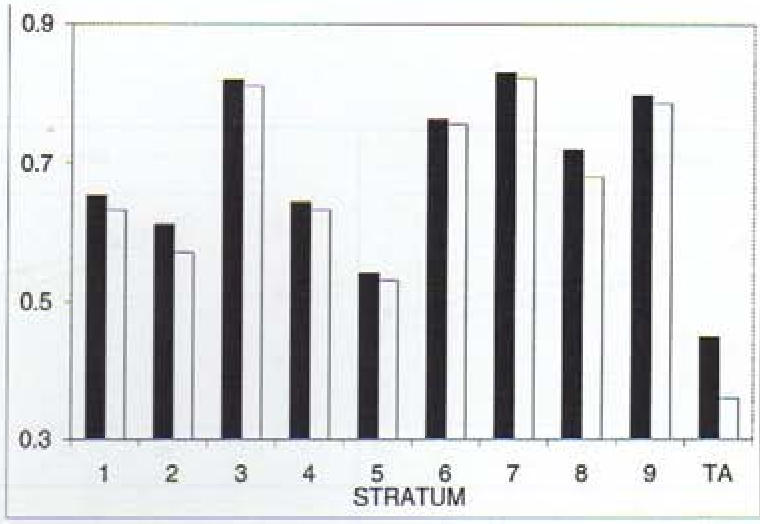

Figure 5. Risk ($R_{0.25}$) of evaluating the mean by stratum with an error equal to or greater than 25% of the respective population mean, from simulations with a sample size equal to those effectively used during the 1995 survey. Filled bars: arithmetic mean; empty bars: delta estimator. TA: Total Area.

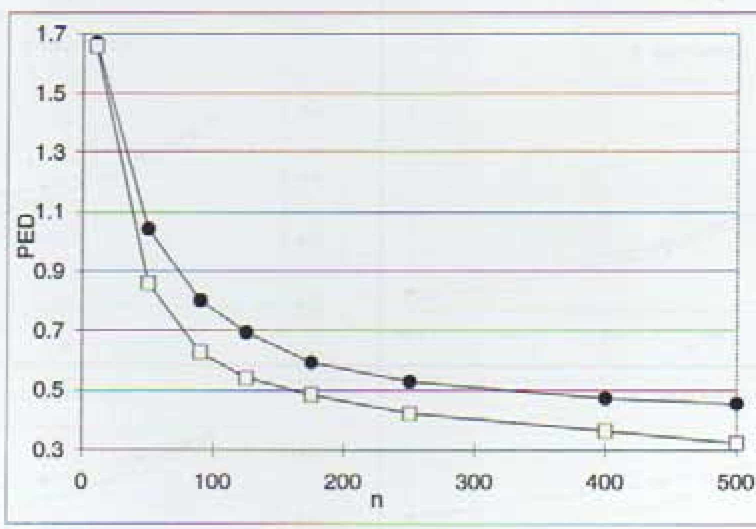

Figure 6. Percentage of error in estimating mean density (PED) with a risk of 0.05 corresponding to the total area, as a function of sample size. ●: arithmetic mean; □: delta estimator.