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Estimated total abundance and numbers-at-age of longtail hake (*Macruronus magellanicus*) in the Southwest Atlantic during the years 1987-2000*

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SUMMARY: *Delta*-based estimates of longtail hake biomass off Argentina were derived from the results of summer trawl surveys carried out on an irregular basis since 1987. Annual estimates of biomass within the whole area ranged from 1.2 to 4.5 million tons, consistent with those obtained by sequential population analysis. There was no clear trend throughout the period 1987-1995, but the 1987 estimate was higher than those for the same area during the years 1992-1995, and estimates since 1997 were much higher than the mean for the four-year period 1992-1995. Since 1992 the largest concentrations of fish have been between 50 and 100 m deep. Most of those were adults, small fish being scarce. Analysis of numbers-at-age showed the dominance of 4-8 year old fish in 1987 and from 1992 to 1994 and the existence of two very strong year-classes, those of 1993 and 1995.

Key words: biomass assessment, delta distribution, *Macruronus magellanicu*s, size and age, southwest Atlantic.

RESUMEN: ESTIMACIÓN DE LA ABUNDANCIA TOTAL Y DEL NÚMERO POR EDAD DE LA MERLUZA DE COLA (*MACRURONUS MAGELLANICUS*) EN EL ATLÁNTICO SUDOESTE DURANTE LOS AÑOS 1987-2000. – A partir de los resultados de campañas de arrastre de verano realizadas irregularmente desde 1987 se derivaron estimas, basadas en la distribución Delta, de la biomasa de la merluza de cola frente a Argentina. Las estimas anuales de la biomasa dentro de toda el área oscilaron de 1.2 a 4.5 millones de toneladas métricas, lo que fue consistente con los resultados obtenidos por análisis secuencial de poblaciones. No se obtuvo una tendencia clara a lo largo del periodo 1987-1995, pero la estima de 1987 fue más alta que las de la misma área durante los años 1992-1995, y las estimas desde 1997 fueron mucho más altas que la media para el cuatrienio 1992-1995. Las concentraciones más grandes de peces desde 1992 se han hallado entre 50 y 100 m de profundidad. La mayoría de ellos eran adultos, y los peces de pequeña talla eran escasos. Los análisis del número por edad mostraron la dominancia de los peces de 4 a 8 años en 1987 desde 1992 a 1994, y la existencia de dos clases de edad-talla muy fuertes, las de 1993 y 1995.

Palabras clave: evaluación de la biomasa, distribución Delta, *Macruronus magellanicus*, talla y edad, Atlántico sudoeste

INTRODUCTION

The longtail hake (*Macruronus magellanicus*) is an abundant fish species of the Southwest Atlantic Ocean. It inhabits both pelagic and demersal cold-temperate waters over the continental shelf and slope off Argentina between 36 and 56°S (Angelescu and Gneri, 1960), at depths between 20 and 600 m (Inada, 1983; Wöhler, 1987; Chesheva, 1995). The greatest concentrations are found south of 45°S at depths of 50–200 m (Fig. 1).

Commercial fishing for longtail hake began during the mid-1970s, but catches were not significant

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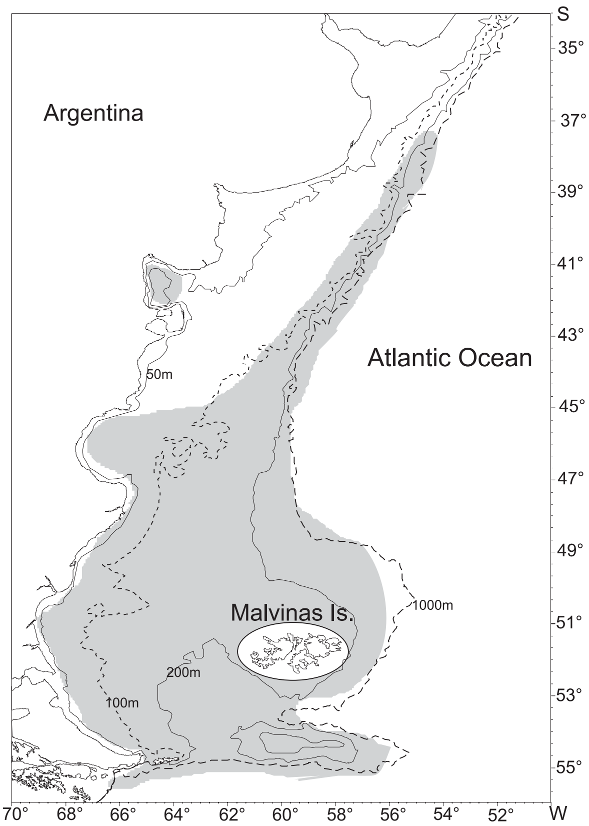

FIG. 1. – Distribution of longtail hake *Macruronus magellanicus* in the southwest Atlantic Ocean.

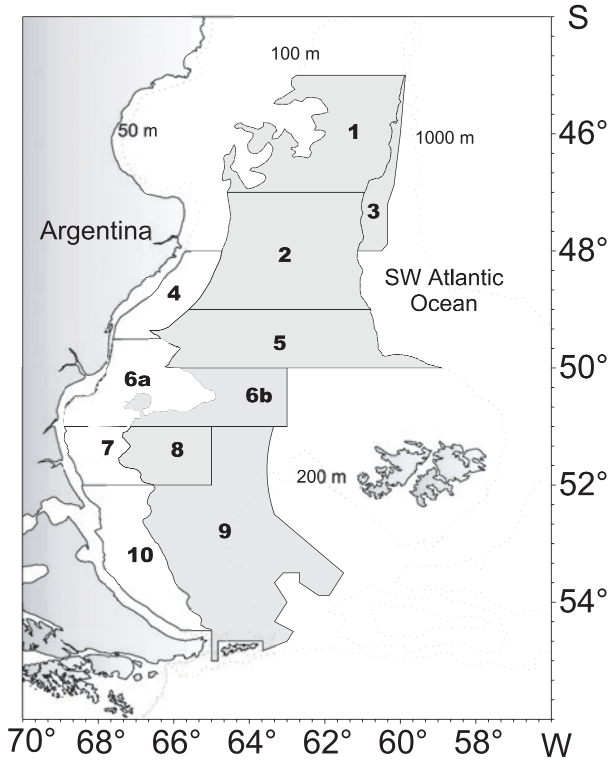

FIG. 2. – Areas used in the current analysis for assessments of longtail hake *Macruronus magellanicus* summer biomass off Argentina. Area A consists of all strata (numbered 1-10) and Area B only those strata deeper than 100 m (1, 2, 3, 5, 6b, 8 and 9).

until the mid 1980s, when fishing vessels from several countries started to operate around the Islas Malvinas and outside the Argentine Exclusive Economic Zone. Annual catches immediately increased sharply, peaking at some 145,000 tons in 1988, largely as a result of the effort of Bulgarian and Soviet vessels that operated under joint ventures with Argentine enterprises. Thereafter, the annual catch decreased, averaging some 42,000 tons per year between 1989 and 1997. Since 1993, most catches have been made by Argentina's traditional factory boats and surimi vessels. Then, following closely on the heels of the downturn in Argentina's hake *Merluccius hubbsi* fishery, the catch again reached some 170,000 tons in 2000.

A few estimates of longtail hake biomass off Argentina are available from research and survey cruises carried out sporadically since 1969. Then, starting in 1992, Argentina's National Institute for Fisheries Research and Development (INIDEP) systematically surveyed the species annually every summer, except in 1996, in an attempt to derive reasonably accurate estimates of biomass on which to base advice on sustainable levels of exploitation. Wöhler *et al.* (1999a) summarized the original results of these cruises. More recently, longtail hake density data (tons per square nautical mile) from the surveys carried out between 1992 and 1995 were reviewed by Hansen *et al.* (2001), and a model approach using a *delta* distribution estimate (Pennington, 1983, 1986; De La Mare, 1994) was suggested on which to base management advice.

This paper addresses the *delta*-based estimates of longtail hake biomass off Argentina from data drawn from all trawl surveys carried out in 1987 and since 1992. Size distributions and age-length keys from the cruises are used to generate the numbers-at-age. These estimates are required both to identify possible trends in abundance of the resource and to calibrate some of the indirect models based on commercial catches, e.g. sequential population analysis, currently used to assess the fishery.

MATERIAL AND METHODS

Trawl surveys and biomass assessments

Research cruises designed to assess the abundance of longtail hake have been carried out since 1987 only

TABLE 1. – Number of trawls by area on each of the surveys.

Survey	Vessel used	Trawls in Area A	Trawls in Area B
1987	*Capt. Oca Balda*	-	76
1992	*Dr E. Holmberg*	114	86
1993	*Capt. Oca Balda*	102	82
1994	*Capt. Oca Balda*	123	93
1995	*Capt. Oca Balda*	118	90
1997	*Capt. Oca Balda*	121	92
1998	*Dr E. Holmberg*	128	100
1999	*Dr E. Holmberg*	127	97
	Capt. Oca Balda		
2000	*Capt. Oca Balda*	118	90
	Dr E. Holmberg		

during the austral summer, because the distribution of the fish is less widespread during summer than in other seasons. No such cruises were undertaken between 1988 and 1991. A stratified random sampling design (Cochran, 1977) was originally adopted for biomass assessments (Fig. 2) and the surveys were carried out by one of the research vessels *Capt. Oca Balda* and *Dr E. L. Holmberg* (Table 1). Both vessels are stern trawlers of similar size that operate with an Engels bottom trawl rigged with a 32-m headrope. The overall length of the net is 60 m, and during trawling the new spread averages about 22 m and its height some 5 m. The stretched mesh size at the wings is 200 mm, and at the codend 20 mm.

The mean duration of tow during the 1987 survey was about 30 minutes. However, shorter trawl durations of about 15 minutes were adopted in 1992, because the rough nature of the seabed of the Patagonian shelf, especially between 50 and 100 m deep, precluded longer tows. The swept area method (Alverson and Pereyra, 1969) was used to estimate fish density by haul, under the assumption that the catchability coefficient was constant (q = 1) for both vessels. The area studied (Area A, Fig. 2) was bounded by the 50 and 400 m isobaths and latitudes 45 and 55°S (101,508 nautical miles^2) on every cruise analysed here except that of 1987, when only the grounds deeper than 100 m (Area B, Fig. 2) were surveyed (73,487 miles^2).

Since 1997, the surveys have been designed from their outset with a *delta*-based approach, using just the area of the strata in allocating the total number of trawls to be made (Hansen *et al.*, 2001). However, for the current analysis, some of the hauls made during the cruises of 1992–1995 had to be eliminated randomly so that the number of tows used in the analysis for each stratum was proportional to the area of that stratum. Further, the results of all tows made during the cruises of the 1990s in an area outside that covered by the 1987 survey were discarded in order to compare the variation in abundance between all years on a similar spatial basis. The number of hauls trawled within each Area (A and/or B) during the different surveys is listed in Table 1.

The equations proposed by Aitchison (1955), Aitchison and Brown (1957), Pennington (1983, 1986) and Hansen *et al.* (2001) were used to estimate the mean density (c) and variance per cruise under the assumption of a *delta* distribution. Finally, the biomass in tons per area as defined above, z (where z = Area A or Area B), was estimated from

$$B_{\mathrm{est},z} = c_z \cdot \mathrm{Area}_z$$

Sample size, raising factors and age-length keys

During the surveys, either all or a subsample of longtail hake was taken from every tow on which >60 kg of the species was caught (Table 2). Fish total length (*TL*) was measured to the nearest centimetre. In order to estimate numbers-at-length within a given area, raising factors for the sampling frequencies ($Rf_{i,z}$) were calculated as follows:

$$Rf_{i,z} = (B_{\mathrm{est},z} \,/\, SW_{i,z}) \cdot (d_{i,z} \,/\, \Sigma d_{i,z})$$

where $SW_{i,z}$ is the weight of the ith sample, $d_{i,z}$ is the longtail hake density (tons per square nautical mile) corresponding to the trawl represented by the ith sample, and $\Sigma d_{i,z}$ is the sum of the densities of every haul represented by a sample within area z.

The observed frequencies by class interval corresponding to each sample were finally raised by the appropriate factor, and the estimates for the same class intervals from different samples were summed to calculate the numbers-at-length in the area.

TABLE 2. – Number of samples and individuals measured during the different surveys.

	Area A		Area B	
Survey	Number of samples	Number of longtail hake measured	Number of samples	Number of longtail hake measured
1987	-	-	44	7,078
1992	99	11,412	74	8,591
1993	60	9,191	43	6,311
1994	74	6,318	54	4,702
1995	80	11,035	57	7,254
1997	85	13,683	61	8,571
1998	114	25,770	75	15,582
1999	123	24,361	80	16,313
2000	104	17,016	78	12,004

TABLE 3. – Basic statistics relating to the age-length keys from surveys made in 1987, 1992-1995, and 1997-2000.

Parameter	1987	1992	1993	1994	1995	1997	1998	1999	2000
Minimum size (*TL*, cm)	30	31	32	14	25	18	30	27	30
Maximum size (*TL*, cm)	120	105	110	122	121	110	110	110	103
Minimum age (years)	1	1	1	0	1	0	1	1	1
Maximum age (years)	15	14	13	19	12	13	15	12	15
Size of sample	1,086	1,025	2,234	2,449	2,888	2,571	2,420	3,127	2,595

In all, 14,673 otoliths were collected during the surveys and read following the methodology proposed for the species by Giussi (1996), in order to construct annual age-length keys. The basic data included in the age-length keys, the length and age ranges and the sample size for each year are listed in Table 3. The age-length keys and the estimated numbers-at-length were combined to determine the numbers-at-age in each area (Areas A and B) annually. Those numbers were finally compared with the annual commercial catch-at-age derived from data collected by observers on board commercial vessels.

RESULTS AND DISCUSSION

Abundance assessments

The applicability and advantages of using a *delta*-based estimate to assess the total biomass of longtail hake were discussed by Hansen *et al.* (2001). Estimates for the whole area (Area A) ranged between 1.2 and 4.5 million tons annually (Tables 4, 5). Clearly, longtail hake is the most abundant finfish in the Southwest Atlantic south of 45°S, as already stated by Wöhler *et al.* (1999b); the current results are consistent with those calculated by sequential analysis (Wöhler *et al.*, 2000). Survey estimates for each area followed the same trend (Fig. 3). The asymmetric limits of the confidence intervals around the annual *delta* estimate averaged –40 and +84%.

Despite being higher than the estimates for Area B alone during the years 1992-1995, the estimate from the 1987 survey still fell into a reasonable range of natural variation of stock biomass. Obviously the stock would have been able to absorb the fishing mortality of those years with a maximum catch of some 145,000 tons. In 1997 and 1998, the abundance within both Areas A and B was double the mean for the period 1992-1995 (Table 4), probably more because of good recruitment than changes in the commercial fishing pattern.

TABLE 4. – Estimates of longtail hake abundance by survey in Area A (confidence intervals at $\alpha = 0.05$).

Parameter	1987	1992	1993	1994	1995	1997	1998	1999	2000
Mean density (tons nautical mile^{-2})	–	18.34	15.57	12.06	17.98	31.61	44.68	45.04	37.34
Lower confidence interval	–	11.38	9.43	7.41	10.52	18.70	27.14	27.46	22.28
Upper confidence interval	–	32.59	28.67	21.64	34.47	59.73	81.21	81.59	69.72
Biomass (‘000 tons)	–	1,861.8	1,580.6	1,223.9	1,825.1	3,209.1	4,535.3	4,572.4	3,790.8
Lower confidence interval	–	1,155.2	957.1	752.4	1,067.7	1,897.8	2,755.0	2,787.9	2,262.0
Upper confidence interval	–	3,308.0	2,910.7	2,196.5	3,498.8	6,063.5	8,243.5	8,281.7	7,077.5

TABLE 5. – Estimates of longtail hake abundance by survey in Area B (confidence intervals at $\alpha = 0.05$).

Parameter	1987	1992	1993	1994	1995	1997	1998	1999	2000
Mean density (tons nautical mile^{-2})	18.05	16.21	11.24	9.31	15.24	23.74	32.18	41.38	28.81
Lower confidence interval	9.64	9.37	6.61	5.62	8.03	12.83	19.29	22.69	16.16
Upper confidence interval	39.82	31.98	21.69	17.28	33.96	51.15	60.16	87.09	59.04
Biomass (tons)	1,326.3	1,191.5	826.0	684.4	1,120.1	1,744.4	2,365.1	3,041.1	2,117.0
Lower confidence interval	708.2	688.5	485.5	412.8	590.0	942.6	1,417.2	1,667.3	1,187.3
Upper confidence interval	2,926.2	2,350.0	1,594.0	1,269.7	2,495.9	3,758.8	4,420.8	6,395.6	4,339.1

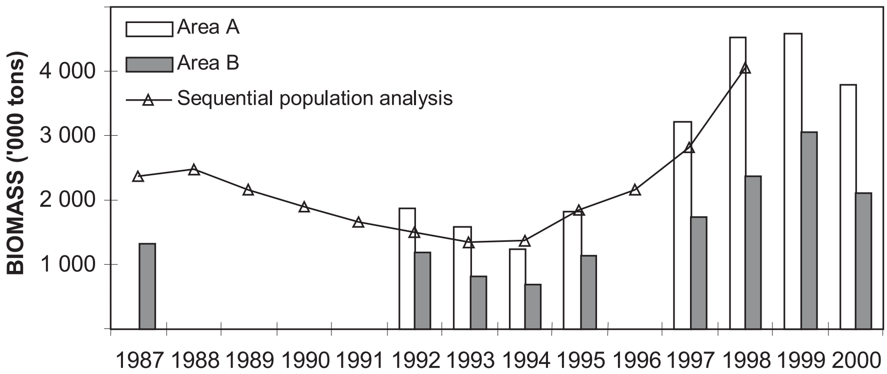

FIG. 3. – Longtail hake biomass estimates by area and survey, 1987-2000, and the total annual biomass estimated by sequential population analysis.

Since 1992, 52-64% of the estimated biomass has been in water deeper than 100 m (Area B), i.e. in an area about 72% of the whole area surveyed (Area A). Stated differently, 36-48% of longtail hake biomass was concentrated between the 50 and 100 m isobaths, an area constituting just 28% of the whole area surveyed.

Two research vessels were used for the surveys, under the assumption that both were equally efficient at catching longtail hake, and in fact the magnitude of and annual variation in the biomass estimates does not seem to depend on the vessel used. Unfortunately, however, it is not possible to guarantee that the capture efficiency of both vessels was the same, even though they are of the same size, used the same fishing gear (nets, bridles and doors) throughout, and trawled at the same speed for similar duration. For species such as longtail hake, that is distributed patchily rather than uniformly over the seabed, it would not be possible to calculate a calibration factor that might standardise data and quantify the differences in efficiency

TABLE 6. – Longtail hake numbers-at-age (millions) by survey in Area A.

Age	1987	1992	1993	1994	1995	1997	1998	1999	2000
1	–	136.8	9.4	6.0	2 467.9	132.0	1,003.4	103.5	1,425.8
2	–	740.3	289.5	244.4	299.5	105.0	4,285.5	1,253.9	633.8
3	–	225.8	280.5	269.2	755.5	2,637.1	352.6	3,953.6	1,519.6
4	–	112.5	117.5	143.5	240.1	346.4	2,003.8	312.5	1,511.4
5	–	205.4	155.0	97.2	129.4	424.1	310.5	1,423.8	438.8
6	–	399.3	279.2	93.2	83.5	266.6	295.5	308.2	624.8
7	–	163.8	318.0	126.5	141.4	120.2	139.0	195.4	137.1
8	–	158.3	98.0	133.6	133.1	103.3	94.7	73.4	62.7
9	–	92.1	70.0	59.9	58.4	96.5	71.8	45.0	28.3
10	–	40.5	25.9	32.5	27.1	72.4	36.7	28.8	24.9
11	–	14.7	6.4	26.6	13.6	34.7	16.5	11.8	6.3
12	–	1.1	4.4	7.4	2.7	9.8	7.2	2.6	3.4

TABLE 7. – Longtail hake numbers-at-age (millions) by survey in Area B.

Age	1987	1992	1993	1994	1995	1997	1998	1999	2000
1	141.8	128.5	5.0	3.9	1,966.7	85.7	640.6	87.6	990.6
2	91.0	694.9	205.9	193.7	189.7	62.1	2,679.9	826.7	343.3
3	67.3	207.5	208.3	190.1	492.6	1,572.3	121.8	2,487.4	810.2
4	434.1	79.0	61.8	79.8	156.7	190.8	731.4	179.5	823.9
5	178.4	99.7	54.2	43.8	70.0	205.0	160.9	917.6	223.2
6	235.6	188.5	103.7	43.4	39.1	124.6	169.0	219.5	321.4
7	160.9	93.6	139.6	59.6	69.9	57.1	92.5	152.1	83.0
8	135.7	94.7	57.0	68.2	67.6	52.7	68.6	60.0	40.8
9	54.8	56.1	42.3	35.0	31.3	51.4	53.7	38.4	19.0
10	19.8	26.5	16.4	19.5	15.8	38.7	30.5	25.7	19.3
11	7.1	9.7	4.4	16.1	8.0	18.4	11.6	10.2	4.7
12	3.6	1,635	3.9	7.4	1.6	7.4	5.5	2.5	2.9

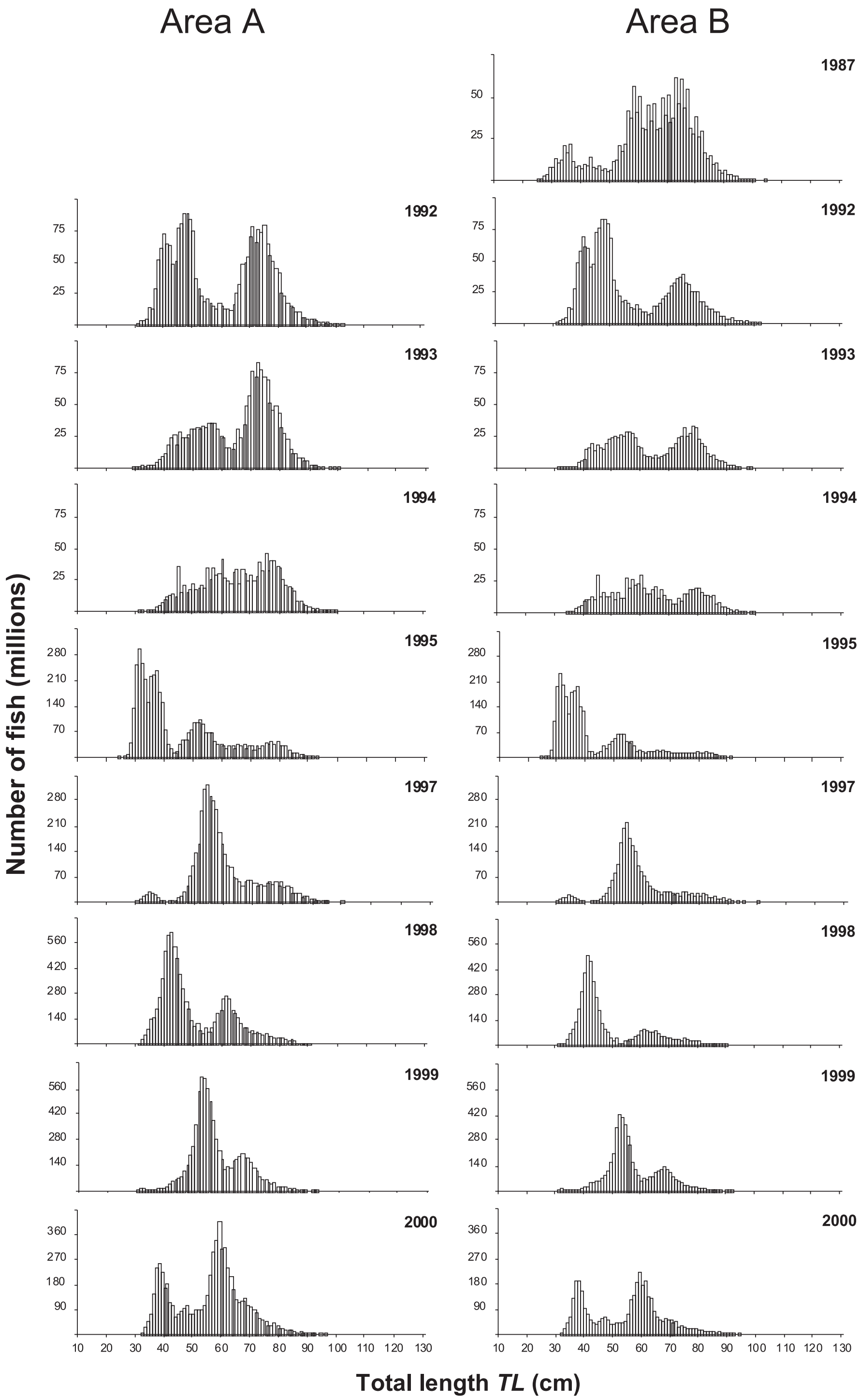

FIG. 4. – Longtail hake numbers-at-length off Argentina, 1987-2000, by area and survey.

between the two research vessels with some measure of confidence.

Numbers-at-length

The size distributions of longtail hake caught on each survey were similar (Fig. 4). Fish >30 cm *TL* were clearly vulnerable to the 20-mm-mesh codends used during the surveys, but smaller fish were caught only very exceptionally. In an analysis of commercially fished longtail hake, Mituhasi *et al.* (2000) discovered that length at 50% retention was 68.4 cm *TL* with a codend mesh size of 120 mm and 34.0 cm *TL* with a mesh size of 60 mm.

If winter and spring are the spawning seasons (Inada, 1983; Bezzi, 1984; Janusz, 1987; Giussi, 1993), the youngest fish would have been 3-7 months old at the time the surveys were carried out, making their capture rather unlikely. Nevertheless, modal analysis did reveal good recruitment. For instance, the 1995-1997 and 1998-2000 length distributions are suggestive of strong 1993 and 1995 cohorts respectively (Tables 6, 7).

The numbers of fish of each length-class estimated for Areas A and B were similar, and it was also possible to follow some of the modes through successive annual length distributions (Fig. 4). The distributions for each area and year showed that the proportion of adult fish tended to be greater when shallower tows were included in the analysis, largely because there were relatively few small fish in the 50-100 m depth stratum. Giussi (1996) analysed longtail hake length distribution during several seasons of the years 1978 and 1993 for the same area; the largest fish were close to the coast, rarely deeper than 100 m. Giussi *et al.* (1999) confirmed the presence of adult fish (up to 7 years old) in relatively shallow water north of 51°S, but they also found juveniles near the coast south of 53°S. Nevertheless, it is still possible that, during autumn, winter and spring, adult fish could be offshore as a result of a spawning migration, a behaviour already documented by Hart (1946) and Giussi *et al*. (2001).

Finally, the shape of the length distributions within each area was highly variable among years, as a result of variable annual recruitment strength

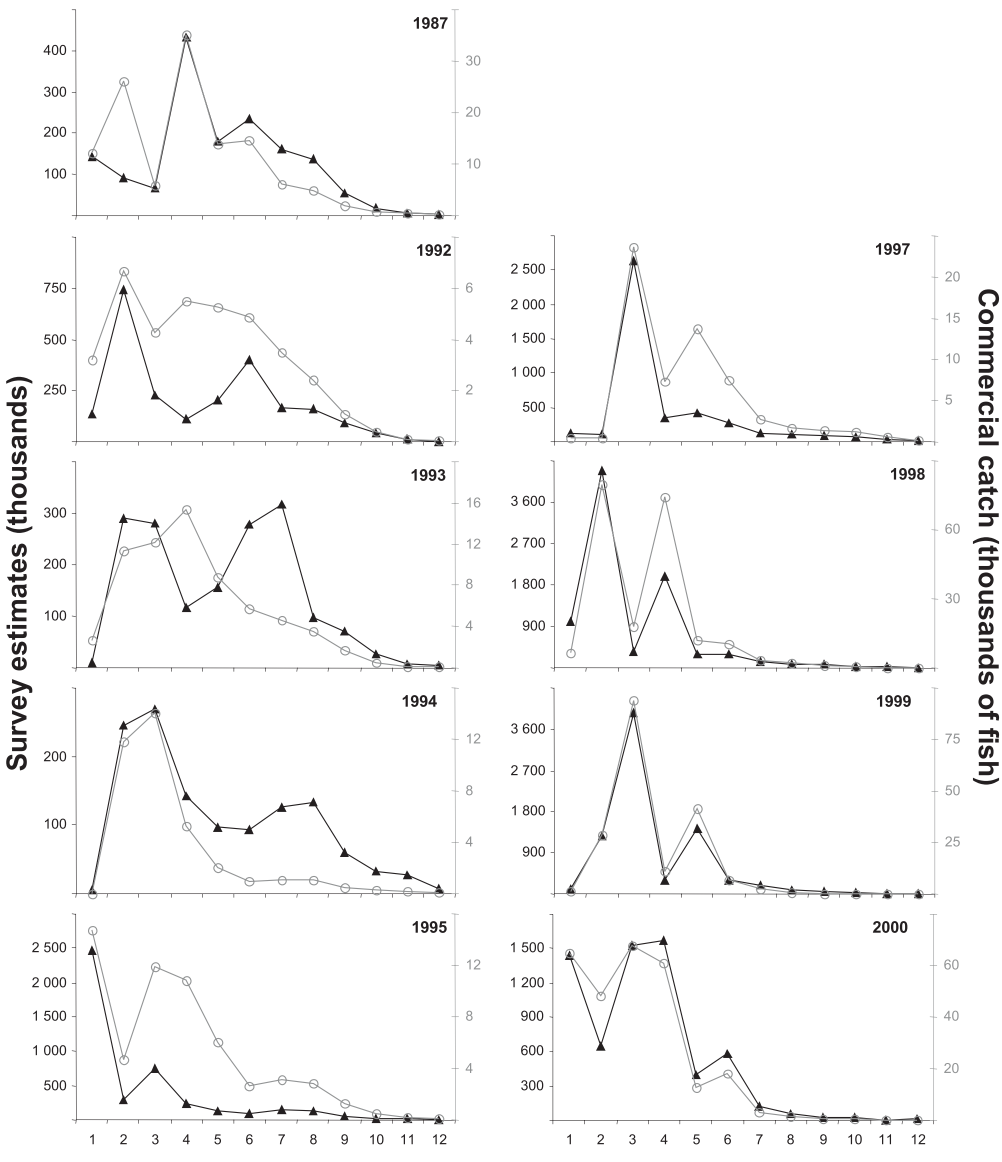

FIG. 5. – Argentine longtail hake commercial catches-at-age (❍) and the numbers-at-age estimated by research survey (▲), 1987-2000.

and survival, lending support to the contention of Wöhler *et al.* (1999a) that longtail hake recruitment is highly variable.

Numbers-at-age

The numbers of longtail hake at age estimated for Areas A and B during the various surveys are shown in Tables 6 and 7 respectively. A relatively large number of fish 4-8 years old were caught during the 1987 and 1992-1994 surveys, and this age groups were also important in the commercial catches of that year (Fig. 5). From 1995 onwards, this trend changed and the presence of fish younger than 5 years increased. The annual age compositions of commercial longtail hake catches were similar to those constructed from research survey catches, except in 1993. The presence of a very strong 1993 year-class in both Areas A and B, represented by fish aged 4 in 1998, 3 in 1997 and 1 in 1995, the last year when they were not yet fully available to the fishing gear, is clear. As the birthdate of the species is currently assumed to be 1 July (Giussi, 1996), fish hatched in July 1993 (the austral winter) would have been 1 year old in July 1994, and they would still have belonged to the 1+ group by the time the 1995 summer cruise was carried out in February/March. The 1995 year-class would also have been very strong, according to its numbers-at-age caught during the summer cruises of 1998-2000. Finally, indications from the cruise in the year 2000 are that the 1998 year-class was also fairly strong.

The variability in length distributions between years was also detected in age compositions, obviously reflecting the great recruitment variability (Wöhler *et al.*, 1999a). The strength of different year-classes would probably be related to favourable environmental conditions and food availability.

CONCLUSIONS

- Estimates of longtail hake biomass in annual surveys conducted since 1987 ranged from 1.2 to 4.5 million tons, consistent with the results of sequential population analysis. Confidence intervals around the annual *delta* estimates averaged –40 and +84%. Abundance in 1987 was apparently higher than the mean observed for the period 1992-1995, but it was even greater in 1997 and 1998. Recruitment strength seemed to be more important than fishing effort in generating the variations.
- Since 1992, 36-48% of the longtail hake found during summer have been concentrated within a region between 50 and 100 m deep, which represents only 28% of the whole studied area.
- The size distributions of the longtail hake resource caught in different years was similar, most of the fish having a *TL* of >30 cm. Modal analysis revealed strong year-classes in 1993 and 1995, which caused great interannual variability in the shape of the size distributions of longtail hake within each area.
- During summer (February-March) and south of 45°S, most adult longtail hake were between the 50 and 100 m isobaths; at the same depths there were relatively few small fish.
- Age compositions of the commercial catches were similar to those calculated from research cruise data, except for 1993. A large number of 4-8 year old fish were caught during the 1987 and 1992-1994 surveys, and fish of these ages also dominated the commercial catches of those years. From 1995, the proportion of fish younger than 5 years increased. Interannual variability in length distribution, resulting from variability in recruitment, was also clear in age compositions.

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