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Study of the blue whiting movements around the Bay of Biscay using acoustic methods

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Abstract

During March–April 1994 and 1996 two cruises were carried out around Bay of Biscay in order to study movements of blue whiting using acoustic methods. These cruises consisted in a double coverage of an area from 47°30′N, 7°15′W to 43°30′N, 6°30′W along the French and Spanish continental shelf-break (200–1000 m isobaths). Changes in spatial structure, abundance estimation, age structure and maturity stages have been analysed in each survey and coverage.

Blue whiting is known as an important migratory species in the North Atlantic. By February/March, adult fish are concentrated around Porcupine Bank where they spawn. After this, it is believed that the fish migrate northward. From this study, rapid changes in both number of fish and population structure of blue whiting are clear. In 1994 the age structure was found and the differences in maturity stages together with an increasing in fish abundance from the first to the second leg, could indicate a southward movement after the spawning season from the main spawning ground. Results in 1996 were different from those of 1994. Juvenile fish were predominant and there was an important decrease from the first to the second trip. Nevertheless, it seems most likely that any southward postspawning migration from Porcupine Bank is undertaken by only a few young mature fish, but this migration is sparse compared to that undertaken northward.

Due to the absence of adult fish, the abundance of younger fish as well as the lack of significant known spawning grounds, the studied area should be regarded as a nursery area as a result of a juvenile migration or a southward larvae drift. This process could be suggested rather than a postspawning migration.

Keywords: Blue whiting; Bay of Biscay; Acoustic methods; Spatial distribution; Migration

1. Introduction

Blue whiting (*Micromesistius poutassou*, Risso) is important in terms of its abundance in the North Atlantic. It has a widespread distribution along the continental slope in the North Atlantic and also in the Mediterranean Sea. Contrary to the normal behaviour of other gadoids, blue whiting is not a typical demersal species, and spends the major part of its life with no noticeable relationship with the sea bottom (Zilanov, 1980). This has enabled this species to be studied by acoustic methods since 1972 (Anon, 1982). Its movements between feeding and spawning areas in the North Atlantic are well documented (Zilanov, 1980; Anon, 1982; Bailey, 1982; Anon, 1993a). A series of acoustic surveys have been carried out, usually in March/April around the west of the British Isles where the major spawning stock is congregated over a rela-

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Table 1
Main features of the cruises

Survey	Trip	Date	Design	No of transects	Fishing ST	CTD ST
SEFOS 0394	First (FT)	15/03–31/03	Zigzag	34	10	80
	Second (ST)	19/04–25/04	20 nmi apart	34	9	–
SEFOS 0396	First (FT)	20/03–31/03	Parallel	22	12	78
	Second (ST)	07/04–15/04	24 nmi apart	22	9	–

tively small area. After spawning, there is a rapid migration towards feeding areas.

However, in the southern part of the distribution area, no attempt has been made to demonstrate the movements of the blue whiting. Under the EU AIR project SEFOS (*Shelf Edge and Oceanographic Studies*), whose main objective is the study of the relationship between the distributions and migrations of commercially important fish and the hydrography of the shelf edge, the Instituto Español de Oceanografía programmed two acoustic surveys in 1994 and in 1996 to study the movements of blue whiting around the Bay of Biscay.

Spanish acoustic surveys for blue whiting had previously been carried out in 1991–1993. These surveys had a zigzag track with 10–12 miles between peaks, between the 20 and 1000 m isobaths. The blue whiting distribution in each survey was studied by means of geostatistical techniques using the integration values for each transect as unit sampling. The losses in precision were known to be negligible when the distance between corners is increased to a maximum of 20 miles. This analysis was carried out by calculating an experimental variogram with the three cruises combined and testing the confidence intervals as a percentage of the mean, when transects were eliminated both systematically and randomly. As a result of this analysis, the 1994 and 1996 surveys were redesigned to cover the shelf edge (between 200 and 1000 m) where blue whiting are mainly distributed (Meixide et al., 1991). In order to check movements, the area was covered twice.

2. Material and methods

The surveys were carried out on board RV "Cornide de Saavedra". The acoustic surveys were performed in the Bay of Biscay (VIIIa–c ICES Divisions) and consisted in a double coverage. Table 1 summarises the main features of these surveys. Survey designs in both cases were normal to the depth contours, from 200 to 1000 m isobath (Fig. 1) and in 1996 in the Spanish area during the first leg, transects were extended to the 20 m isobath.

A Simrad EK-500 echo-sounder–echo-integrator with a 38 kHz split beam transducer was used. In 1994 results of the calibration performed in November 1993 were used whereas in 1996 the equipment was calibrated before the survey according to Foote et al. (1987). Surveys were conducted day and night at a ship speed of 10 knots. Acoustic backscatterings (S_a values, expressed as m^2 nmi^{-2}, Bodholt, 1990) were directly collected every nautical mile (nmi) and stored in a PC, which controlled the main settings of the echo-sounder. Geographical position was taken by GPS. Total echo-integrated energy per ESDU was manually allocated into fish species by the scrutinisation of the different echo traces which were corroborated at the fishing stations.

Three hypotheses were stated to test movements: (a) Significant changes in fish abundance occurred between coverages. In addition, the spatial distribution, fish density and the spatial autocorrelation and their relation with abundance was also studied; (b) Significant changes occurred in the population age structure between coverages and (c) Significant changes in fish maturity stages occurred between coverages.

Prior, the surveyed area was firstly divided into three zones as follows: north France, from the upper surveyed limit to 45°N; south France, from 45°N to the Spanish–French border; Spain, from the Spanish–French border to 6°15′W.These main areas were chosen due to the different direction of the continental shelf-break (225° degrees approximately in north France, 0° in south France and 90° in Spain), where blue whiting is mainly concentrated.

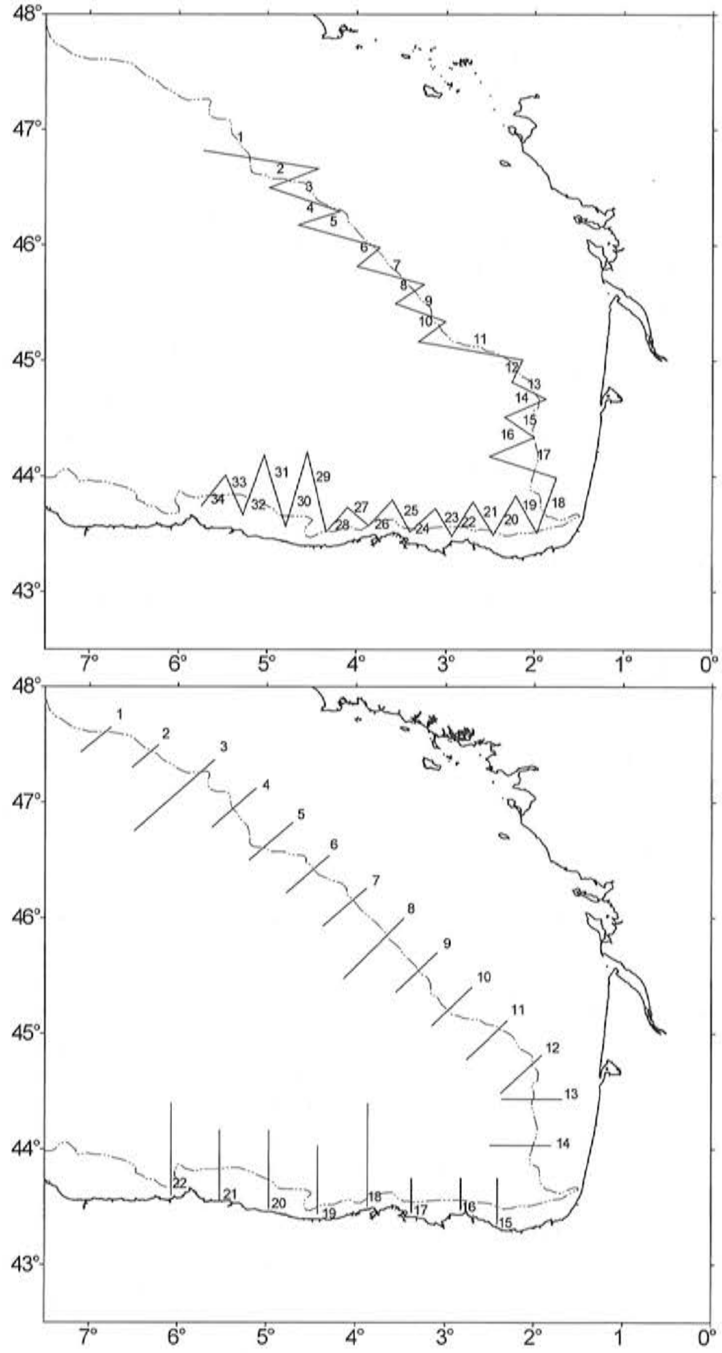

Fig. 1. Map of the survey area in the Bay of Biscay and the Cantabrian Sea showing the cruise track and transect numbers, above 1994 and below 1996.

Mean S_a value for blue whiting of each zone and the surface of its distribution area were used to estimate the abundance according to Nakken and Dommasnes (1975). The following TS/length relationship (Anon, 1982) was used:

$$\mathrm{TS} = 21.8\log(L) - 72.8\,(\mathrm{dB})$$

Changes in spatial distribution and autocorrelation of blue whiting were studied by means of geostatistics tools. The use of geostatistical techniques (Matheron, 1971) and their applications in fisheries research, both for mapping and variance estimates, is well documented in Conan (1985) and Petitgas (1991, 1993) and has been recommended as a tool for the analysis of acoustic survey data in Anon (1993b). In addition, fitted models gave an estimation of the spatial variance, which has been used to test differences. This analysis was performed using EVA v1.0 (Petitgas and Prampart, 1993) and SURFER v6.0 (Golden Software) packages.

Biological samples were obtained at pelagic trawl stations to identify blue whiting and its age structure. In each trawl station a random sample of 80 fish was sampled (length, weight, sex, maturity and otolith) and 40 were aged on board. This random sampling strategy was adopted in order to obtain unbiased parameters (Anon, 1994) and to make the examination of age structure easier during the cruise.

Changes in population age structure as well as maturity stages using a key of six empirical stages (Abaunza et al., 1995) were tested with the Kolmogorov–Smirnov as described in Zar (1984).

3. Results

A total of 811 and 762 nmi, respectively were surveyed in 1994. In 1996, 640 nmi were surveyed during the first leg and 580 nmi during the second one. Fig. 2a and b shows a proportional representation of the data. Fig. 3 shows the total blue whiting echo-integrated energy by transect in each trip and survey.

As in previous surveys, blue whiting distribution is related to the continental shelf-break. In both surveys the external limit of the distribution seemed to be reached. There were only positives values at the end of two transects located in the northern part of the area of the second trip undertaken in 1994. Over the continental shelf, the inner limit appeared to be close to the slope. This was clearer during the surveys performed in 1996 than in those carried out in 1994. Although there was a evidence that the inner limit of the stock in the north France area was not reached, these values were, in general, quite low and, therefore, we have assumed that the survey covered the bulk of the distribution.

Within each area and trip there were a few samples with high values, which made an important contribution on both arithmetical mean and the variance. The global estimate and its precision are therefore determined by a few very large values (Petitgas, 1993). Whereas in south France and Spain there is no clear zonation of these high values, in north France during the second leg of the 1994 survey, they were concentrated on the northern part of this area.

Nevertheless, due to the skewness of the frequency distribution, variograms were first performed on transformed data (logarithmic transformation). These variograms did not show clear anisotropy and therefore isotropic variograms were constructed. These variograms were used to clarify the spatial structures found for the raw data.

Main results are shown in Table 2. Significant differences in fish abundance were found within each zone and year. Changes in fish abundance from the first to the second trip were always higher than 50%. In 1994 the number of fish increased from the first to the second trip whilst in 1996 there was a decrease. In addition, changes in fish abundance were in general accompanied with changes in the surface of the distribution area of blue whiting. Only in south France the area remained stable. Changes in fish abundance in north France and Spain occurred without noticeable changes in mean S_a values. In south France there was important changes in mean echo-integrated values. On the contrary, fish density, expressed as a number of fish per square nmi, showed important differences between trips (Fig. 4). Only in north France during the 1994 survey the fish density remained stable. The high values in fish density found in south France and Spain in 1996 could be related to the high abundance of juvenile fish.

The pattern of acoustic abundance distribution shows spatial autocorrelation in all areas and surveys. The range of this autocorrelation was reached at

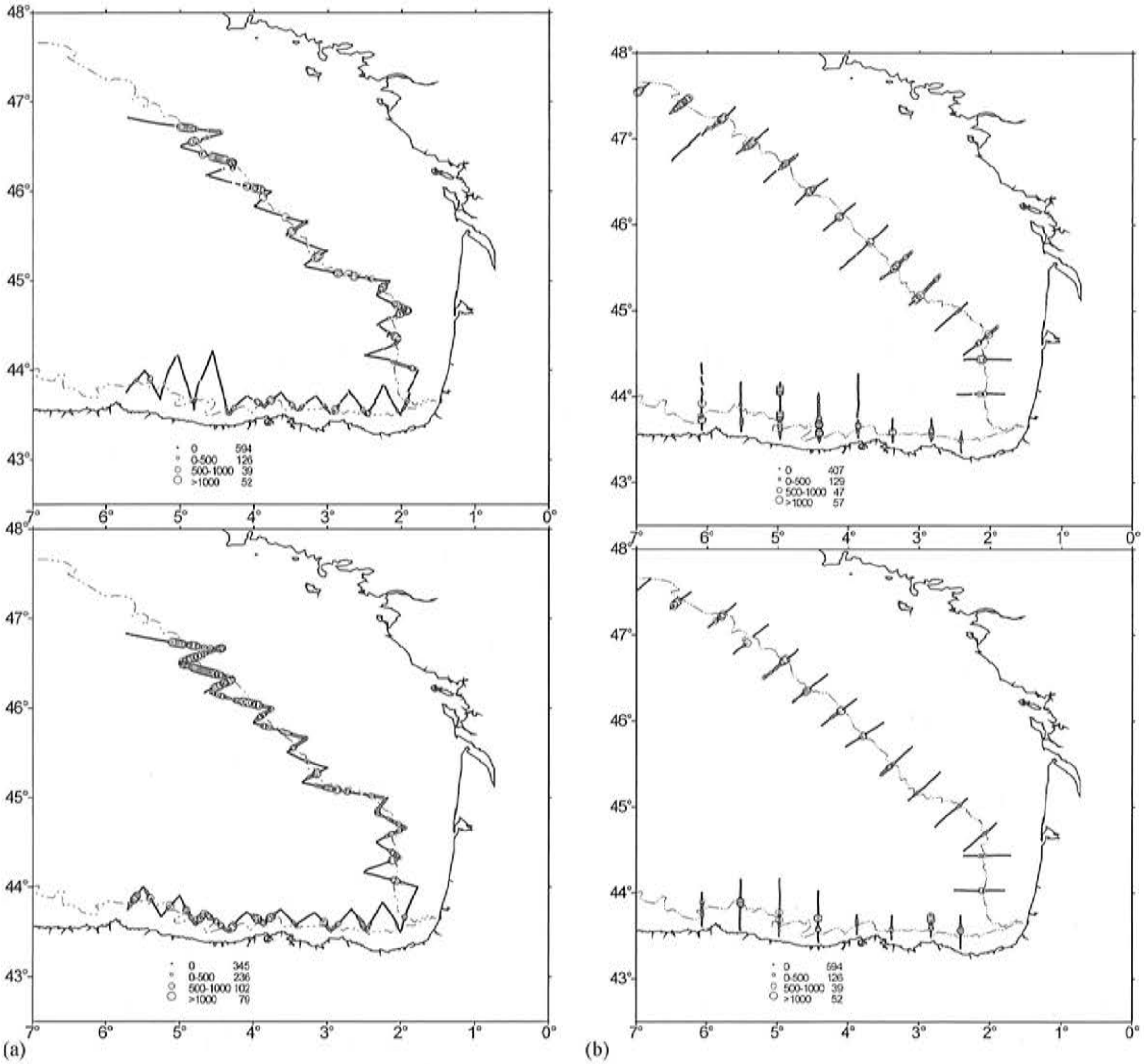

Fig. 2. (a) Acoustic backscattering values per ESDU (nmi) during the 1994 acoustic survey. Above part 1, below part 2; (b) Acoustic backscattering values per ESDU (nmi) during the 1996 acoustic survey. Above part 1, below part 2.

8–12 nmi and seems to be independent of the fish abundance.

The population structure found in 1994 was different from that of 1996. Age group 3 was the most abundant in 1994 whereas in 1996 age 1 and 2 represented up to 95% of the population. In 1994 it seems that the major change occurred in the total number of fish (Fig. 5) retaining a stable age structure of the population from the first trip to the second in the different areas. A Kolmogorov–Smirnov test performed over the total aged fish in each area did no show any significant change in population age structure from the first to the second trip in 1994 but in 1996 there were significant differences. The decreasing in number of fish from the first to the second trip in 1996 was also accompanied with a change in the population structure.

Concerning the proportion of maturity stages, in both years there were significant changes from the first to the second trip ($p > 0.001$). In 1994 most of the fish

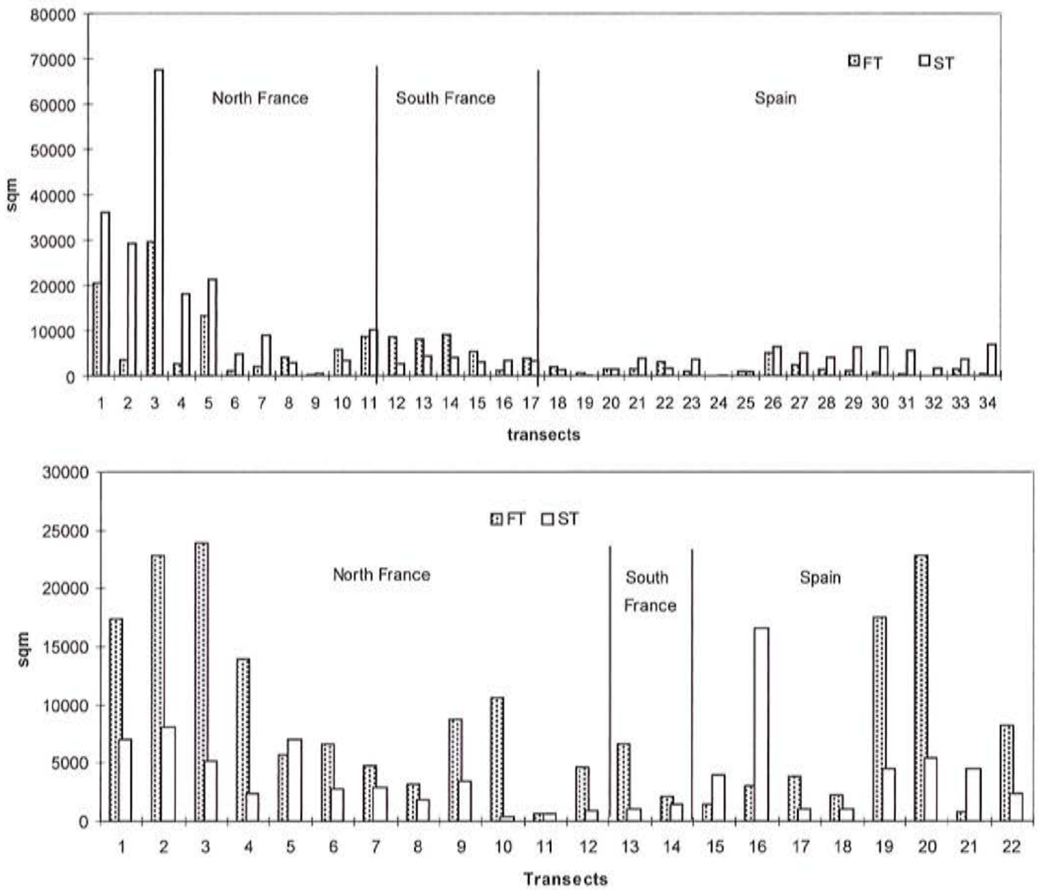

Fig. 3. Cumulated backscattering values for each transect and survey. FT and ST denote part 1 and part 2, respectively. Above, 1994 survey; below, 1996 survey.

were in stage 6 (resting) during the second trip, with no indication of spawning activity (stages 3–5, Fig. 6). In 1996 an important part of the population were immature.

4. Discussion

Since 1960, blue whiting has been known as an important migratory species in the North Atlantic (Bailey, 1982). While in summer and autumn the species is widely dispersed over most of the Norwegian Sea, important concentrations begin to form at the end of the year. By February/March adult fish are concentrated around Porcupine Bank where they spawn. After the spawning season there is an exodus from this area. To the north this movement is well documented. Monstad and Belikov (1993) found an important change in fish density in a short time, and the main spawning area became almost empty by the beginning of April, 1 month after the peak spawning. However, these surveys did not cover waters further south than 49°N, so the possibility of migration southwards was unknown.

The present study was made in 1994 and 1996 in the southern area with acoustic surveys conducted in spring in two legs covering the same area with short period of time between trips. From this, the main conclusions are:

- Around the Bay of Biscay there are significant changes in blue whiting abundance in spring. These

Table 2
Abundance estimations by area, trip and year; FT and ST mean first trip and second trip, respectively (for each area and trip, fitted variogram model when available, variance estimate, coefficient of variation, the degree of coverage and the total abundance estimation in number are also shown)

Area	Trip	No.[a]	No inside[b]	Range[c]	Mean[c]	Area[d]	Variogram model	Variance estimate	CV[e]	d.c.[f]	No.[g]
North France	1994 FT	307	102(94)	0–7400	895.0	926.7	$\exp(1.22E+6; 10)$	21796.3	16.5	3.35	1368
	1994 ST	325	223(220)	0–16000	910.0	2012.2	$1.75E+5+\exp(1.9E+6; 12)$	18916.4	15.1	4.97	2926
	1996 FT	345	166(135)	0–7000	741.9	4052.6	$\exp(1.59E+6; 8)$	26114.9	21.8	2.61	5958
	1996 ST	315	101(91)	0–4000	423.0	2377.8	$2.0e+5+\mathrm{Sph}(1.9E+5; 12)$	7750.1	20.8	2.07	2290
South France	1994 FT	123	56(55)	0–4000	644.1	553.4	$1.0E+5+\exp(6.3E+5; 10)$	29454.8	26.6	2.38	657
	1994 ST	127	62(61)	0–1600	334.9	511.7	$1.0E+4+\exp(8.9E+4; 12)$	2963.4	16.3	2.74	265
	1996 FT	58	10(9)	0–3700	880.0	151.0	n.a.	n.a.	n.a.	0.81	332
	1996 ST	58	8(7)	0–600	312.5	148.8	n.a.	n.a.	n.a.	0.66	99
Spain	1994 FT	381	68(66)	0–2500	344.3	657.9	$\exp(1.53E+5; 10)$	4322.1	19.1	2.57	363
	1994 ST	310	141(136)	0–2000	415.5	1207.4	$1.0E+4+\exp(1.39E+5; 8)$	1990.5	10.7	4.06	855
	1996 FT	237	99(89)	0–3800	606.2	2608.8	$\mathrm{Sph}(7.84E+5; 12)$	23255.5	25.2	2.04	5789
	1996 ST	207	65(61)	0–10000	606.9	1361.7	$8.0E+5+\mathrm{Sph}(8.3E+5; 12)$	45348.7	35.1	2.09	2236

[a] No.: number of data.
[b] No. inside: number of data within the delimited area of blue whiting distribution, with the positive values in brackets.
[c] Range and mean value in $S_a$units.
[d] Area (surface expressed as nmi^2) are referred to the delimited area.
[e] Coefficient of variation.
[f] Degree of coverage.
[g] Total abundance estimation in number.

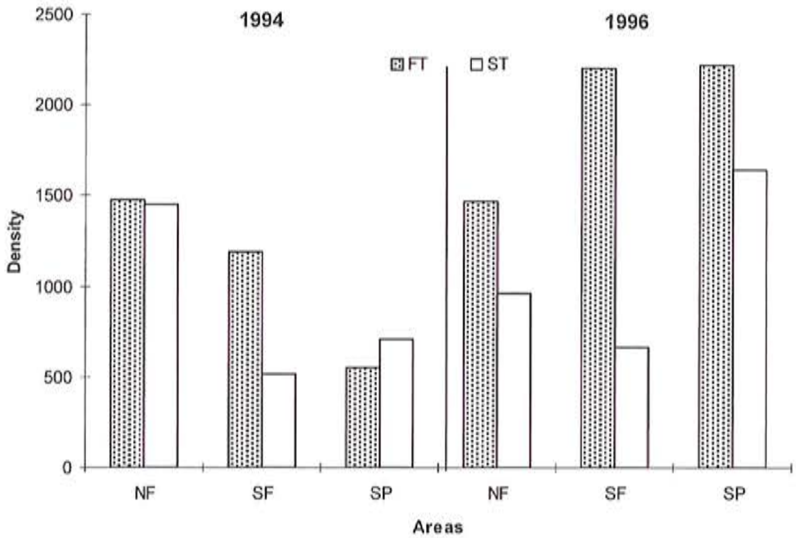

Fig. 4. Mean density (number of fish (millions) nmi^{-2}) for each zone (NF, North France; SF, South France; SP, Spain), trip (Ft, part 1; ST, part 2) and year.

changes were detected after the main spawning period.

- Blue whiting distribution showed spatial autocorrelation and the range of this autocorrelation, which was around 8–12 nmi, was independent of both fish abundance and fish density.
- The spatial distribution changes significantly according to the fish abundance. Only at low values of abundance (i.e. south France) the spatial distribution remains more stable but with important changes in fish density.
- In the studied area, blue whiting appears to be strongly associated to the continental shelf-break. Nevertheless in the Spanish area blue whiting is also found over the continental shelf whilst in French waters the area is extended into deeper waters, in a pelagic layer at around 200–300 m.
- The age structure of the blue whiting population did not present significant changes from the first coverage to the second one in 1994, but these changes were significant for the 1996 survey.
- Between coverages, there were significant changes in the proportion of maturity stages in both surveys.

In 1994 the differences in maturity stages together with the changes in fish abundance from the first to the second coverage could indicate a southward movement after the spawning season from the main spawning ground. Results in 1996 were different to that got in 1994. During this survey, the bulk of the estimated fish belonged to age group 1 (juveniles) and its abundance decreased from the first trip to the second one. Since this population was mainly immature, no indication of a southward post spawning migration should be expected.

The range of the spatial autocorrelation agrees with that found in the analysis of the previous surveys (1991–1993). The relative stability and independence of the variogram ranges and, in some cases, of the fish density from the total abundance suggests a habitat expansion or contraction process according to the changes in population abundance as explained in MacCall (1990).

Although blue whiting was mainly observed in pelagic or near bottom layers, juveniles were also found in dense schools. This aggregation pattern was detected in 1996 in Spain and south France in juveniles of 14 cm length. The occurrence of these schools could explain the differences in fish density observed in this year in the southern areas.

As the overall number of fish increases, the distribution area becomes wider. In France the area was extended into deeper waters, in a pelagic layer at around 200–300 m, with almost no presence on the shelf, as described in Foote and Ostrowski (1996). In

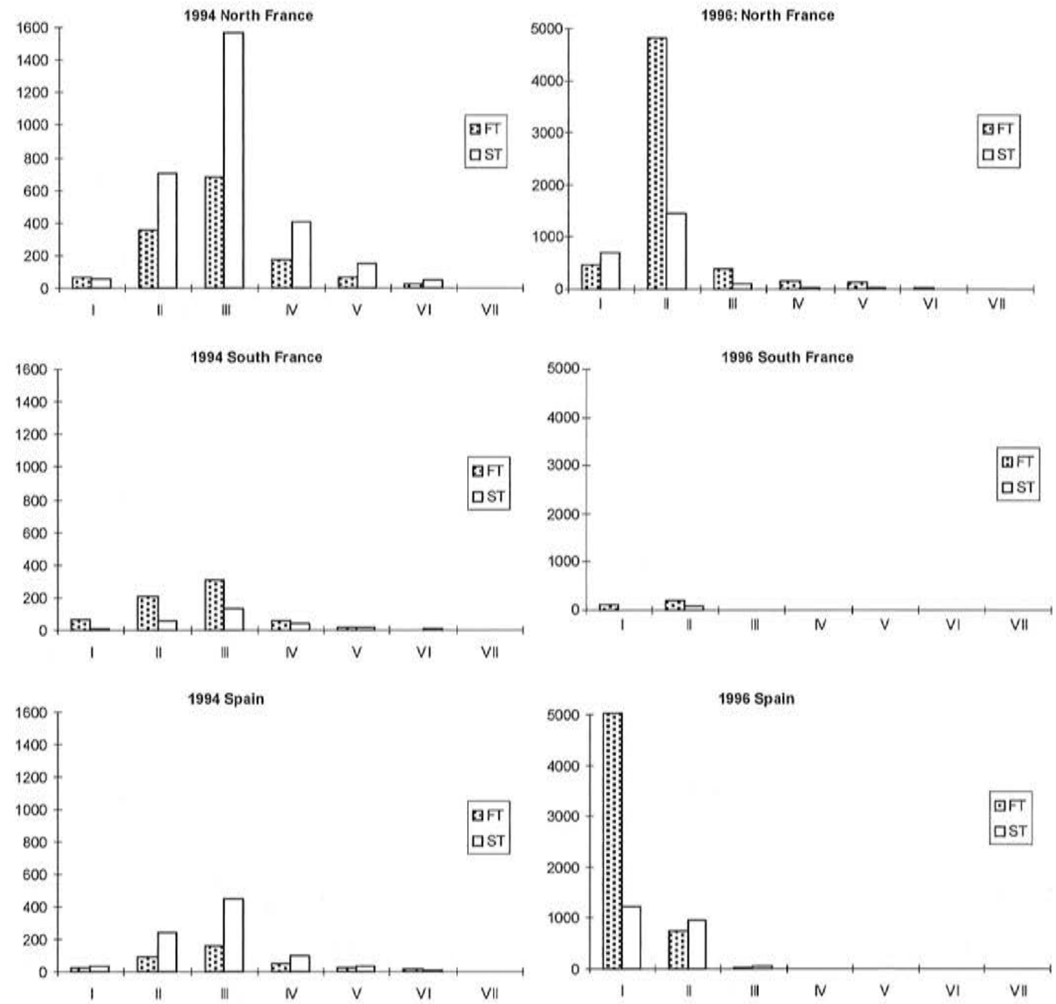

Fig. 5. Number of fish (millions) by age group, area and trip (Ft, part 1; ST, part 2).

Spanish waters at a low abundance blue whiting was mainly distributed on the slope as in France. When abundance increased, the area was extended over the continental shelf until 100–150 m, with almost no extension in a pelagic layer as found in France. The Spanish shelf is narrower than the French one, but it also tends to be deeper than the French. This topographical difference may explain the presence of blue whiting over the Spanish shelf, but it would not explain its lack of extension in a pelagic layer as in French waters. According to Porteiro et al. (1996) this different behaviour of blue whiting may be explained by differences in hydrodynamic regime between the two areas.

Age structure and length composition (age groups 0–3 and length range between 16 and 22 cm) of the studied area reflect a prevalence of younger fish, which agrees with the available information for this area (Meixide et al., 1991; Anon, 1993a, 1996). This structure is, however, different and complementary to that found in northern areas where length distribution at the spawning season has the mode at 28 cm and ranges from 19 to 40 cm. In summer, is bimodal, with a minor mode at 10–14 cm and major mode at 28 cm (Jacobsen, 1990a,b; Monstad, 1993; Monstad and Belikov, 1993).

Although significant blue whiting movements in the Bay of Biscay were detected, the relationship with a

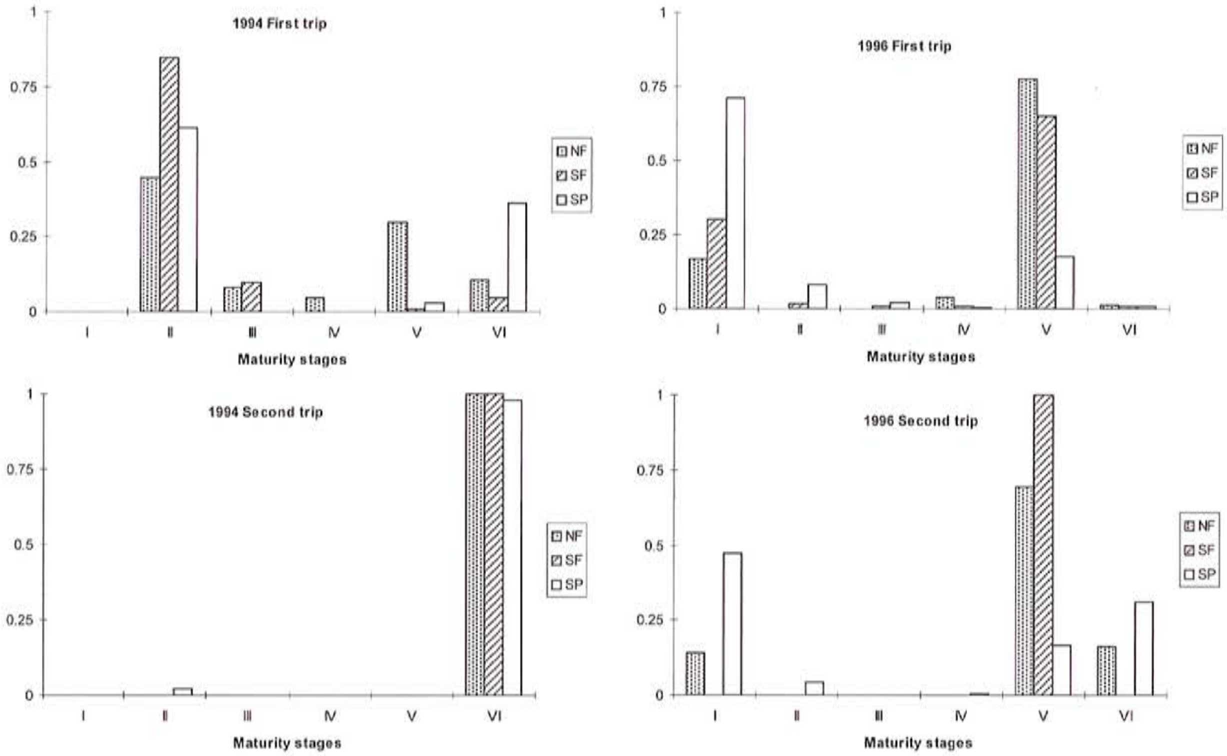

Fig. 6. Maturity stages proportion for each area, trip and survey (NF, North France; SF, South France; SP, Spain).

postspawning migration is unclear. It would appear that the southward postspawning migration from the Porcupine area includes only few young mature specimen (mainly age groups 2 and 3). But this migration is sparse compared to the northward migration (Monstad et al., 1996). Based on the low number of adult fish and the lack of known significant spawning grounds in this area (Porteiro et al., 1996), a juvenile migration or a southward larvae drift (Fraser, 1958) rather than any postspawning migration could be postulated. Accordingly, it likely seems that the southern area represents a nursery area for this species. Juveniles have been reported (Maucorps, 1979) and were also detected during these surveys (Carrera et al., 1996).

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References

Abaunza, P., Fariña, A.C., Carrera, P., 1995. Geographic variations in sexual maturity of horse mackerel, *Trachurus trachurus* (L.), in the Galician and Cantabrian shelf. Sci. Mar. 59 (3–4), 211–222.

Anon, 1982. Report of the International Acoustic Survey on Blue Whiting in the Norwegian Sea, July/August 1982. ICES CM, 1982/H:5.

Anon, 1993a. Report of the Blue Whiting Assessment Working Group. ICES CM, 1993/Assess:4.

Anon, 1993b. Report of the Workshop on the Applicability of Spatial Techniques to Acoustic Survey Data. ICES Cooperative Research Report, No. 195, 87 pp.

Anon, 1994. Report of the Workshop on Sampling Strategies for Age and Maturity. ICES CM, 1994/D:1, Ref. G, H, J.

Anon, 1996. Report of the Atlanto-Scandian Herring, Capelin and Blue Whiting Assessment Working Group, IMR Bergen, Norway (12–18 October, 1995). ICES CM 1996/Assess: 9.

Bailey, R.S., 1982. The population biology of blue whiting in the North Atlantic. In: Advances in Marine Biology, Vol. 19. Academic Press, New York.

Bodholt, H., 1990. Fish density derived from echo-integration and in situ target strength measurements. ICES CM, 1990/B:11, 15 pp.

Carrera, P., Porteiro, C., Valdés, L., 1996. Depth and spatial distribution of blue whiting juveniles in Bay of Biscay. ICES CM, 1996/S:15.

Conan, G.Y., 1985. Assessment of shellfish stocks by geostatistical techniques. ICES CM, 1985/K:30.

Foote, K.G., Ostrowski, M., 1996. Bathymetric conformal variography of the spawning stock of northern blue whiting. ICES CM, 1996/S:46.

Foote, K.G., Knudsen, H.P., Vestnes, G., MacLennan, D.N., Simmonds, E.J., 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. ICES Cooperative Research Report, No. 144.

Fraser, J.H., 1958. The drift of the planktonik stages of fish in the Northeast Atlantic and its possible significance to the stocks of commercial fish. ICNAF, Special Publication No. 1, pp. 289–310.

Jacobsen, J.A., 1990a. Acoustic surveys on blue whiting north of the Faroes in August/September 1988 and 1989. ICES CM, 1990/H:33.

Jacobsen, J.A., 1990b. Acoustic survey on blue whiting north of the Faroes in August/September 1990. WD to the ICES Blue Whiting Assessment Working Group Meeting, Copenhagen, 1990.

MacCall, A.D., 1990. The dynamic geography of marine fish populations. In: Recruitment Fishery Oceanography. Washington Sea Grant. University of Washington Press, Seattle, 153 pp.

Matheron, G., 1971. The theory of regionalised variables and its applications. Les cahiers du CMM, 5, Ecole Nat. Sup. Mines Paris, Fontainebleau, 211 pp.

Maucorps, A., 1979. Le merlan bleu. Scien et Pêche. Bulletin d'Information et de Documentation de l'Institut Scientifique et Technique des Pêches Maritimes, No. 294, pp. 3–13.

Meixide, M., Carrera, P., Miquel, J., 1991. Acoustic abundance estimates of blue whiting off the Spanish Atlantic coast in March–April 1991. ICES CM, 1991/H:29.

Monstad, T., 1993. Observations of blue whiting during summer 1993. WD to the ICES Blue Whiting Assessment Working Group Meeting, Tórshavn, 1993. ICES CM, 1993/Assess:4.

Monstad, T., Belikov, S.V., 1993. Report of the joint Norwegian–Russian acoustic survey on blue whiting, Spring 1993. ICES CM, 1993/H:10.

Monstad, T.S., Belikov, V., Shamrai, E.A., 1996. Report of the joint Norwegian–Rusian acoustic survey on blue whiting, Spring 1996. ICES CM, 1996/H:12.

Nakken, O., Dommasnes A., 1975. The application for an echo integration system in investigations on the stock strength of the Barents Sea capelin (*Mallotus villosus*, Müller) 1971–74. ICES CM, 1975/B:25.

Petitgas, P., 1991. Contribution géostatistiques à la biologie des pêches maritimes. Thèse doctorat. Centre Géostatisteque, Fontainebleau, 211 pp.

Petitgas, P., 1993. Geostatistics for fish stock assessments: a review and an acoustic application. ICES J. Mar. Sci. 50, 285–298.

Petitgas, P., Prampart, A., 1993. EVA (Estimation VAriance). A geostatistical software on IBM-PC for structure characterization and variance computation. ICES CM, 1993/D:65l.

Porteiro, C., Cabanas, J., Valdés, L., Carrera, P., Franco, C., Lavín, A., 1996. Hydrographic features and dynamics of blue whiting, mackerel and horse mackerel in the Bay of Biscay, 1994–1996. A multidisciplinary study on SEFOS. ICES CM, 1996/S:13.

Zar, J.H., 1984. Biostatistical Analysis. 2nd Edition. Prentice-Hall, Englewood Cliffs, NJ.

Zilanov, V.K., 1980. Short results of the Soviet study of blue whiting (*Micromesistius poutassou*, Risso) ecology in North Atlantic. ICES CM, 1980/H:32.