Distribution and abundance of snipefish (*Macroramphosus* spp.) off Portugal (1998-2003)*

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SUMMARY: Data from 10 acoustic surveys targeting sardine (spring and autumn), 3 acoustic surveys targeting blue whiting (spring) and 9 groundfish surveys (summer and autumn) were used to describe the distribution and relative abundance of snipefish (*Macroramphosus* spp.) off Portugal and the Gulf of Cadiz in recent years (1998-2003). Snipefish (8-17 cm) were regularly found off Portugal, occasionally in large concentrations, but were absent from the Gulf of Cadiz. Off northern Portugal, snipefish were distributed along the outer shelf and upper slope, clearly separated from sardine (the most abundant species in the inner shelf) and partially overlapping with blue whiting (*Micromesistius poutassou)*, the most abundant species in the upper slope. Snipefish were most abundant in the outer shelf of south-western Portugal, preferentially distributed in large aggregations around the Canyon of Setubal and partially overlapping with the distribution of boarfish (*Capros aper*) and blue whiting (both abundant in the upper slope of south-western Portugal). Off southern Portugal snipefish were almost exclusively distributed in the outer shelf and were significantly smaller than in south-western (intermediate) and northern Portugal (large). Acoustic estimates of total snipefish biomass ranged between 176 – 504 thousand tonnes within the study period, with more than half off south-western Portugal. Within the period 1998-2003, and despite the lack of directed fishing activity, a marked decline in abundance and a small but significant increase in mean length were observed, particularly off south-western Portugal.

Keywords: *Macroramphosus*, acoustics, distribution, abundance, fish community.

RESUMEN: DISTRIBUCIÓN Y ABUNDANCIA DE TROMPETERO (*MACRORAMPHOSUS* SPP.) EN AGUAS PORTUGUESAS (1998-2003). – Datos de 10 cruceros acústicos dirigidos a la sardina (*Sardina pilchardus*) (primavera y otoño), 3 cruceros acústicos dirigidos a la bacaladilla (*Micromesistius* poutassou) y 9 cruceros demersales (verano y otoño) fueron utilizados para describir la distribución y abundancia relativa del trompetero (*Macroramphosus* spp.) en la costa portuguesa y Golfo de Cádiz en los últimos años (1998-2003). El trompetero (con tallas comprendidas entre 8 y 17 cm) estuvo presente frecuentemente en aguas portuguesas, en ocasiones en elevadas concentraciones y ha estado ausente del Golfo de Cádiz. En las aguas del Norte de Portugal, el trompetero estuvo presente sobre el exterior de la plataforma continental y la parte superior del talud, claramente separado de la sardina (la especie más abundante de la plataforma interior) y sobrepuesto parcialmente a la bacaladilla, la especie más abundante del talud superior. El trompetero fue más abundante en el exterior de la plataforma continental del Sudoeste de Portugal, encontrándose preferencialmente en elevadas densidades alrededor del cañón de Setúbal, solapándose parcialmente al ochavo (*Capros aper*) y a la bacaladilla, ambos abundantes en el talud superior del sudoeste de Portugal. Al sur de Portugal, el trompetero se encontró casi exclusivamente en la plataforma exterior, siendo los individuos significativamente más pequeños que en el sudoeste (medianos) y en el norte (mayores). La estimación acústica de la biomasa del trompetero osciló entre 176000-504000 toneladas en el periodo estudiado, con más de mitad en la zona sudoeste de Portugal. En el periodo de 1998-2003, se verificó un descenso acentuado en la abundancia y un ligero aumento del tamaño medio de los individuos, especialmente en el sudoeste de Portugal.

Palabras clave: *Macroramphosus*; acústica, distribución, abundancia, comunidad de peces.

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INTRODUCTION

Snipefish of the cosmopolitan genus *Macroramphosus* occur within the continental shelf (Oliver and Fernandez, 1974; Brêthes, 1979; Clarke, 1984; Silva, 1999), upper slope (Oliver and Fernandez, 1974; Silva, 1999), and oceanic seamounts (Ehrich, 1976; Fock *et al*., 2002), of all oceans (Fage, 1918). Although some authors (e.g. Morais, 1981), suggest that distribution extends as far north as southern Norway and western Scotland in the north-eastern Atlantic (i.e. > 55° N), snipefish are mainly found between 20 and 40° of latitude in the warm temperate waters of both hemispheres (Brêthes, 1979; Clarke, 1984). Several studies have focused on the taxonomy of the genus (Ehrich, 1976; Clarke, 1984; Assis, 1993), but the definition of the species remains inconclusive. Two species are generally recognized in the north-eastern Atlantic: the long-spine snipefish *M. scolopax* (Linnaeus), originally described as *Balistes scol*opax, and the slender snipefish *M. gracilis*, (Lowe), originally described as *Centriscus gracilis*. The two species are mainly separated by body shape (Brêthes, 1979; Clarke, 1984; Assis, 1993), growth (Brêthes, 1979; Borges, 2000), and feeding patterns (Brêthes, 1979; Clarke, 1984; Matthiessen *et al*., 2002), although in all cases specimens with intermediate characteristics are found.

Despite the cosmopolitan distribution and the large abundance that snipefish can occasionally attain (Brêthes, 1979; Morais, 1981), relatively little is known on the biology of the species. Snipefish are a fast growing, short-lived species that only reach up to 5-6 years of age and a maximum length of 22.8 cm (Borges, 2000; Borges, 2001). Reproduction mainly takes place in winter (January-March) in the north-eastern Atlantic (Brêthes, 1979; Morais, 1981; Arruda, 1988; Lopes and Farinha, 1996), and the western Mediterranean (Matallanas, 1982). Snipefish are considered to spawn once within the reproductive season, although histological samples of female gonads have shown the simultaneous presence of oocytes ranging from <100 to >500 mm in the maturing gonad (Arruda, 1988). Very little is known on the early life history of snipefish, although the morphological characteristics of snipefish post-larvae are well described (Fage, 1918), and large densities of snipefish eggs and larvae have been identified within the continental shelf and upper slope of the western coast of the Iberian peninsula (Lopes and Farinha, 1996). Post-larvae metamorphose at approximately 4.5 – 5 cm and juveniles assume a more demersal distribution (Brêthes, 1979).

Snipefish are frequently found in the Portuguese continental shelf, where they occasionally create large schools of high densities (Morais, 1981; Silva, 1999). Snipefish have been relatively abundant off Portugal at least since the 1960s, but commercial landings were first reported in 1971, mainly in a few ports of south-western and southern Portugal (Morais, 1981). In the early 1970s snipefish were mainly landed as bycatch by purse seiners, particularly when sardine (*Sardina pilchardus*, Walbaum) were scarce. At that time, snipefish catches of 25-30 tonnes per boat per day were often reported and annual landings by purse seiners peaked at around 10000 tonnes in 1973 (Morais, 1981). During the late 1970s demersal trawls became the main gear landing snipefish (mainly in the outer shelf, between 120-180 m depth) and total annual catches peaked at 33000 tonnes in 1978 (Morais, 1981). In the 1980s some effort was put into developing cost-efficient heading and gutting techniques for reducing snipefish to fishmeal (Knyszewski, 1988), but this never passed the experimental phase due to a marked decline in abundance during the 1980s. The commercial exploitation of snipefish by Portuguese fishing vessels is currently very limited (practically non-existent), usually contributing to the discarded component of the bycatch. However, snipefish are an important component of the marine ecosystem, frequently found in the stomachs of several demersal species (Silva, 1999; Cabral and Murta, 2002), and pelagic (Barreiros *et al*., 2003), fish predators, sea birds (Granadeiro *et al*., 1998), and marine mammals (Silva, 1999), in the Portuguese continental shelf and the Azores.

A few studies have described the spatial distribution of snipefish and provided estimates of abundance and its inter-annual variation: (Oliver and Fernandez, 1974), in the Gulf of Cadiz; (Anonymous, 1978) off Portugal; (Brêthes, 1979) off Morocco; (Fock *et al*., 2002) in the Meteor Bank. Here, we review spring and autumn Portuguese acoustic surveys targeting sardine, and summer and autumn groundfish surveys targeting demersal species to provide estimates of snipefish distribution and abundance within the continental shelf and upper slope of Portugal and the Gulf of Cadiz during the period 1998-2003. Additional data from three spring acoustic surveys targeting blue whiting (*Micromesistius poutassou*, Risso) are used to

TABLE 1. – Summary information of the Portuguese acoustic surveys targeting sardine used for estimating snipefish distribution and abundance off Portugal and the Gulf of Cadiz: survey period, total number of miles in the survey (Nt), number of miles with sardine (Nsar) and snipefish (Nsni), total number of fishing stations (Ht) and number of stations with snipefish (Hsni) and acoustic energy attributed to sardine (Esar) and snipefish (Esni).

Survey	Period	Nt	Nsar	Nsni	Ht	Hsni	Esar	Esni
Spring 1998	06/3-08/4	1038	420	81	43	1	4275	1708
Autumn 1998	14/11-13/12	1008	370	61	53	0	4211	1800
Spring 1999	05/3-01/4	902	210	102	30	3	2588	1362
Autumn 1999	25/11-20/12	1008	240	62	22	1	1969	1328
Spring 2000	10/3-08/4	950	246	135	31	4	2695	1374
Autumn 2000	08/11-16/12	974	279	43	41	1	6100	1012
Spring 2001	12/03-19/04	942	204	60	43	3	4054	693
Autumn 2001	07/11-07/12	942	324	51	32	1	5437	652
Spring 2002	06/03-20/04	1010	303	71	37	1	4668	581
Spring 2003	06/02-09/03	992	305	31	23	2	3331	719

describe snipefish distribution in the outer shelf and the upper slope of northern Portugal (here defined as the depth strata of 100-200 m and >200 m respectively). Acoustic estimation of snipefish abundance is mainly based on empirical species identification from the echograms and biological data on the length distribution and length weight relations from the groundfish surveys. Uncertainties associated with the acoustic estimates of abundance are highlighted (impact of assumed target strength, problems in acoustic identification of species, incomplete offshore coverage in sardine acoustic surveys) and the series of abundance estimates is used to describe the importance of snipefish in the fish community off Portugal and its evolution in recent years. Although most recent evidence points to the presence of two distinct species, for the purposes of this study we have only been able to consider the *Macroramphosus* spp. complex.

MATERIAL AND METHODS

Description of surveys

The acoustic estimation of snipefish distribution and relative abundance was primarily based on acoustic surveys targeting sardine. These surveys are performed annually within the continental shelf of Portugal and the Gulf of Cadiz during spring (March) and autumn (November) to provide estimates of sardine abundance at age for assessment purposes (e.g. ICES, 2003). Although acoustic surveys have been done off the Iberian Peninsula since the late 1970s (e.g. Anonymous, 1978; Morais, 1981), an internationally adopted survey design and estimation methodology were defined in 1986 (ICES, 1986), and revised in 1997 (ICES, 1998), by the Planning Group for Acoustic Surveys in ICES Sub-Areas VIII and IX. Until 1997 echo-integration was performed both during the day and night, but from the spring of 1998 onwards, sardine acoustic surveys have only been performed during daytime. In this study, we have opted to use only the most recent surveys (1998-2003, Table 1) to avoid additional problems with snipefish identification from echograms collected during the night (when snipefish schools are less clearly defined).

The study area of sardine acoustic surveys is delimited by the 20 m and 200 m isobaths, from the river Minho in the north (41.86° N, 8.9° W) to the inner Gulf of Cadiz in the south (36° N, 6° W) (Fig.

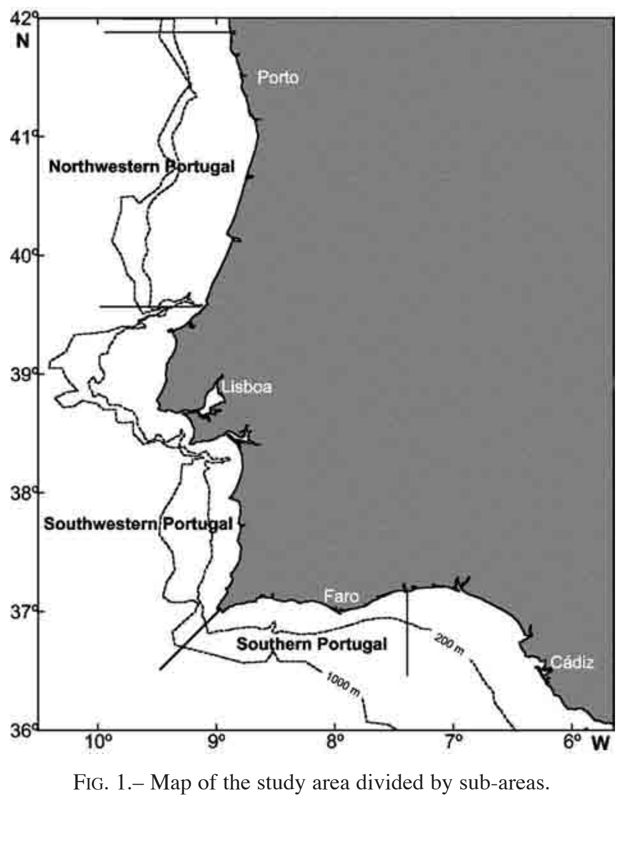

FIG. 1.– Map of the study area divided by sub-areas.

TABLE 2. – Summary information of the Portuguese acoustic surveys targeting blue whiting used for estimating snipefish distribution and abundance off northern Portugal: survey period, latitude range, acoustic energy attributed to snipefish (Es), number of miles in the survey (Nt), miles with snipefish (Ns), total number of fishing stations (Ht) and number of stations with snipefish (Hs).

Survey	Period	Latitude	Es	Nt	Ns	Ht	Hs
Spring 1998	14/5-31/5	39.6-41.8	229	293	38	23	6
Spring 1999	10/2-28/2	38.6-41.8	1088	367	96	26	9
Spring 2000	2/5-10/5	40.0-41.8	512	230	75	15	4

1), following a fixed parallel grid of 69 cross-shelf transects with a mean distance of 8 nautical miles between them. In all surveys, average survey speed was 10 knots and the acoustic signals were integrated over intervals of one nautical mile, using a hull-mounted Simrad 38 kHz EK500 scientific echo sounder with a nominal beam angle of 8^o. The backscattered acoustic signal was registered in hardcopy and, since 2000, has also been digitalized using the software MOVIES (Weill *et al*., 1993). Prior to each survey an acoustic calibration with a copper sphere was carried out following the procedures described by Foote *et al*. (1981). Biological data for species identification, length distribution, length/weight and age/length relations were collected in fishing stations with pelagic or bottom trawls. However, as the surveys predominantly targeted sardine and the distribution of sardine and snipefish generally did not overlap, the biological information collected for snipefish during the surveys was inadequate for acoustic estimation (Table 1). Additional information from three acoustic surveys targeting blue whiting was used to describe the distribution of snipefish in the upper slope of northern Portugal, an area insufficiently covered by sardine acoustic surveys (Table 2).

Information on snipefish bathymetric distribution and biology was obtained from groundfish surveys routinely performed off Portugal to provide abundance and recruitment indices for the assessment of species with commercial interest, such as hake (*Merluccius merluccius*, Linnaeus) and horse mackerel (*Trachurus trachurus*, Linnaeus). These surveys took place in summer (July) and autumn (October) and covered an area extending from 41°20’ N (near the Minho river) to 36°30’ N (near the Guadiana river) (Fig. 1). Fishing is performed on fixed stations along pre-defined depth strata (from 20 to 750 m depth), separately within broad geographical areas. Although groundfish surveys have been performed off Portugal since 1979, only the surveys within the period 1998 – 2002 were considered in this study (Table 3). Most of these surveys were performed onboard the RV *Noruega* using a bottom trawl net (Norwegian Campell Trawl 1800/96 NCT) with a 20 mm codend mesh size and a ground-rope with bobbins. The 1999 surveys were conducted with the RV *Capricórnio* using a bottom trawl net without bobbins in the ground-rope. Tow duration was 60 minutes at a trawling speed of 3.5 knots in all surveys apart from autumn 2002 (for which tow duration was reduced to 30 minutes).

Estimation of abundance indices

Identification of snipefish in the acoustic surveys was mainly based on the empirical scrutiny of the echograms, given that snipefish distribution was inadequately covered in the fishing stations of the sardine surveys (Table 1). Despite the subjectivity that expert decisions introduce to acoustic species identification, visual inspection of the echograms by an experienced acoustician permitted a consistent definition of snipefish schools that was corroborated by the general aspect of the echograms in the few fishing stations dominated by snipefish. Snipefish identification was facilitated by the fact that echograms were only collected during the day, when snipefish are generally known to rise from the bottom and form characteristically large, loose schools with a triangular shape extending from the bottom up to mid water (Anonymous, 1978; Brêthes, 1979).

Abundance estimation for snipefish in the acoustic surveys followed the methodology adopted for the acoustic estimation of sardine (ICES, 1998). The acoustic energy attributed to snipefish was transformed to biomass estimates using an empirical target strength relationship and biological information (length distribution and length-weight relationship) from the samples of autumn groundfish surveys performed within the study period. Estimation of fish density was based on the following relationship between snipefish target strength (TS) and total fish length (L): $TS = 20\log L - 80$ dB. This relationship was derived empirically (Carrera, 2001), to reflect the low acoustic density of large aggregations identified as snipefish by trawling. Snipefish backscattering cross-section is reduced mainly due to the body tilt position of almost 45º while feeding and swimming.

Significant differences in length distribution were detected among areas and periods (prior and after 2001), so a separate length distribution and length-weight relation was applied to each geographical area up to and after autumn 2000.

A relative index of abundance (catch in weight per hour fishing) was also estimated for the groundfish surveys used in this study, following the methodology described by Cochran (1977) for stratified sampling. Strata at areas deeper than 500 m were excluded from the estimation since preliminary analysis indicated that snipefish did not occur at those depths. Estimates were separately obtained for depths below and above 200 m within each geographical area. These estimates were used to provide a broad indication of the level of negative bias introduced into acoustic estimates of snipefish due to inadequate offshore coverage. An overall index of relative abundance was also estimated for each groundfish survey to be compared with the series of acoustic estimates of abundance within the study period.

Statistical analysis

The depth distribution of snipefish and acoustically similar species (boarfish – *Capros aper*, Linnaeus and blue whiting) from the groundfish surveys were described by the Generalized Additive Model (GAMs), using the library mgcv (Wood, 2001), of the software R. A binomial error distribution with a logit link function was applied to the presence/absence data of all surveys within the study period (species presence was defined as the presence of more than 0.5 kg h^{-1} of each species in a station in order to eliminate the impact of some hauls where very few individuals were present). A depth:area interaction was considered to account for different depth distributions among geographical areas of the Portuguese coast. The significance of the interaction and the appropriate level of smoothing for the depth variable were defined by the generalized cross validation score (Wood, 2001), and the adequacy of the fitted models was examined by standard residual plots. Spatio-temporal differences in the length distribution of snipefish from the autumn groundfish surveys were explored using continuation-ratio logit models (Rindorf and Lewy, 2000). The method permits the statistical comparison of samples of length distributions, considering the effects of both continuous (length) and discrete (geographical area and period) variables. Unlike Rindorf and Lewy (2000), the effect of length was fitted by a smooth spline (instead of a high order polynomial) using the GAM estimation framework of the library mgcv (Wood, 2001). Length-weight relations were obtained by non-linear regression applied to the pooled biological data of the autumn groundfish surveys, separately for each geographical area and period.

RESULTS

Tables 1-3 summarize the acoustic and trawl surveys used to describe snipefish distribution and abundance off Portugal and the Gulf of Cadiz during the period 1998-2003. Snipefish were identified in all surveys, being present in 3-14% of the sampled miles of the sardine acoustic surveys (continental shelf), in 13-33% of the blue whiting acoustic surveys (outer continental shelf and upper slope) and in 19-48% of the fishing stations in the groundfish surveys (continental shelf and slope). Frequency of snipefish presence declined over the study period, as seen both by the declining proportion of miles with snipefish in the sardine acoustic surveys (Table 1) and by the reduction in the proportion of groundfish stations containing snipefish over time (Table 3). This decline is also reflected in the total energy attributed to snipefish during the acoustic surveys

TABLE 3. – Summary information of the Portuguese groundfish surveys used for estimating snipefish distribution and abundance: survey depth range, total number of fishing stations (Ht) and number of stations with snipefish (Hs), median and inter-quartile range of snipefish bio mass (kg) per hour fishing within stations with snipefish presence in each survey.

Survey	Period	Depth (m)	Ht	Hs	Snipefish CPUE (Kg h-1)		
					Median	Mean	IQ Range
Summer 1998	05/07- 29/07	37-675	87	42	330	770	737
Autumn 1998	09/10-10/11	40-708	96	36	1	754	131
Summer 1999	12/07-02/08	44-703	65	28	147	951	1008
Autumn 1999	29/10-22/11	41-666	79	29	5	234	59
Summer 2000	19/07-14/08	37-676	88	27	41	464	382
Autumn 2000	07/10-05/11	37-702	78	25	1	765	8
Summer 2001	06/07-31/07	35-544	83	23	25	611	252
Autumn 2001	10/10-03/11	40-445	58	11	15	2214	1767
Autumn 2002	06/10-31/10	30-370	66	13	1	5	1

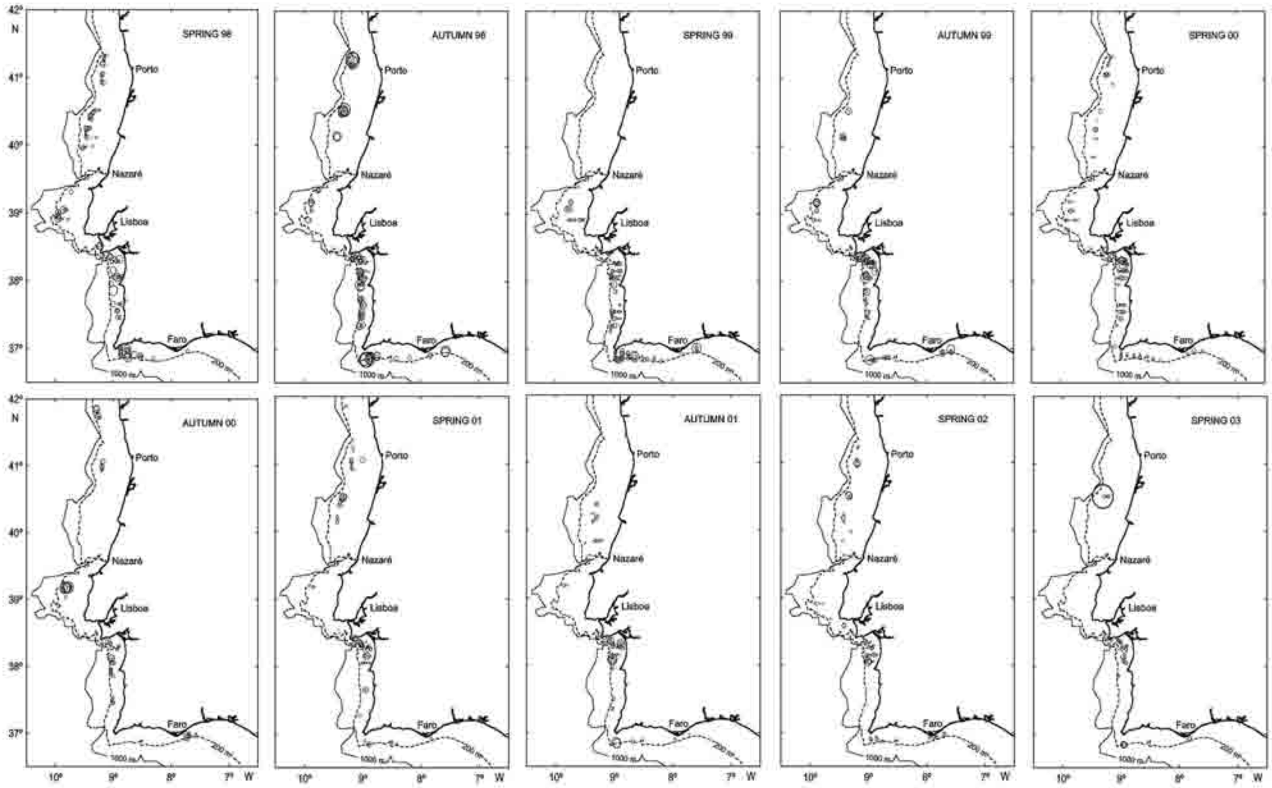

FIG. 2.– Distribution and relative abundance of snipefish in the Portuguese acoustic surveys of autumn and spring (1998 – 2003). Point size is proportional to the acoustic energy allocated to snipefish in each mile.

and the median biomass per hour fishing in the groundfish surveys. However, these survey data also indicate that snipefish distribution is patchy, with a few, large aggregations dominating the survey estimates (for example, maximum snipefish catch is larger than 5 tonnes per hour fishing in most groundfish surveys, while the mile with the highest snipefish density in each acoustic survey contributes 7-17% of the total energy attributed to the species).

Figure 2 shows snipefish distribution and relative abundance off Portugal and the Gulf of Cadiz based on the echograms of the 10 acoustic surveys (NASC- Nautical Area Scattering Coefficient- attributed to snipefish per nautical mile) that targeted sardine from spring 1998 to spring 2003. Figure 3 provides the same information off Portugal based on the catch data (Kg h^{-1}) from the 9 groundfish trawl surveys from summer 1998 to autumn 2002. These data indicate that snipefish were regularly present off the western and southern coasts of Portugal during the study period, but were absent from the Gulf of Cadiz. Off northern Portugal (where the continental shelf is widest), snipefish were exclusively distributed along the outer shelf and upper slope, with fewer observations in the most recent surveys. Snipefish were always detected off northern Portugal except for during the spring 1999 acoustic survey, but this was due to a reduced offshore coverage in that year (Fig. 5). Both sets of surveys seem to indicate that snipefish were most abundant off south-western Portugal during the study period, mainly distributed in large aggregations around the Canyon of Setubal. There is an indication of a reduction in snipefish abundance off south-western Portugal over time, particularly in the acoustic data. Finally, off southern Portugal snipefish were mainly found close to the edge of the continental shelf, with a clear indication of a reduction in abundance over time in the acoustic data.

Although the acoustic data are better suited to describing the spatial distribution of snipefish within the continental shelf, only the groundfish survey data provide an unmistakable identification of snipefish and cover the entire bathymetric distribution of the species. Given that the acoustic identification of snipefish can be confused with that of blue whiting (particularly at night) and boarfish (for which little information exists), the pooled data from the 9 groundfish surveys were used to describe the broad patterns of the bathymetric distribution of these species and the degree of their spatial overlap, separately for each geographic area (northern,

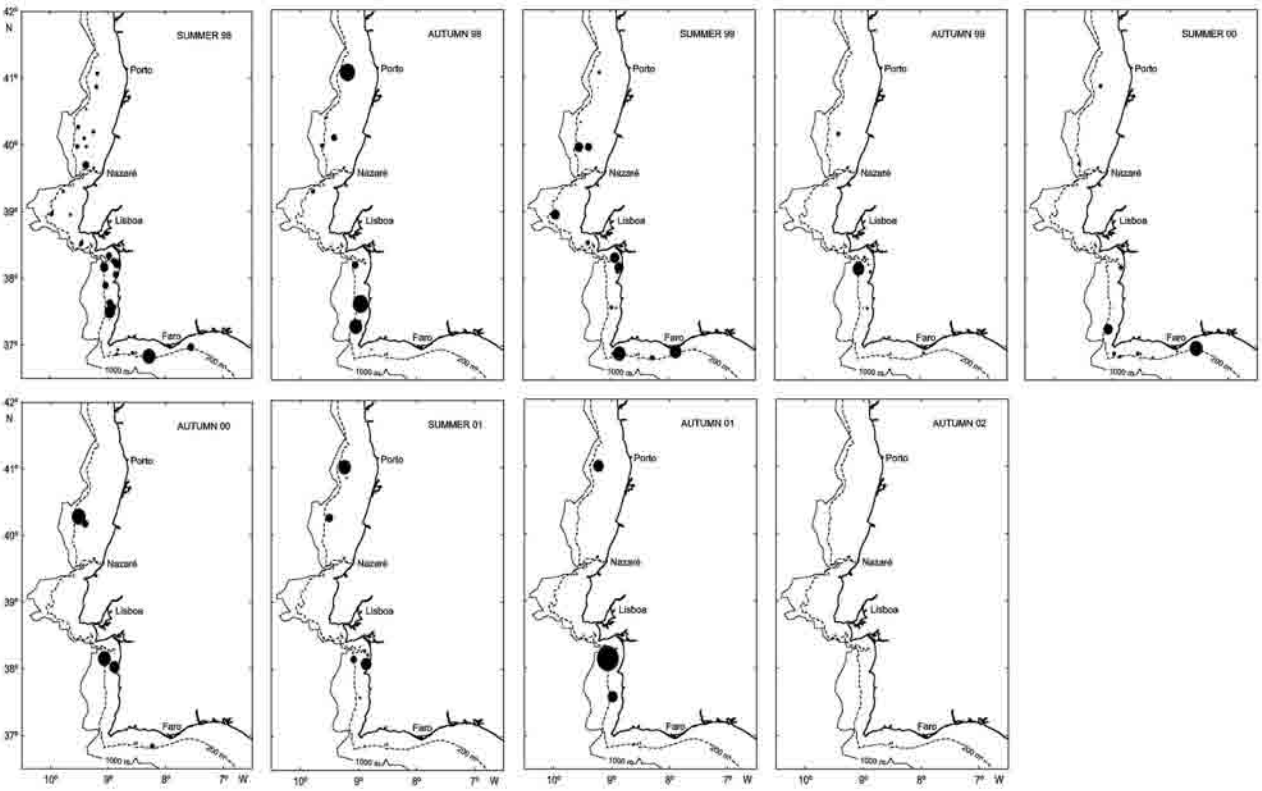

FIG. 3.– Distribution and relative abundance of snipefish in the Portuguese groundfish surveys of summer and autumn (1998 – 2002). Point size is proportional to catch per unit of effort (kg h^{-1}).

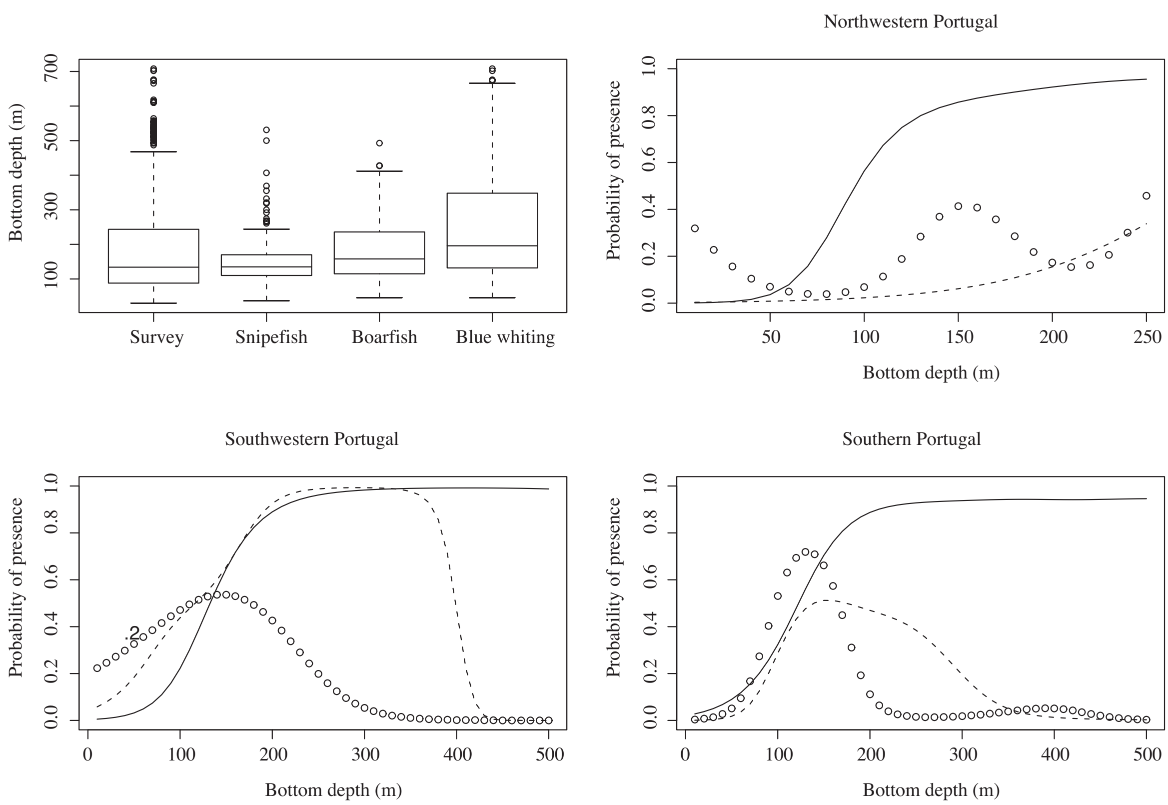

FIG. 4.– Depth distribution of snipefish, boarfish and blue whiting in the groundfish surveys of 1998-2002 overall and by geographical area. Probability distributions result from a GAM with a binomial error distribution accounting for a depth:area interaction for each species (snipefish – points; boarfish – broken line; blue whiting – solid line).

TABLE 4.– Total number of groundfish stations (Nt) according to the geographical area and depth stratum (shelf: <= 200 m; slope: >200 m) during the period 1998-2002, number of stations with snipefish (Ns), boarfish (Nb) and blue whiting (Nw), and median index of abundance (kg per hour fishing, given species presence) for snipefish (Bs), boarfish (Bb) and blue whiting (Bw) respectively.

Area	Depth	Nt	Ns	Nb	Nw	Bs	Bb	Bw
North-west	Shelf	221	53	54	119	21.5	0.1	70.0
	Slope	34	8	15	33	14.9	0.1	65.0
South-west	Shelf	142	85	98	65	60.0	25.9	34.0
	Slope	104	17	68	102	0.4	118.5	93.0
South	Shelf	110	56	54	40	19.5	0.6	121.0
	Slope	89	5	29	86	0.1	0.1	18.3

south-western and southern Portugal). The GAMs fitted to the presence/absence data of the three species indicated a significant, smooth effect of depth that had a different shape in the three areas (i.e. significant depth:area interaction). The selected models (that did not account for temporal variation) explained 28% of the total deviance for snipefish, 50% for boarfish and 45% for blue whiting.

Figure 4 shows the observed depth distribution of snipefish, boarfish and blue whiting (in comparison to the depth distribution of all fishing stations), as well as the fitted depth effect for the three species in each geographical area. Table 4 shows the frequency of species presence and their relative abundance (median biomass per hour fishing considering only stations with species presence) in the fishing stations, separately for the continental shelf and upper slope of each geographic area. The three species coexist in the outer continental shelf and upper slope of Portugal, although their relative importance varies geographically and with depth. Blue whiting have the widest depth distribution (ca. 100-600 m), being practically omni-present and abundant in the fishing stations of the continental slope across Portugal. Boarfish have an intermediate depth distribution (ca. 100-400 m), being most abundant in the outer shelf and (particularly) upper slope off south-western Portugal (Table 4). Snipefish have the narrowest depth distribution (ca. 100-250 m), being considerably more abundant within the shelf (particularly off south-western and southern Portugal) than the upper slope (Table 4). These results suggest that sardine acoustic surveys cover a large part, but not the entire distribution area of the species off Portugal, while problems in species identification are most likely to occur in south-western Portugal, where the distinction between snipefish and boarfish schools may be inadequate.

Figure 4 also shows that the outer distribution of the three species is inadequately described off north-

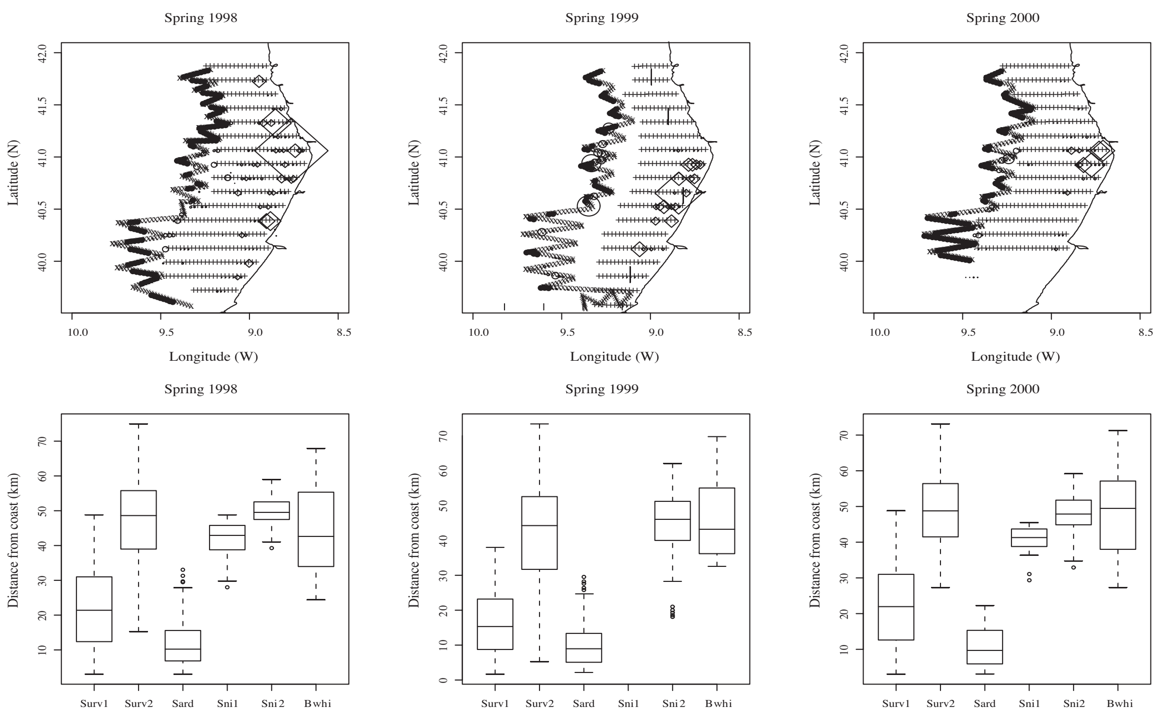

FIG. 5.– Sardine (diamond) and snipefish (circle) relative abundance in the sardine (Surv1) and blue whiting (Surv2) acoustic surveys off northern Portugal in spring 1998-2000 (upper panels) and distribution of distances from the coast for miles with sardine presence (Sard), blue whiting presence (Bwhi), snipefish presence in the sardine survey (Sni1) and snipefish presence in the blue whiting surveys (Sni2) separately for each survey (bottom panels). In the upper panels miles with blue whiting presence are highlighted by black circles.

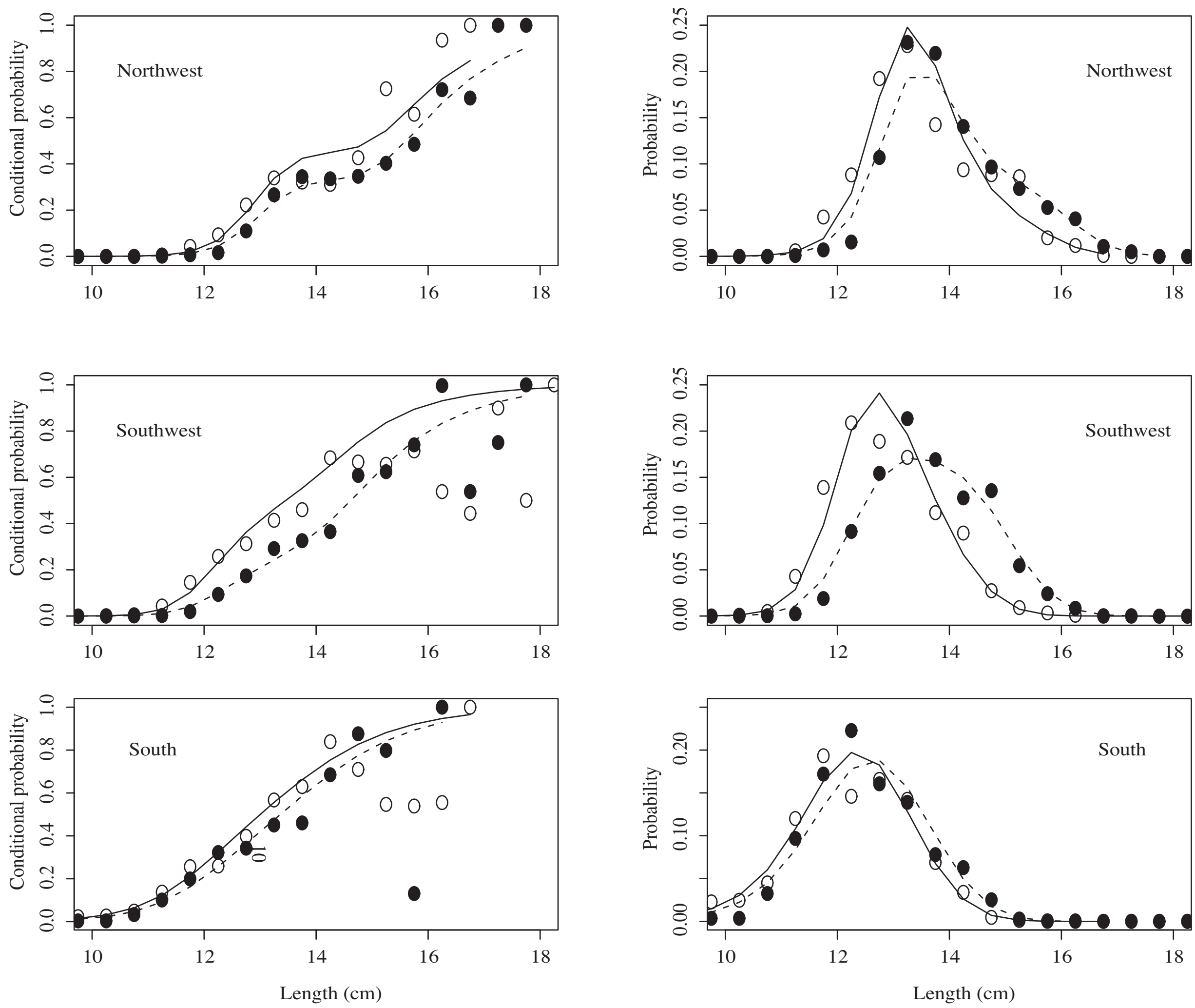

FIG. 6.– Snipefish length distribution off Portugal: conditional (left) and unconditional (right) probabilities of being at length in each geographical area and period (open circles: observations in early period; closed circles: observations in late period; solid lines: model fit in early period; broken lines: model fit in late period).

ern Portugal, where a relatively extended shelf is followed by a steep slope that is poorly sampled in the groundfish surveys. In that area, the three acoustic surveys targeting blue whiting provide additional information on snipefish distribution. Figure 5 shows the acoustic survey distribution of sardine, snipefish and blue whiting in the spring acoustic surveys of 1998 to 2000. Bottom depth was not available in the acoustic surveys and distance from the coast was used as a proxy to describe the bathymetric distribution of these species off northern Portugal. Snipefish and blue whiting were clearly separated from sardine, which was by far the most abundant species in the inner shelf of northern Portugal. These data also confirm that blue whiting has a wider depth distribution than snipefish, and that the sardine acoustic surveys do not cover the offshore distribution of snipefish. The latter was particularly obvious in the spring of 1999 when the transects of the sardine survey were shorter, missing the distribution area of snipefish completely.

Biological data from the autumn groundfish surveys were used to define the appropriate snipefish length distribution and length-weight relationship to be used for acoustic estimation. Following preliminary exploration of the length frequency distribution in each survey, data from various surveys were pooled and the effect of geographical area and period (up to and after autumn 2000) were tested. The GAM fitted to the conditional probability of being at length, given that fish were of this length or greater (binomial error distribution with logit link), revealed highly significant effects of length (smooth), area and period and a significant length:area and area:period interaction. Despite the large overdispersion (due to the pooling of data from various

Table 5.- Summary information of the fitted length-weight relationships (parameters a and b) and the respective length range for each geographical area prior and after October 2000.

Period	Area	a	b	Length Range (cm)	n
1998-2000	Northwest	0.0012	3.58	11.0-15.0	217
	Southwest	0.0027	3.25	10.5-15.0	664
	South	0.0053	3.04	8.5-14.5	695
2000-2002	Northwest	0.0046	3.02	11.5-16.5	522
	Southwest	0.0048	3.081	10.5-17.0	1570
	South	0.0033	3.209	10.5-15.0	1013

hauls and surveys), the resulting model adequately captured the main features of the data (Fig. 6). These results show that snipefish length distribution had a consistent latitudinal trend in the two periods considered (largest fish in the northwest and smallest in the south), and that in the latter period larger snipefish were present in all areas (particularly in south-western Portugal). Based on these results, a separate length-weight relation was calculated for the two periods and used for acoustic estimation in each area (Table 5).

Figure 7 shows acoustic estimates of snipefish abundance (biomass) within the Portuguese continental shelf during the period 1998-2003, separately for each area and overall. The acoustic estimates of sardine biomass in the same period (the most abundant commercial fish species off Portugal) are also presented for comparison. Overall, snipefish abundance off Portugal declined from more than 500 thousand tonnes in 1998 to around 175 thousand tonnes in 2003. This was mainly due to a marked decline off south-western Portugal in 2000 and off southern Portugal in 1999. In these areas, snipefish was more abundant than sardine during the early period and became similarly abundant after the decline. On the contrary, off northern Portugal sardine were more abundant than snipefish throughout the study period, but particularly since the unprecedented sardine recruitment during 2000. It is worth noting that, across Portugal, the year 2000 marks an inversion in the relative abundance of the two species, although the increase in sardine and the

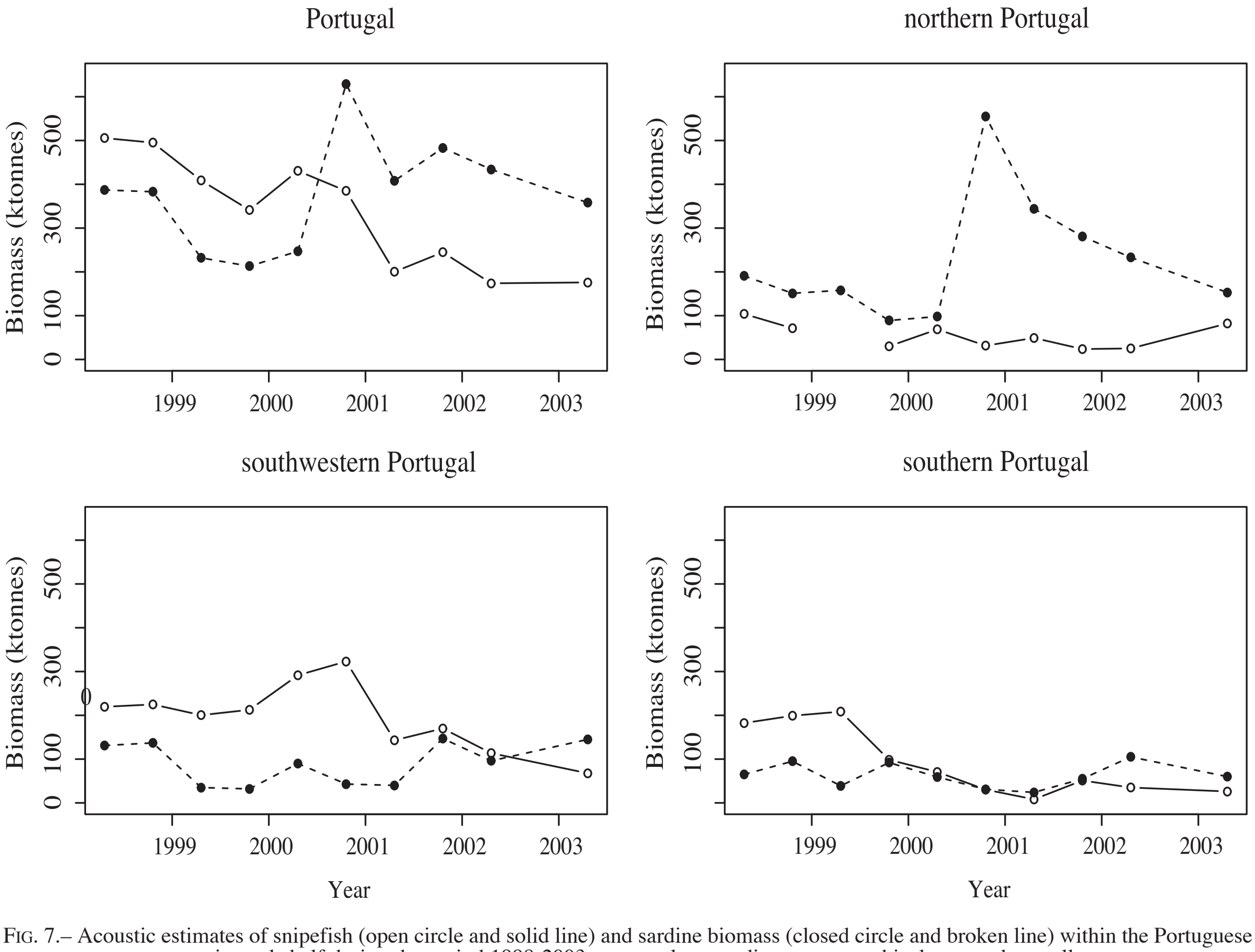

FIG. 7.– Acoustic estimates of snipefish (open circle and solid line) and sardine biomass (closed circle and broken line) within the Portuguese continental shelf during the period 1998-2003, separately according to geographical area and overall.

TABLE 6. – Index of relative snipefish abundance (Kg per hour fishing) according to the geographical area and depth stratum for the 9 groundfish surveys used in this study (1998-2002). The last column provides an overall index of snipefish abundance off Portugal in each survey.

Survey	North-west		South-west		South		Portugal
	Shelf	Slope	Shelf	Slope	Shelf	Slope	All
Summer 1998	192.0	21.1	851.5	52.0	583.1	0.0	322.5
Autumn 1998	724.8	258.0	1422.8	7.5	11.1	0.1	615.8
Summer 1999	224.7	0.7	952.5	0.2	814.7	0.0	378.6
Autumn 1999	19.3	0.0	243.6	0.1	27.0	0.1	57.3
Summer 2000	21.0	43.2	150.6	0.1	343.3	0.0	76.5
Autumn 2000	478.5	0.0	382.2	0.0	63.2	0.0	315.8
Summer 2001	293.0	0.2	200.2	0.0	4.1	0.0	194.2
Autumn 2001	152.0	0.0	1546.5	10.9	17.6	0.0	410.4
Autumn 2002	0.0	0.1	0.4	0.1	0.3	0.0	0.1

decline of snipefish occurred in different geographical areas. Finally, Table 6 provides estimates of relative snipefish abundance in the groundfish surveys of 1998-2002, by area and overall. These estimates indicate that more than 90% of the snipefish biomass was present within the continental shelf and that relative abundance was higher in all areas up to 2000, although the correlation between acoustic and groundfish survey estimates is generally poor, both regionally and overall.

DISCUSSION

This study provides the first detailed description of snipefish distribution and relative abundance off Portugal based on 13 acoustic and 9 groundfish surveys during the period 1998-2003. Although the snipefish data available in these surveys have limitations (none of these surveys targeted snipefish), their combined use indicates the importance of snipefish in the fish community of the Portuguese continental shelf in recent years. Snipefish were among the most abundant fish species of the outer continental shelf of Portugal, generally not overlapping with the bathymetric distribution of sardine (the most abundant species in the inner shelf) and partially overlapping with boarfish and blue whiting (which are most abundant in the upper slope). On the contrary, snipefish were absent during the study period from the Gulf of Cadiz, despite the thorough coverage of its continental shelf during the sardine acoustic surveys. This absence is remarkable given that during the 1970s snipefish were the second most abundant fish species in the outer shelf of the Gulf of Cadiz (groundfish survey described by Oliver and Fernández, 1974), and were extremely abundant off northern Morocco (in spring 1976 an acoustic survey estimated 1300 thousand tonnes of snipefish off Morocco, with 73% of the total biomass in the northern part of the country (Brêthes, 1979)).

The acoustic estimates of snipefish abundance off Portugal during the period 1998-2003 point to a biomass of around 500 thousand tonnes in the early surveys, declining to around 175 thousand tonnes in the most recent one. Despite the uncertainties associated with the acoustic estimation of snipefish abundance, these estimates indicate that snipefish can attain a very large biomass off Portugal and that they can show marked variation in abundance within short time intervals. This is in agreement with the limited information on snipefish off Portugal available from past decades. Early acoustic estimates indicated an average snipefish abundance of around 360 thousand tonnes in the late 1970s, when commercial interest for the species was first registered (Morais, 1981). Acoustic estimates are not available from the 1980s, when the commercial exploitation of snipefish was abruptly ceased due to an alleged decline in abundance. The groundfish surveys undertaken off Portugal during 1985-1988 seem to corroborate the decline in snipefish abundance during that period. Although snipefish were caught in these surveys, their relative abundance was low and it did not form a significant element of any of the five fish assemblages identified for the continental shelf and upper slope of Portugal in the late 1980s (Gomes *et al.*, 2001). Snipefish became increasingly abundant off Portugal again during the early 1990s, being among the most abundant fish species in the groundfish surveys of the period 1990-1997 (Borges, 1998).

The importance of snipefish for the fish community of the outer Portuguese shelf indicated in this study is in agreement with information from feeding studies off Portugal. In the early 1990s, snipefish contributed on average 26% of the number of prey items in the stomachs of large John Dory (*Zeus faber*, Linnaeus) caught in the continental shelf and upper slope of Portugal, forming, together with blue whiting, the most abundant prey species (Silva, 1999). In the same period, snipefish formed part of the diet of hake and mackerel (*Scomber scombrus*, Linnaeus) off Portugal, but unlike blue whiting (dominant fish prey for both hake and mackerel), snipefish importance showed a marked seasonality (Cabral and Murta, 2002). Finally, snipefish were the third most numerous prey (after sardine and blue whiting) in the stomachs of 50 common dolphins (*Delphinus delphis*, Linnaeus) stranded or incidentally caught on the western coast of Portugal during 1987-1997 (Silva, 1999). It is also worth noting that in all cases boarfish were a considerably less important prey, either being absent (mackerel, John Dory) or present in small numbers (hake, dolphins) in the diet of the studied species. On the contrary, boarfish formed part of the species assemblage preyed upon by large fish predators like conger eels (*Conger congrus*, Linnaeus) and monkfish (*Lophius* spp.) on the continental slope of southern Portugal (Santos and Borges, 2001).

This study also revealed geographical and bathymetric patterns in snipefish distribution off Portugal. This information is useful for describing snipefish dynamics and, by comparing it with the distribution patterns of blue whiting and boarfish, can help in evaluating the adequacy of acoustic snipefish estimation. Among the three species coexisting in the outer shelf and upper slope of Portugal and forming schools with similar acoustic characteristics, snipefish had the narrowest depth distribution. Unlike blue whiting and boarfish, snipefish were most abundant within the continental shelf, which justifies using the sardine acoustic surveys to provide a relative index of the species abundance. The negative bias introduced into the acoustic estimates of snipefish due to the inadequate offshore coverage seems to be more important off north-western Portugal, but even there only in 4 of the 9 groundfish surveys was the relative index of offshore abundance more than 10% of that inshore (off south-western and southern Portugal the offshore index never exceeded 6% of the inshore one). Snipefish abundance was highest off south-western Portugal, where boarfish were also very abundant, both seemingly associated with the geographical accident imposed by the Canyon of Setubal. In this area, inadequate separation of acoustic energy between snipefish and boarfish is most likely, although boarfish were considerably more abundant beyond the continental shelf and up to a depth of 400 m.

Snipefish length distribution within the study period ranged from 8.5 to 17 cm, with most fish being between 11 and 15 cm. This distribution is very similar to that observed in previous studies of snipefish off Portugal (Anonymous, 1978; Borges, 2000), and the reconstructed length distribution of snipefish present within the stomachs of stranded dolphins (Silva, 1999). There was also a clear latitudinal gradient in mean snipefish length, with the smallest fish being found off the southern coast, intermediate sizes off south-western Portugal, and the largest fish off northern Portugal. The same geographical pattern was described in the late 1970s (Anonymous, 1978), and in the early to mid-1990s (Borges, 1998), suggesting that the snipefish length gradient off Portugal is a persistent feature of the population. This latitudinal gradient is likely to reflect a northward expansion with increasing age. Snipefish below 12 cm (modal length of age 1 fish in Borges, 2000), were practically absent off northern Portugal within the study period, but were abundant off southern Portugal, particularly until 2000 (Fig. 6). The hypothesis of a northward expansion with increasing age is also supported by the temporal differences in the onset of declining abundance between regions (Fig. 7). Off southern Portugal a marked decline in abundance was observed in 1999, off south-western Portugal a decline was only observed more than a year later, while off northern Portugal the decline was considerably more gradual. An alternative hypothesis for the observed changes in the length distribution of the *Macroramphosus* complex could be related to differences in the distribution and changes in the relative abundance of the two species: if *M. scolopax* (which attains larger sizes and grows faster – Borges, 2000), has a more northerly distribution than *M. gracilis*, the observed changes in length distribution could have resulted from a reduction in the abundance of the latter in the most recent years.

The year 2000 seems to mark a change in the pelagic fish community within the Portuguese continental shelf. Until 2000, the acoustic estimates of snipefish abundance off Portugal were higher than those of sardine, mainly due to the high snipefish biomass off south-western and southern Portugal and the historically low levels of the Iberian sardine stock (e.g. ICES, 2003). In 2000, the unprecedented recruitment of sardine in northern Portugal reversed the decline of the stock, and this was confirmed in subsequent acoustic surveys off Portugal and northern Spain (ICES, 2003). At around the same time, snipefish biomass of Portugal was declining, possibly due to a series of recruitment failures (it should be noted that mean snipefish length after 2000 is larger in all regions). Although the comparison of the absolute levels of sardine and snipefish biomass may be affected by the low target strength assumed for snipefish, there is no doubt that the two species have demonstrated opposing dynamics off Portugal in the recent years. Despite the current lack of commercial interest in snipefish, describing its dynamics and identifying the environmental conditions that affect its reproductive success can contribute to a better understanding of the pelagic ecosystem of the Portuguese continental shelf.

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