ICES Journal of Marine Science, 60: 753–766. 2003
doi:10.1016/S1054–3139(03)00089-4

Demersal assemblages and depth distribution of elasmobranchs from the continental shelf and slope off the Balearic Islands (western Mediterranean)

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Massutí, E., and Moranta, J. 2003. Demersal assemblages and depth distribution of elasmobranchs from the continental shelf and slope off the Balearic Islands (western Mediterranean). – ICES Journal of Marine Science, 60: 753–766.

The analysis of 131 hauls from four bottom trawl fishing surveys carried out between depths of 46 and 1713 m in two different areas off the Balearic Islands yielded a total of 23 elasmobranch species belonging to eight families. Cluster analysis and multidimensional scaling (MDS) ordination were applied to detect zonation patterns and some ecological parameters (e.g. species richness, abundance and biomass, mean weight, diversity and evenness) were calculated for each assemblage. For each area, analysis of similitude (ANOSIM) and similarity percentage analysis (SIMPER) were also applied to detect differences between seasons and depths. For the most important species (*Galeus melastomus*, *Scyliorhinus canicula*, *Centroscymnus coelolepis*, *Etmopterus spinax*, *Squalus blainvillei*, *Raja naevus*, *Raja asterias*, *Raja clavata*, *Raja miraletus* and *Raja oxyrhinchus*), abundance and size distributions were analysed by depth.

Keywords: Balearic Islands, bathymetric distribution, community structure, demersal elasmobranchs, length frequency, trawl surveys, western Mediterranean.

Received 8 October 200220January2002; accepted 31 March 200317March2003.

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Introduction

There have been numerous descriptions of the demersal fish assemblages in the Mediterranean Sea (e.g. Stefanescu *et al.*, 1992; Papaconstantinou *et al.*, 1994; Matarrese *et al.*, 1996; among others). However, these studies include both selachians and teleosts. The only papers related exclusively to demersal elasmobranch assemblages are those by Capapé *et al.* (2000) in the Gulf of Lions, Relini *et al.* (2000) in Italian waters and Bertrand *et al.* (2000) in the northern Mediterranean. The latest study covered the whole area, from the Strait of Gibraltar to the Aegean Sea, but did not include the Balearic Islands. Papers on Mediterranean elasmobranchs are more numerous, but they are focused on the distribution and biology of certain species.

In the Mediterranean, there has been an increasing international concern about changes in the abundance and diversity of elasmobranchs. There is increasing evidence that fishing exploitation affects their composition and biodiversity to a greater extent than most teleosts (Stevens *et al.*, 2000). This applies to the Mediterranean Sea, in which there is a high level of exploitation over the continental shelf and upper slope down to a depth of 800 m. Evidence of changes in the number of elasmobranchs and decreases in the abundance and biomass of some species (e.g. *Raja clavata*) throughout the last decade have been reported for the highly exploited area Gulf of Lions (Aldebert, 1997; Bertrand *et al.*, 1998). Elasmobranchs are widespread, although not too specious, resulting in an interesting group for biodiversity process studies.

This paper characterises the assemblages of demersal elasmobranch on the bottom trawl fishing grounds along the continental shelf and upper slope, and in unexploited deeper areas of the middle and lower slope, off the Balearic Islands. Experimental trawl surveys are analysed for the main species in terms of species composition, community structure and distribution and population structure. Our aim was to provide information relating to the diversity and abundance of elasmobranches, which could serve as a reference for the monitoring of future trends in the same area and would allow comparison with other Mediterranean areas.

Materials and methods

Data were collected from 131 hauls made during four bottom trawl surveys off the Balearic Islands (Figure 1). Surveys were carried out in two different seasons (spring and autumn) and two different areas: around Mallorca and Menorca (northern area), and south of Eivissa and Formentera (southern area).

Hauls in the northern area were made between 40 and 800 m depth during the BALAR cruises, on board the R/V "Francisco de Paula Navarro" (length: 30 m; engine power: 1100 hp) in April 2001 (41 hauls) and September–October 2001 (44 hauls). Hauls in the southern area were made between 200 and 1800 m depth during the QUIMERA cruises, on board the R/V "García del Cid" (length: 37 m; engine power: 1500 hp) in October 1996 (32 hauls) and May 1998 (14 hauls). In each haul, fish were sorted and abundance, biomass and length frequency (total length, in cm) of each species determined.

Different sampling gears were used in each area. In the northern area, a GOC73 trawl towed by two warps at 2.8 knots was used. This gear has been used since 1994 by most surveys carried out in the Mediterranean Sea (Abelló *et al.*, 2002). In the south area, an OTMS-27.5 benthic trawl was towed by a single warp at 2.5 knots (Sardà *et al.*, 1998). In both cases, the arrival and departure of the net at the bottom, as well as its horizontal and vertical openings (on average, 16.4–2.8 m for the GOC73 and 14.0–1.9 m for the OTMS-27.5) were measured using a SCANMAR system. The position at the start and the end of each trawl was recorded using Global Position System (GPS). Using this information, catch data was standardised to a common sampled area of 10 000 m^2.

Trawl selectivity is mainly dependent on mouth area, mesh size, towing speed, power of the vessel and whether the net is towed on one warp or two (e.g. Merrett *et al.*, 1991; Gordon *et al.*, 1996). To avoid possible differences, no comparisons were made between areas.

For each area, data on standardised abundance, biomass and mean fish weight were plotted over a depth axis to display trends with depth. The PRIMER package was used to analyse the abundance and biomass matrices of species composition (Clarke and Gorley, 2001). To identify assemblages, cluster analysis and multidimensional scaling (MDS) were applied after square root transformation. The Bray–Curtis index was chosen as the similarity coefficient and the UPGMA was applied to link samples into clusters. Samples in which only one species was caught (36), and species recorded in less than 5% of samples (13) were omitted from the analysis, since it was statistically more informative than when all samples and species were included. Analysis of similitude (ANOSIM) and similarity

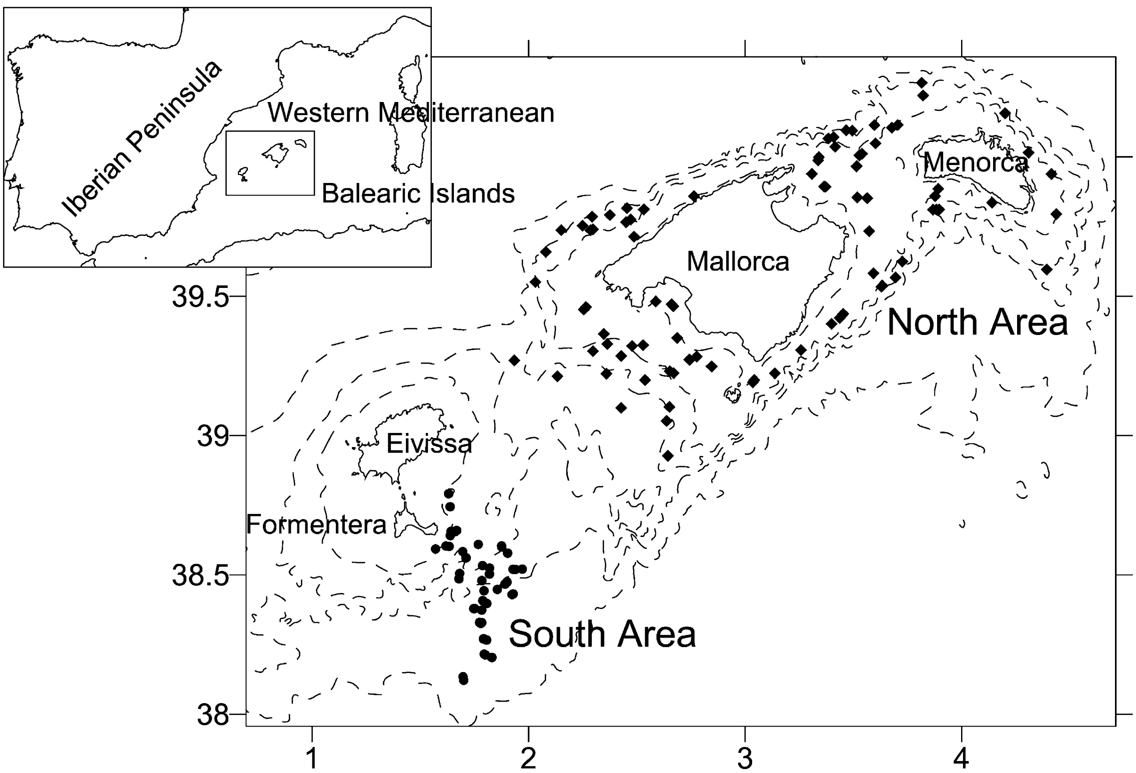

Figure 1. Location of the two areas studied off the Balearic Islands (south and north; showing the 50, 200, 600, 1000 and 2000 m isobaths) and the trawl stations surveyed during the different surveys: BALARs (♦) and QUIMERAs (●).

percentage analysis (SIMPER) were also applied to detect differences between seasons and depths. The ecological parameters, species richness and mean species richness, total abundance and biomass, mean fish weight and the Shannon–Wiener diversity index (H′) and evenness (J′) were also calculated in each group resulting from the cluster analysis.

To show the bathymetric distribution of the main species along the whole depth range surveyed, the standardised mean abundance (fish per 10 000 m^2) was calculated in each area at 10 established depth intervals. The overall length frequency distribution by sex was also calculated for these species. For the most abundant, the length frequency distribution was calculated by each of the depth intervals considered.

Results

A total of 6402 specimens (789 kg of biomass) belonging to 23 elasmobranch demersal species and eight families were collected from 131 bottom trawls carried out between 40 and 1800 m depth in two different areas off the Balearic Islands (Table 1). In the northern area (40–800 m depth-strata) 22 species (5379 specimens; 630 kg) were caught, while in the south (200–1800 m depth-strata) 10 species (1023 specimens; 159 kg) were caught. In both areas, the most abundant species were *Galeus melastomus* and *Scyliorhinus canicula*. Other important species in the overall assemblage were the sharks *Etmopterus spinax*, *Squalus blainvillei* and *Centroscymnus coelolepis*. Rays were captured almost exclusively in the northern area, with *Raja miraletus*, *Raja clavata*, *Raja asterias*, *Raja naevus* and *Raja oxyrhinchus* being the most important species. The remaining species were captured occasionally over the whole area.

In both areas, the bathymetric distribution of standardised abundance and biomass of elasmobranches, as well as mean fish weight, showed similar trends above a depth of 800 m (Figure 2). Abundance reached its maximum between 300 and 400 m depth, whereas the biomass had minimum values around 500 m and mean fish weight reached its minimum between 400 and 500 m. In the southern area, abundance and biomass values showed a decreasing trend below depths of 500 and 800 m, respectively, while mean fish weight remained constant below 800 m.

The similarity dendrograms for the trawls revealed the existence of four assemblages, which were confirmed by the MDS analysis (Figures 3 and 4), with the bathymetric gradient being the factor of association, without seasonal differences. In the northern area (Figure 3), the first cluster separated samples taken above a depth of 235 m (SH) from the rest, which were grouped in two depth intervals: 326–632 m (SL1) and 624–745 m (SL2). In the southern area (Figure 4), the first cluster separated samples taken above

Table 1. Elasmobranch species caught between depths of 40 and 1800 m during BALAR and QUIMERA trawl surveys carried out in two different areas off the Balearic Islands. Total abundance (A; in number of specimens) and biomass (B; in kg), frequency of occurrence (F) and depth range (D; in metres) are shown by species for each surveyed area.

		Northern area				Southern area			
Family	Species	A	B	F	D	A	B	F	D
Scyliorhinidae	*Galeus melastomus* Rafinesque, 1810	2471	135.43	38	101–745	563	88.49	73	239–1713
	Scyliorhinus canicula Linnaeus, 1758	2440	261.75	67	44–416	305	14.56	18	195–402
Triakidae	*Mustelus asterias* Cloquet, 1821	1	0.17	1	103	–	–	–	–
	Mustelus mustelus Linnaeus, 1758	1	0.76	1	68	–	–	–	–
Squalidae	*Centrophorus uyato* Rafinesque, 1810	1	3.96	1	686	5	4	2	802
	Centroscymnus coelolepis Bocage and Capello, 1864	–	–	–	–	39	23.22	29	1012–1713
	Dalatias licha Bonnaterre, 1788	2	3.73	2	624–698	5	9.01	9	595–892
	Etmopterus spinax Linnaeus, 1758	65	5.90	19	616–745	76	13.31	53	311–1416
	Squalus blanvillei Risso, 1826	53	39.95	7	103–649	24	2.4	2	241
Torpedinidae	*Torpedo nobiliana* Bonaparte, 1835	1	0.22	1	371	–	–	–	–
	Torpedo marmorata Risso, 1810	5	0.87	6	108–180	–	–	–	–
Rajidae	*Raja oxyrinchus* Linnaeus, 1758	23	21.43	11	235–444	–	–	–	–
	Raja naevus Müller and Henle, 1841	44	15.52	18	52–337	4	1.602	4	908
	Raja asterias Delaroche, 1809	42	20.63	20	44–399	5	2.19	4	195–264
	Raja brachyura Lafont, 1873	1	0.67	0	70	–	–	–	–
	Raja clavata Linnaeus, 1758	92	83.26	28	85–400	–	–	–	–
	Raja miraletus Linnaeus, 1758	112	20.56	32	69–399	–	–	–	–
	Raja montagui Fowler, 1910	2	1.12	1	77	–	–	–	–
	Raja polystigma Regan, 1923	7	2.14	4	63–127	1	0.22	2	398
	Raja undulata Lacepède, 1802	1	1.40	1	53	–	–	–	–
Dasyatidae	*Dasyatis pastinaca* Linnaeus, 1758	3	3.92	4	41–53	–	–	–	–
Myliobatidae	*Myliobatis aquila* Linnaeus, 1758	10	10.69	4	41–46	–	–	–	–
Chimaeridae	*Chimaera monstrosa* Linnaeus, 1758	2	0.15	2	494–538	–	–	–	–

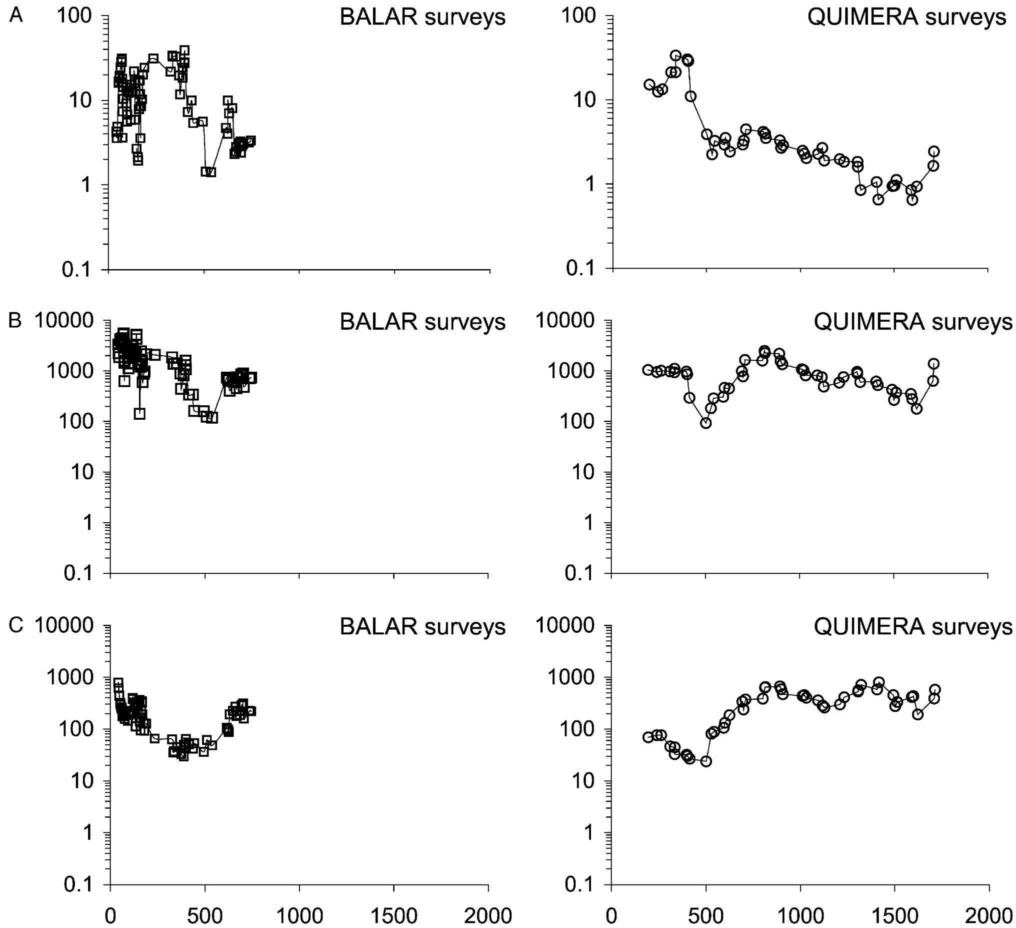

Figure 2. Distribution by depth of the standardised abundance (A: fish per 10 000 m^2) and biomass (B: g 10 000 m^{-2}) and the mean weight (C: g per fish) of elasmobranchs captured during bottom trawl surveys carried out in two areas off the Balearic Islands.

a depth of 264 m (SH) from the rest, which were grouped in three depth intervals: 335–415 m (SL1), 502–1322 m (SL2) and 1416–1713 m (SL3).

The values of some ecological parameters in the different assemblages by area are given in Table 2. Large differences were obtained in species richness, with highest (17) and lowest (3) values in the SH and SL3 assemblages of the northern and southern areas, respectively. By contrast, mean species richness was similar in all assemblages and ranged between 1.5 in the SL3 of the south area and 2.8 in the SH and SL1 of the northern area. Although different sampling gear was used, mean abundance by assemblage was similar between areas, with maximum values (21–25 fish per 10 000 m^2) for the SL1 assemblage. In the northern area, the highest mean biomass was for SH (2.5 kg 10 000 m^{-2} from GOC73), with a value very different from the rest. In the southern area, mean biomass were also similar among assemblages, except for SL3, which showed the lowest value (0.46 kg 10 000 m^{-2} from OTMS-27.5). In the northern area, the highest diversity and evenness were obtained for SH, while in SL1 and SL2 these parameters showed similar values. In the southern area, diversity was higher in the SH and SL2 assemblages, while maximum evenness was obtained for the SL2 and SL3 assemblages.

In both areas, the ANOSIM analysis showed no seasonal differences, in terms of abundance and biomass, but a high dissimilarity between assemblages obtained from cluster and MDS analyses (Table 3). No differences were obtained only between the SH and SL1 assemblages from the south area. In all other instances, either abundance, or biomass or both were significantly different. The results of the SIMPER analysis showed the separate contributions, in terms of abundance, of the most important species to the average similarity within each assemblage and the average dissimilarity between them (Tables 4 and 5). These results indicated a high dissimilarity between assemblages and confirmed the existence of well-defined groups, with changes in the abundance of the main species. In the

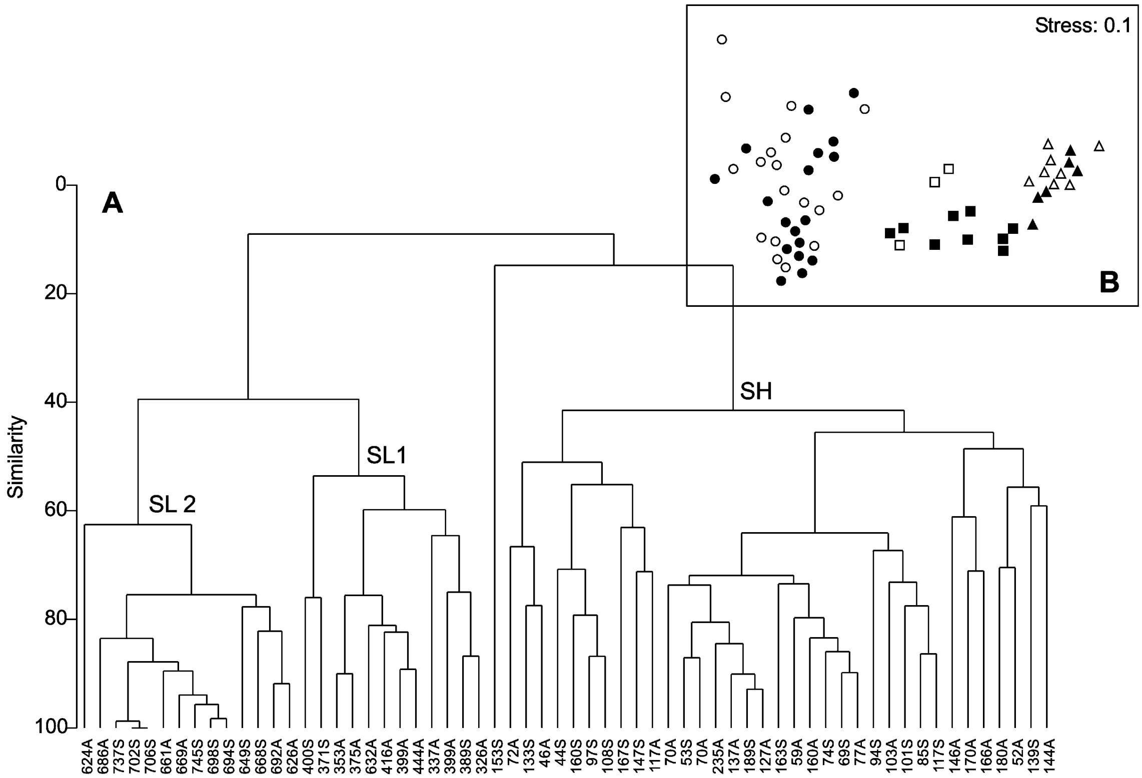

Figure 3. Dendrogram (A) and MDS ordination (B; indicating the groupings obtained from cluster analysis: ○ SH; □ SL1; △ SL2) of elasmobranch samples obtained during BALAR bottom trawl surveys carried out between depths of 40 and 800 m in the northern area off the Balearic Islands. The dendrogram shows the mean depth (in metres) and season (S, spring; A, autumn) for each sample. The groupings obtained from cluster analysis are indicated in MDS by different white (spring) and black (autumn) symbols.

northern area, the species which characterised the different assemblages were *S. canicula* and *R. miraletus* for SH, *G. melastomus*, *S. canicula* and *R. oxyrhinchus* for SL1 and *G. melastomus* and *E. spinax* for SL2. In the southern area, the main species by assemblage were *S. canicula* for SH, *S. canicula* and *G. melastomus* for SL1, *G. melastomus* and *E. spinax* for SL2 and *C. coelolepis* and *Centrophorus uyato* for SL3.

The bathymetric distribution of mean abundance for the above mentioned main species in each area is shown in Figure 5. Clear differences were obtained among species, but for each species similar trends were obtained within them in the two surveyed areas. Within the sharks, *S. canicula* reached its maximum abundance above a depth of 100 m but was captured down to 500 m. *S. blainvillei* was captured almost exclusively between 101 and 300 m depth. *G. melastomus* appeared between depths of 301–1800 m, with clear maximum abundance between 301 and 500 m. *E. spinax* was captured between 301–1500 m depth, with similar values of abundance from 301 to 1300 m. *C. coelolepis* was only caught below a depth of 1301 m and reached its maximum abundance at the deepest interval surveyed. By contrast, most of the analysed rays were abundant above a depth of 300 m, reaching their maximum values at <100 m for *R. miraletus*, and between 101 and 300 m depth for *R. asterias*, *R. clavata* and *R. naevus*. The only exception was *R. oxyrhinchus*, which appeared from 101 to 500 m, reaching its maximum abundance between 301 and 500 m depth.

Length frequency distribution by depth for *S. canicula*, *G. melastomus* and *E. spinax* showed clear differences. For *S. canicula*, the overall length frequency ranged from 5 to 50 cm (Figure 6), although specimens ≥25 cm were most frequent at depths of <100 m, while smaller fish were only distributed between depths of 101 and 500 m. By contrast, in *G. melastomus*, the length ranged between 10 and 70 cm (Figure 6), and specimens ≤30 cm were most common above a depth of 700 m, while females ≥40 cm predominated below this depth. Similar results were obtained for *E. spinax* (Figure 7); lengths ranged between 5 and 45 cm, with specimens ≤20 cm distributed almost exclusively from 301 to 900 m, while fish ≥30 cm predominated below a depth of 701 m.

The other sharks *S. blainvillei* and *C. coelolepis* ranged between 20 and 70 and 20 and 90 cm, respectively, and showed a bimodal distribution (Figure 8). In *S. blainvillei*

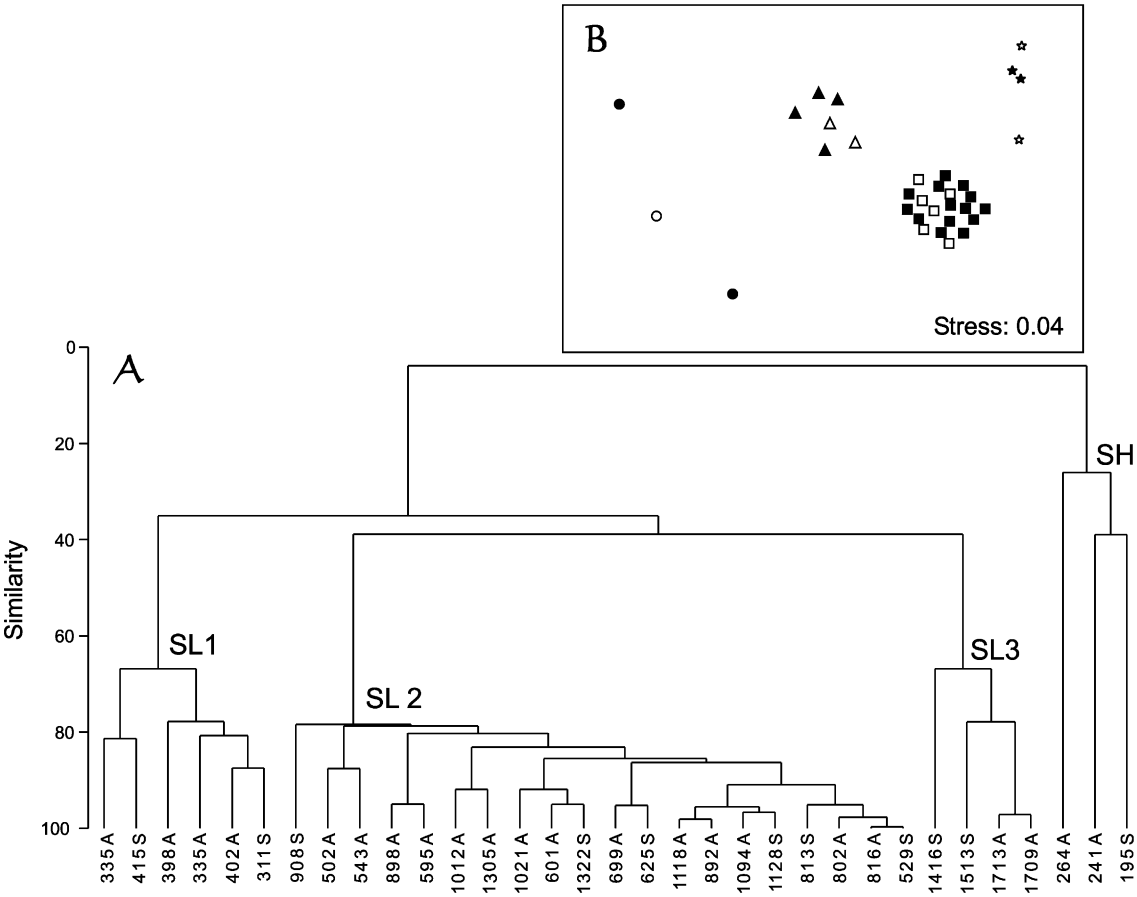

Figure 4. Dendrogram (A) and MDS ordination (B; indicating the groupings obtained from cluster analysis: ○ SH; △ SL1; □ SL2; ☆ SL3) of elasmobranch samples obtained during QUIMERA bottom trawl surveys carried out between depths of 200 and 1800 m in the southern area off the Balearic Islands. The dendrogram shows the mean depth (in metres) and season (S, spring; A, autumn) for each sample. The groupings obtained from cluster analysis are indicated in MDS by different white (spring) and black (autumn) symbols.

Table 2. Number of hauls analysed and mean ecological parameters (standard error) for each group resulting from cluster and MDS analyses (see Figures 3 and 4) of elasmobranch samples obtained during bottom trawl surveys carried out in two areas off the Balearic Islands.

	Northern area			Southern area			
	SH	SL1	SL2	SH	SL1	SL2	SL3
Hauls	52	15	18	3	6	26	10
Number of species	17	10	6	4	4	6	3
Mean species richness	2.8 (0.2)	2.8 (0.4)	2.1 (0.1)	2.3 (0.3)	2.1 (0.2)	2.1 (0.1)	1.5 (0.2)
Fish per 10 000 m^2	13.1 (1.8)	21.0 (5.6)	3.8 (1.0)	12.4 (1.3)	25.1 (7.2)	2.7 (0.2)	1.0 (0.2)
g 10 000 m^{-2}	2564.3 (365.2)	876.1 (217.1)	612.4 (141.6)	945.5 (205.9)	900.2 (242.9)	982.5 (157.4)	461.3 (132.6)
Mean fish weight (g)	246.3 (25.7)	45.6 (5.5)	184.0 (38.3)	76.8 (18.4)	36.1 (7.4)	431.9 (92.6)	480.9 (139.1)
Diversity (H′)	0.52 (0.06)	0.36 (0.09)	0.36 (0.05)	0.42 (0.23)	0.25 (0.08)	0.46 (0.16)	0.25 (0.10)
Evenness (J′)	0.55 (0.04)	0.42 (0.09)	0.51 (0.05)	0.46 (0.18)	0.36 (0.12)	0.70 (0.09)	0.79 (0.02)

Table 3. Results of the ANOSIM routine to analyse differences between seasons and depths, using the groups resulting from cluster and MDS analyses for elasmobranch samples obtained during bottom trawl surveys carried out in two areas off the Balearic Islands.

	R Global			
	Northern area		Southern area	
Comparison	Abundance	Biomass	Abundance	Biomass
Between seasons				
Autumn vs spring	−0.001	−0.001	−0.066	−0.007
Between depth ranges	0.62*	0.72*	0.72*	0.53*
SH vs SL1	0.52*	0.63*	0.23	0.13
SH vs SL2	0.81*	0.92*	0.86*	0.82*
SH vs SL3			1.00*	1.00
SL1 vs SL2	0.52*	0.52*	0.64*	0.38*
SL1 vs SL3			0.92*	0.81*
SL2 vs SL3			0.69*	0.47*

(*) Denotes a statistically significant difference at the 95% confidence interval.

there was a dominance of large fish (between 40 and 70 cm, with a mode at 50 cm), while small specimens ranged from 20 to 30 cm. By contrast, small specimens (mode at 20–30 cm) dominated in *C. coelolepis*, which also showed a second mode at 50–65 cm.

The overall length frequency distributions of rays *R. miraletus* (length range of 10–50 cm), *R. asterias* (15–90 cm) and *R. naevus* (10–55 cm) showed modes situated at 20, 20 and 35–40 cm, respectively (Figure 9). By contrast, no clear modes could be observed in *R. clavata* and *R. oxyrhinchus*, the two species with a major presence of large specimens (>40 cm), with length ranges ranging from 10 to 90 and 15 to 115 cm, respectively.

Discussion

The analysis of demersal elasmobranch species distributed in two different areas off the Balearic Islands, along the

Table 4. Results of the SIMPER routine to analyse dissimilarity between groups resulting from cluster and MDS analyses for elasmobranch samples obtained during BALAR bottom trawl surveys, carried out between depths of 40 and 800 m in the northern area off the Balearic Islands and percentage contribution, in terms of abundance, of the main species to each group. $\overline{A}$: abundance; $\overline{S}_i$: average similarity; $\overline{\delta}_i$: average dissimilarity, SD: standard deviation.

Depth range	Species	$\overline{A}$	$\overline{S}_i$	$\overline{S}_i$/SD	$\overline{S}_i$%	$\sum S_i$%
SH $\overline{S}_i = 30.44$	*S. canicula*	10.72	27.16	1.02	89.22	89.22
	R. miraletus	0.64	1.42	0.34	4.66	93.88
SL1 $\overline{S}_i = 30.56$	*G. melastomus*	16.73	27.24	1.03	89.11	89.11
	S. canicula	3.93	3.07	0.45	10.04	99.15
	R. oxyrhinchus	0.19	0.24	0.44	0.79	99.94
SL2 $\overline{S}_i = 56.32$	*G. melastomus*	3.59	50.57	2.36	89.79	89.79
	E. spinax	0.45	5.74	1.1	10.19	99.98
Pair-wise comparisons			$\overline{\delta}_i$	$\overline{\delta}_i$/SD	$\overline{\delta}_i$%	$\sum\delta_i$%
SH vs SL1 $\overline{\delta}_i = 89.36$	*G. melastomus*		43.16	1.43	48.3	48.3
	S. canicula		34.55	1.19	38.67	86.96
	R. miraletus		3.06	0.43	3.42	90.39
SH vs SL2 $\overline{\delta}_i = 98.40$	*S. canicula*		48.66	1.54	49.45	49.45
	G. melastomus		29.76	1.26	30.25	79.69
	R. miraletus		4.65	0.56	4.72	84.42
	E. spinax		4.09	0.86	4.16	88.58
SL1 vs SL2 $\overline{\delta}_i = 74.66$	*G. melastomus*		54.89	2.13	73.51	73.51
	S. canicula		13.44	0.68	18	91.52
	E. spinax		3.77	0.72	5.05	96.57
	R. oxyrhinchus		1.2	0.44	1.6	98.17

Table 5. Results of the SIMPER routine to analyse dissimilarity between groups resulting from cluster and MDS analyses of elasmobranch samples obtained during QUIMERA bottom trawl surveys, carried out between depths of 200 and 1800 m in the southern area off the Balearic Islands and percentage contribution, in terms of abundance, of the main species to each group. $\overline{A}$: abundance; $\overline{S}_i$: average similarity; $\overline{\delta}_i$: average dissimilarity, SD: standard deviation.

Depth range	Species	$\overline{A}$	$\overline{S}_i$	$\overline{S}_i$/SD	$\overline{S}_i$%	$\sum S_i$%
SH $\overline{S}_i = 50.24$	*S. canicula*	9.55	49.55	1.73	98.63	98.63
	S. blainvillei	2.12	0.74	0.43	1.01	99.64
	R. asterias	0.5	0.69	0.58	0.36	100
SL1 $\overline{S}_i = 20.4$	*S. canicula*	9.29	10.97	0.5	53.79	53.79
	G. melastomus	14.5	8.97	0.56	43.96	97.75
SL2 $\overline{S}_i = 54.98$	*G. melastomus*	1.98	45.17	1.65	82.16	82.16
	E. spinax	0.51	9.42	0.98	17.13	99.29
SL3 $\overline{S}_i = 51.20$	*C. coelolepis*	0.87	47.51	2.08	92.80	92.80
	C. uyato	0.20	3.69	0.41	8.20	100
Pair-wise comparisons			$\overline{\delta}_i$	$\overline{\delta}_i$/SD	$\overline{\delta}_i$%	$\sum \delta_i$%
SH vs SL1 $\overline{\delta}_i = 72.88$	*S. canicula*		28.78	1.6	39.49	39.49
	G. melastomus		28.5	0.86	39.11	78.6
SH vs SL2 $\overline{\delta}_i = 99.96$	*S. canicula*		62.51	2.56	62.53	62.52
	S. blainvillei		15.55	0.7	15.56	78.10
	G. melastomus		12.86	1.81	12.86	90.96
SH vs SL3 $\overline{\delta}_i = 100$	*S. canicula*		69.26	2.58	69.26	69.26
	S. blainvillei		17.42	0.69	17.42	86.68
	C. coelolepis		6.35	1.51	6.35	93.03
SL1 vs SL2 $\overline{\delta}_i = 86.97$	*S. canicula*		37.64	0.99	43.27	43.27
	G. melastomus		36.20	0.99	41.63	84.90
	E. spinax		12.41	0.52	14.27	99.17
SL1 vs SL3 $\overline{\delta}_i = 98.29$	*S. canicula*		40.54	0.99	41.25	41.25
	G. melastomus		38.31	0.93	38.97	80.22
	E. spinax		14.47	0.47	14.72	94.94
SL2 vs SL3 $\overline{\delta}_i = 82.62$	*G. melastomus*		47.27	2.01	54.84	54.84
	C. coelolepis		23.64	1.47	27.42	82.62
	E. spinax		13.68	1.16	15.86	98.12

continental shelf and slope between depths of 41 and 1713 m, has shown that some assemblages were related to depth. These results are similar to those obtained in Atlantic waters, when elasmobranch species were also analysed separately (Roel, 1987). The bathymetric boundaries obtained in this study are similar in both areas, and they are in accordance with those obtained in previous studies of fish communities (both selachians and teleosts) carried out in our study area (Massutí *et al.*, 1996; Moranta *et al.*, 1998) and in other areas of the western Mediterranean (Stefanescu *et al.*, 1993; Demestre *et al.*, 2000).

The assemblages found in this study can be attributed to the different fish zonations proposed by Haedrich and Merret (1988) for Atlantic waters and corroborated in the Mediterranean by Stefanescu *et al.* (1993) and Demestre *et al.* (2000). Samples taken above a depth of 250 m correspond to the continental shelf (SH), over which the highest diversity of demersal elasmobranchs is reached. In this depth-strata, the most abundant species is *S. canicula*, although there are also other characteristic species such as the shark *S. blainvillei* and the rays *R. miraletus*, *R. asterias*, *R. clavata* and *R. naevus*. The low capture of ray species in the southern area could be attributed to the low number of samples taken on the continental shelf and the absence of samples above a depth of 195 m. In the northern area, where a large number of samples were taken on the shelf, higher numbers of rays (*Raja brachyura*, *Raja montagui*, *Raja polystigma* and *Raja undulata*), other sharks (*Mustelus* spp.) were captured, as well as other batoid species (*Torpedo* spp., *Dasyatis pastinaca* and *Myliobatis aquila*), which appeared at a very low frequency in bottom trawls (e.g. Massutí *et al.*, 1996; Matarrese *et al.*, 1996; Bertrand *et al.*, 2000). This could be due to the scarcity of these species and their solitary habits, and to the low capture efficiency of the gear used.

Along the slope, three different assemblages can be defined. In contrast to the shelf, these assemblages are characterised mainly by sharks, the only holocephalid species captured (*Chimaera monstrosa*), very few rays (*R. oxyrhinchus* is the only ray with an abundance peak on the slope) and the absence of other batoid species (e.g. the genera *Torpedo*, *Dasyatis* and *Miliobatis*). The shallowest

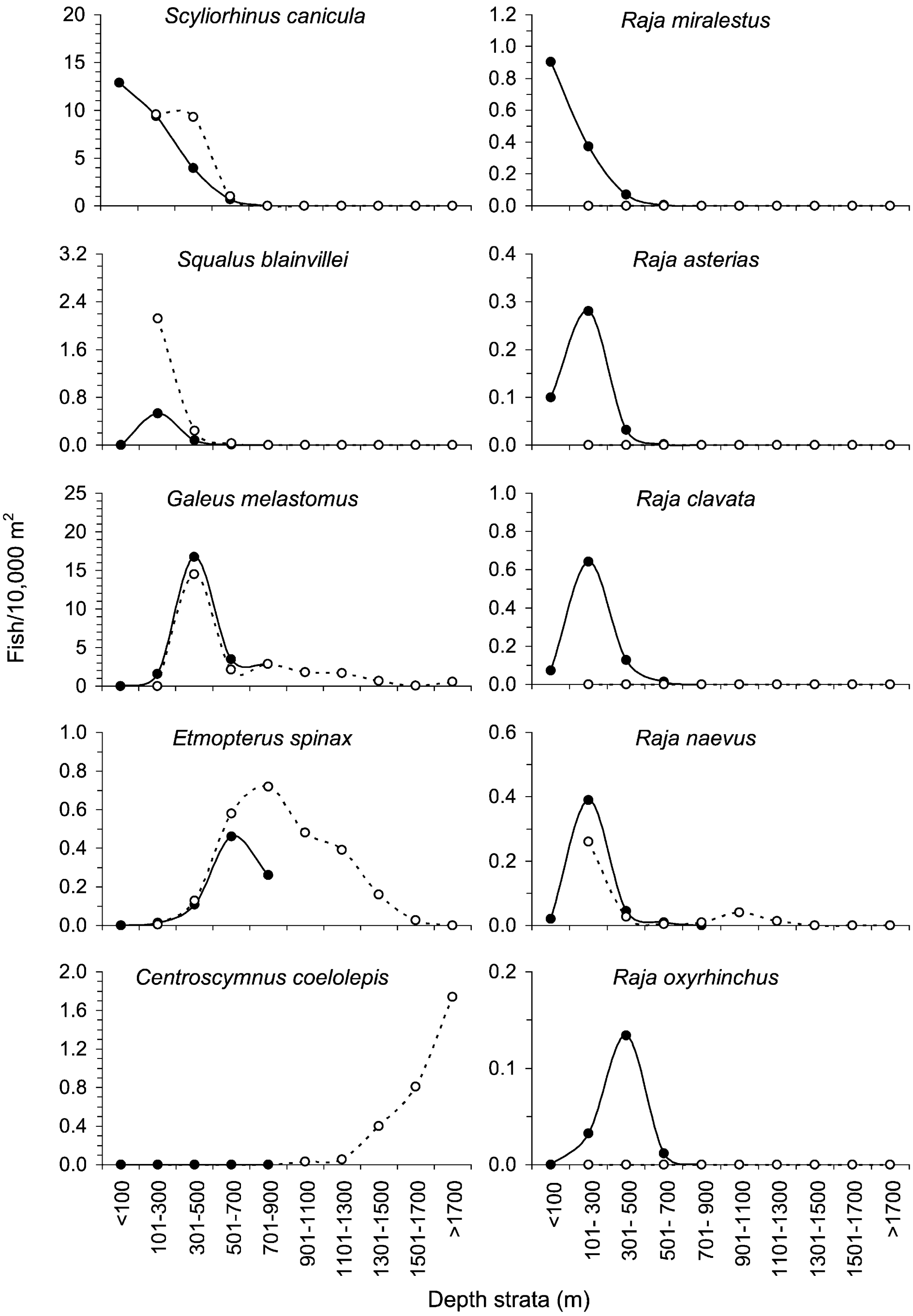

Figure 5. Mean standardised abundance (fish per 10 000 m^2), calculated in the northern (●; from GOC73) and southern (○; from OTMS-27.5) areas surveyed and by depth interval, for the main species of elasmobranchs captured during bottom trawl surveys carried out off the Balearic Islands.

slope assemblage corresponds to the upper slope (SL1; 300–500 m depth) and it is mainly characterised by *G. melastomus*, *S. canicula* and *R. oxyrhinchus*. The deepest slope assemblage, only surveyed in the southern area, corresponds to the lower slope (SL3; >1400 m depth) and it is mainly characterised by *C. coelolepis*, a species restricted to this depth and which, in the western Mediterranean, can occur down to a depth of 2250 m (Carrasón *et al.*, 1992).

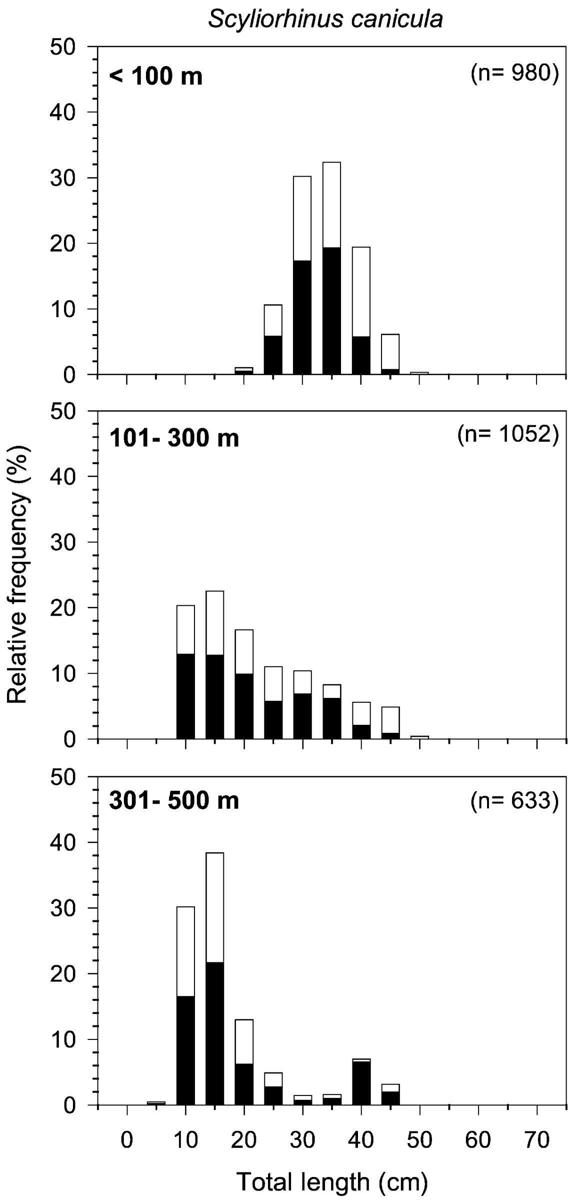

Figure 6. Length frequency distribution (in percentage by 5 cm size classes) by sex (black bars for females and white bars for males) and depth interval of *S. canicula* captured during bottom trawl surveys off the Balearic Islands.

Between these two assemblages, a third group (SL2; 500–1400 m depth) extends from the deep upper to the middle slope. It is characterised by *E. spinax* (a species restricted to this assemblage) and *G. melastomus*. The latter species is the most abundant elasmobranch captured, and has the widest bathymetric range (SL1, SL2 and SL3 assemblages).

Some conclusions can be drawn concerning depth distribution patterns and the population structure of several abundant elasmobranch species collected in this study. In shark species, a clear segregation of sizes by depth was observed. For *S. canicula*, a species mainly distributed over the continental shelf but also occurring on the upper slope down to a depth of 500 m, the juveniles are found below 100 m while in shallower waters the population is composed exclusively of adults. Similar results have been obtained by D'Onghia *et al.* (1995) in the Northern Aegean Sea, who reported juveniles only at depths greater than 200 m. In addition, spawning in shallow waters on hard substrate off the Gulf of Lions has been suggested by Capapé *et al.* (1991). In *G. melastomus* and *E. spinax*, two species mainly distributed on the upper and middle slope, the different bathymetric distribution of juveniles and adults is more evident, with juveniles and adults in shallow and deep fishing grounds within the bathymetric range of the species, respectively. Similar results have been obtained by Tursi *et al.* (1993) in the Ionian Sea. In this area, *G. melastomus* found between 200 and 400 m were almost exclusively small (mainly concentrated at around 300 m), while between 400 and 650 m the population was found to comprise all length classes, including a considerable number of recruits. Considering the available information on length at first maturity for *S. canicula* (Capapé *et al.*, 1991; Ungaro *et al.*, 2002) and *G. melastomus* (Capapé and Zaouali, 1977) in the Mediterranean, the immature specimens of these two species off the Balearic Islands are mainly distributed between depths of 100 and 700 m. This depth range is widely exploited by the trawl fleet and for this reason, *S. canicula* and *G. melastomus* represent an important fraction of discards from this fishery (Moranta *et al.*, 2000).

The bathymetric distribution of *R. miraletus* in the study area is similar to that found in the central Mediterranean, where it is mainly concentrated between depths of 50 and 150 m (Relini *et al.*, 1999) and off Tunisia, where it is distributed down to a depth of 200 m (Capapé and Quignard, 1974). The population found on the trawl fishing grounds off the Balearic Islands is mainly composed of immature specimens of 1 to 3 years of age (Abdel-Aziz, 1994). This species is part of the by-catch of the bottom trawl fishery, with a high proportion of individuals discarded. By contrast, the population structure of *R. clavata* shows a large proportion of mature specimens (>50 cm; Relini *et al.*, 1999). Similar results are obtained for *S. blainvillei*, where a second mode of mature fish older than 3 years of age (Cannizaro *et al.*, 1995) at around 50 cm in length can be observed.

The analysis of available long-term data series has shown the impact of fishing activity on elasmobranchs, which is reflected in the reduction of species numbers and their declining abundance. Some biological factors may contribute to the vulnerability of this type of fish since they are long-lived and slow growing, mature at a late age and have a low fecundity. In the Atlantic Ocean, *R. naevus* and *R. oxyrhinchus* have been shown to be close to extinction in the north-west area (Casey and Myers, 1998) and in the

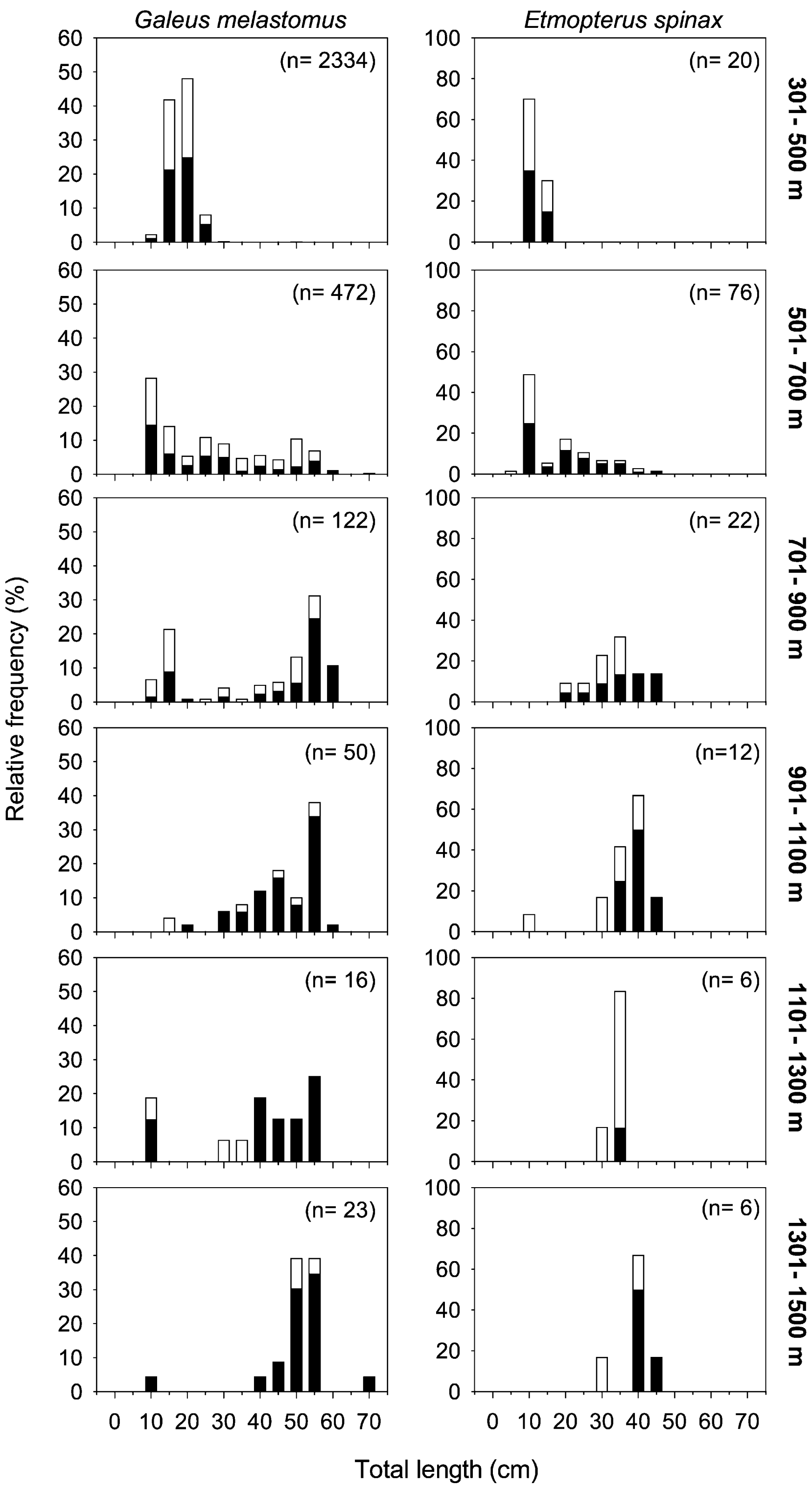

Figure 7. Length frequency distribution (in percentage by 5 cm size classes) by sex (black bars for females and white bars for males) and depth interval of *G. melastomus* and *E. spinax* captured during bottom trawl surveys off the Balearic Islands.

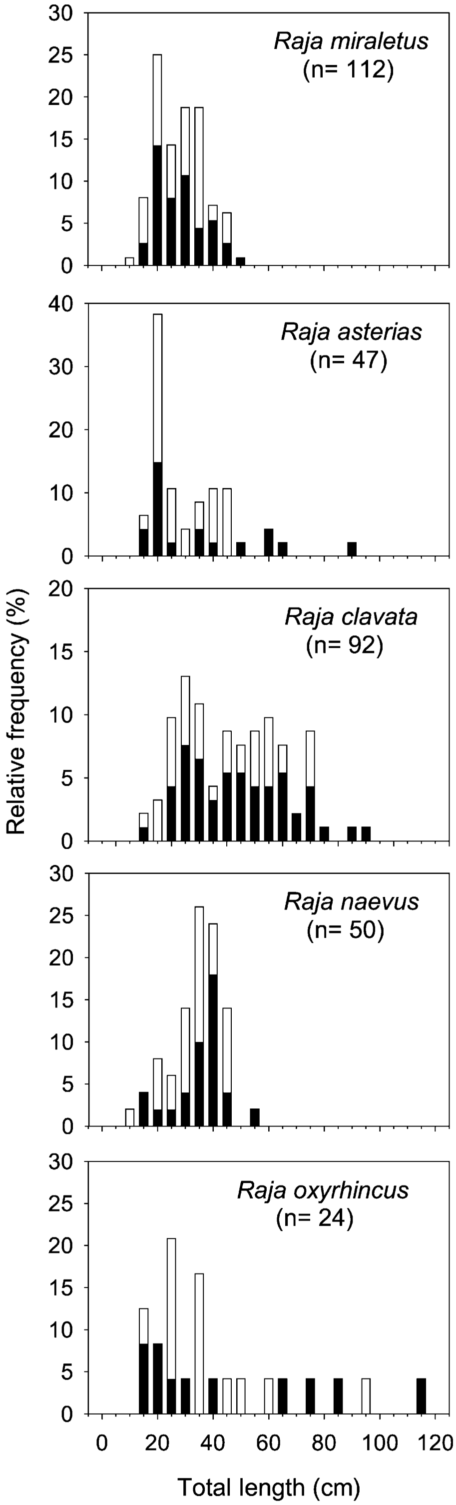

Figure 8. Overall length frequency distribution (in percentage by 5 cm size classes) by sex (black bars for females and white bars for males) of the rays *R. miraletus*, *R. asterias*, *R. clavata*, *R. naevus* and *R. oxyrhinchus*.

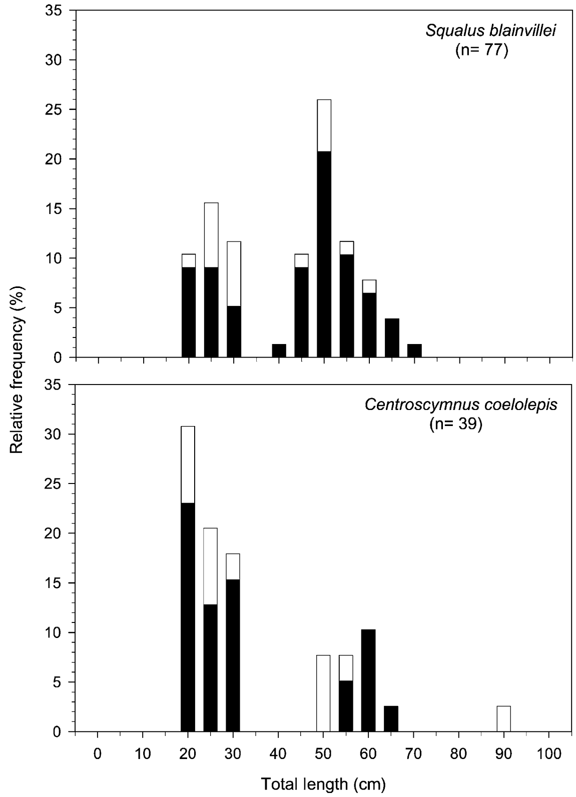

Figure 9. Overall length frequency distribution (in percentage by 5 cm size classes) by sex (black bars for females and white bars for males) of the sharks *S. blainvillei* and *C. coelolepis* captured during bottom trawl surveys off the Balearic Islands.

Irish Sea (Dulvy *et al.*, 2000), respectively. *R. clavata* has decreased both in abundance and in average length in the North Sea (Walker and Heessen, 1996). In the Mediterranean Sea, elasmobranch landings and number of species have decreased during recent decades in the Gulf of Lions, in direct relation to the development of the trawl fishery (Aldebert, 1997). In this area, the decline of abundance indices for *R. clavata* and reductions in its distribution have also been reported (Bertrand *et al.*, 1998).

Our results in the northern area can be compared with those obtained for the whole northern Mediterranean by Bertrand *et al.* (2000), where the same gear and sampling scheme as our study was used (Table 6). Diversity of demersal elasmobranchs in the Balearic Islands, even considering the low number of samples analysed, is higher than in adjacent waters off the Iberian Peninsula and similar to other insular Mediterranean areas (e.g. Sardinia, Corsica and Sicily islands), in which the highest values for the whole northern Mediterranean have been reported. Although biogeographic factors could form the basis of these differences, these results could also suggest the existence of some differences in fishing exploitation between areas, with

Table 6. Number of hauls analysed, elasmobranch species captured and standardised abundance (fish per km^2) for the most abundant species reported from different areas of the western Mediterranean (Bertrand *et al.*, 2000) and those obtained off the Balearic Islands from the BALAR surveys analysed in the present study, in which the same gear and sampling scheme were used. Abundance values from areas throughout the whole northern Mediterranean were obtained from an average of the 1994–1998 data series reported by Bertrand *et al.* (2000) at the different depth-strata in which the species were mainly distributed: (i) 10–200 m for *Raja clavata* and *Raja miraletus*; (ii) 200–800 m for *Galeus melastomus* and *Etmopterus spinax*; (iii) 10–800 m for *Scyliorhinus canicula*. Abundance values from the Balearic Islands were obtained from an average of spring and autumn data, in which no significant differences were detected (see Table 3).

			Abundance: specimens per km^2				
Area	Total hauls	Species number	*R. clavata*	*R. miraletus*	*S. canicula*	*G. melastomus*	*E. spinax*
Alboran Sea	170	16	0.0	0.4	50.2	1876.8	281.0
Central Iberian Peninsula	150	13	3.0	3.2	96.4	176.8	46.2
Northern Iberian Peninsula	215	10	2.0	0.0	231.4	107.4	8.4
Gulf of Lions	325	23	7.4	0.0	92.3	932.2	42.6
Corsica Island	120	26	40.2	101.2	590.4	641.4	54.2
Ligurian and Northern and Central Thyrrhenian	765	24	2.6	7.4	17.9	288.4	52.2
Sardinia Island	625	24	46.4	32.8	255.4	868.0	67.6
Sicily Island and South Thyrrhenian	705	29	7.6	115.6	34.0	253.6	67.8
Balearic Islands	85	22	54.0	88.0	804.0	1131.0	27.0

lower intensity on the insular continental shelf and upper slope than along the peninsular bottoms.

Differences in abundance indices for some of the most important species could be related to fishing pressure. In general, abundance off the Balearic Islands is higher than that reported from the Iberian Peninsula. It is also similar to the maximum abundance reported from other western Mediterranean areas off Corsica and Sicily for *R. miraletus*, off Corsica and Sardinia for *R. clavata* and off Corsica for *S. canicula*. In addition, the regular presence of *R. oxyrhinchus* on the slope bottoms of the Balearic Islands must also be pointed out. According to Bertrand *et al.* (2000), this species, which shows high vulnerability to fishing pressure, only occurs around Corsica and Sardinia, where trawling activity may be lower than in other Mediterranean adjacent areas.

The only exceptions were *G. melastomus* and *E. spinax*, two species restricted to the slope which had maximum abundance off Alboran, with values much higher than those obtained from the other Mediterranean areas. The highest abundance indices of these two species in the Alboran Sea could be due to the low levels of fishing effort below a depth of 500 m in this area. This factor has also been used to explain differences in abundance and population structure obtained in a teleost species between this and other northern areas off the Iberian coast (Massutí *et al.*, 2001).

The present results form a reference point for the present status of demersal elasmobranchs in the Balearic Islands. This area, together with other insular areas, shows the most diverse and abundant elasmobranch assemblages in the western Mediterranean. For this reason, harvest strategies should be linked to the conservation of these species in these areas, and long-term monitoring programmes should be set up.

Acknowledgements

This paper is a result of the Spanish and European Projects MEDER (IEO Project) and Deep-Sea Fisheries (DGXIV/FAIR/96/06-55), respectively. The authors are most grateful to all the participants in the cruises BALAR0401, BALAR0901, QUIMERA-I and QUIMERA-II as well as the crew of R/V "Francisco de Paula Navarro" and "García del Cid" for their help during the sampling, and to Dr C. Rodgers for help with improving the manuscript.

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