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Comparison of fish assemblages between the Sea of Marmara and the Aegean Sea (north-eastern Mediterranean)

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The demersal fish assemblages of the south-western Sea of Marmara and the north-eastern Aegean Sea were examined in relation to their biogeographical and environmental conditions. Sampling was carried out during bottom trawl surveys conducted during five periods between June 2006 and August 2007. A total of 40 hauls were processed, including 16 in the Sea of Marmara (38–74 m deep) and 24 in the north-eastern Aegean Sea (63–401 m deep). A total of 47,940 individuals, from 91 species and 47 families were collected. Cluster analysis of catch data indicated that there were three assemblages, one in the shelf of the Sea of Marmara and two in the Aegean Sea (<100 and >200 m depth). The numerical abundance and biomass of fish, mean fish weight, mean species richness, diversity and evenness were compared between these assemblages. Multivariate analysis was used to test differences in environmental conditions between areas, and relationships between species and environmental variables were explored by using redundancy analysis. In addition to bathymetric differences, differences in both diversity and species composition were observed between shelf assemblages in the two nearby areas. The distinct biogeographical, environmental characteristics (depth, dissolved oxygen and temperature) and fishing pressure are discussed as the main factors which could explain the differences detected.

Keywords: demersal fish assemblages, diversity, biogeography, north-eastern Mediterranean

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INTRODUCTION

Most studies in fisheries biology have focused on the main species targeted by fishing operations. However, this single-species approach is restrictive for multi-species fisheries, such as the Mediterranean bottom trawl fishery (Caddy, 1999). Studying the fish assemblage structure in relation to environmental variables and the characterization of seasonal changes are among the suggested new approaches in the study of exploited populations (Gislason *et al.*, 2000).

Demersal fish and epifaunal assemblages on circalittoral soft bottoms have been extensively studied in the Mediterranean Sea, especially in the western basin (e.g. Demestre *et al.*, 2000; Biagi *et al.*, 2002; González & Sánchez, 2002; Colloca *et al.*, 2003; Massutí & Reñones, 2005). Although most of these works have been focused on the analysis of depth related trends, some geographical and seasonal distribution studies have also been conducted (Abelló *et al.*, 2002; Massutí *et al.*, 2004; Gaertner *et al.*, 2005; Moranta *et al.*, 2008). Information on such assemblages in the eastern Mediterranean is more limited, although they have been described for the southern Adriatic (Ungaro *et al.*, 1998, 1999), the Ionian Sea (D'Onghia *et al.*, 1998; Madurell *et al.*, 2004) and the southern (Kallianiotis *et al.*, 2000) and northern Aegean Sea (Labropoulou & Papaconstantinou, 2000).

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Depth has been reported as the main factor influencing large scale faunal changes over the continental shelf and slope, and both physical (e.g. sediment and characteristics of water masses) and biological factors (resource availability, predator–prey relationships and interspecific competition) have been discussed as underlying causes responsible for this zonation (e.g. Haedrich *et al.*, 1980; Bianchi, 1992; Carney, 2005). The local conditions in such factors, as well as fishing activities, can also determine regional differences of demersal assemblages (e.g. Moranta *et al.*, 2008). It is especially relevant in areas such as the eastern Mediterranean with its particular environmental conditions, e.g. extremely oligotrophic, elevated deep water temperature and high salinity (Stergiou & Pollard, 1994).

The aim of the present paper is to compare the demersal fish assemblages between the Sea of Marmara, a small inland sea connecting the Mediterranean and the Black Seas where no information on this matter exists, and the most eastern part of the Mediterranean in the Aegean Sea. These areas are connected by the Dardanelles Strait, a biological corridor 62 km long with an average width of 4 km and maximum depth of 167 m. The observed differences are discussed in relation to the distinct environmental conditions in both areas.

MATERIALS AND METHODS

The study is based on several scientific surveys carried out on the continental shelf in the south-western part of the Sea of

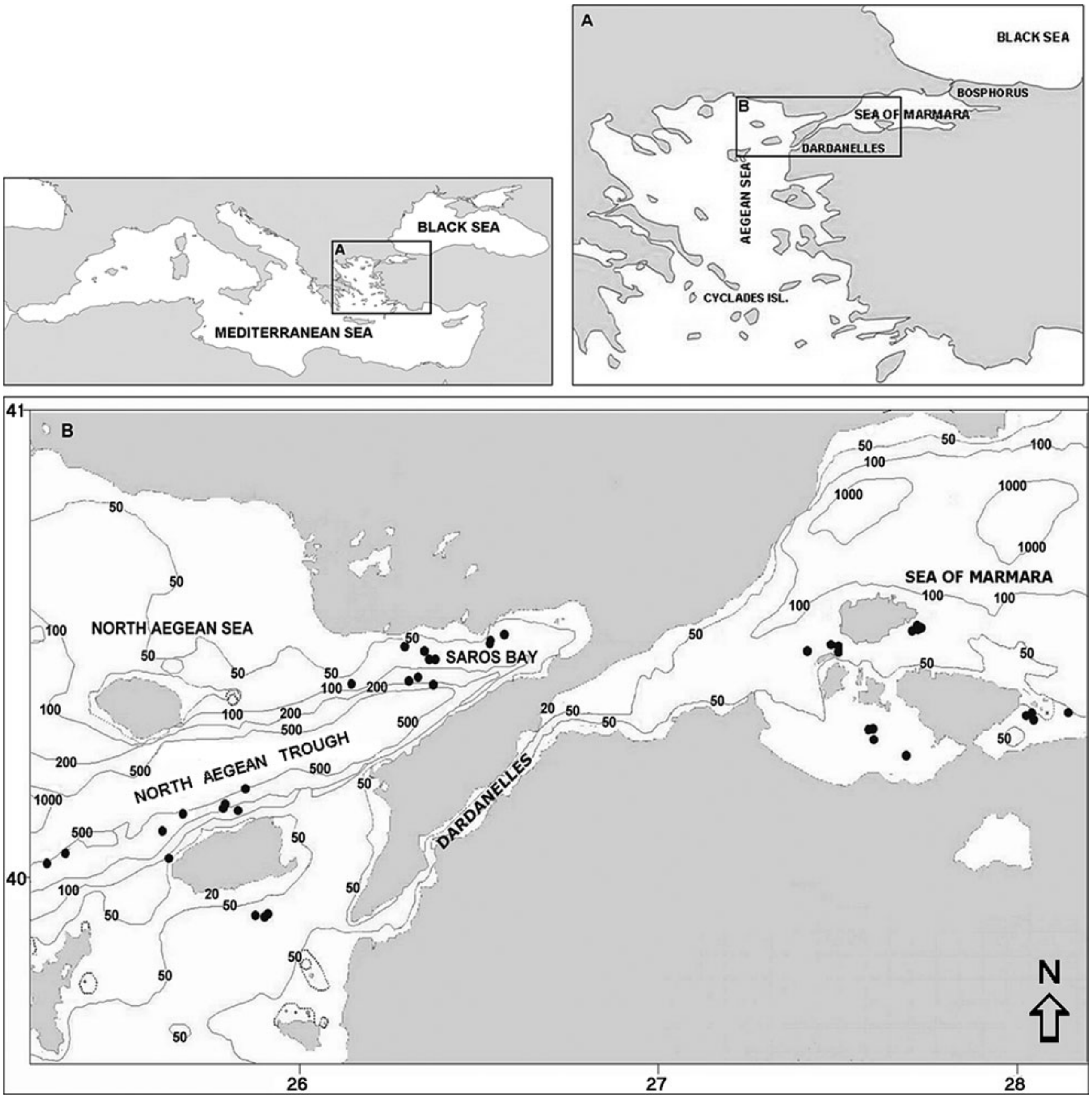

Fig. 1. Map of the study areas: north-eastern part of the Mediterranean (A), the south-western Sea of Marmara and the north-eastern Aegean Sea (B), showing the sampling stations. The 50, 100, 200 and 500 m isobaths are also shown.

Marmara and the continental shelf and upper slope of the north-eastern Aegean Sea (Figure 1), on-board the RV 'Yunus-S' (31.8 m, 202 GT, 510 HP). During these surveys, sampling of demersal (and some pelagic) fish species and hydrographic conditions were undertaken.

Study area

The Sea of Marmara has a large continental shelf, especially in its southern part, with an average and maximum depths of around 500 and 1400 m, respectively. A two layered flow regime exists in the area, as a result of water exchange between the Mediterranean and the Black Sea. Black Sea waters (7–24°C and 22–26 psu) enter through the Bosphorus Strait in the upper layer (20–25 m), with a renewal time of about 5–6 months. Below there are the sub-halocline waters of the Marmara basin, which possess near constant temperatures (14.5–15.0°C) and higher salinity of 38.5–38.6 psu, with a renewal time of about 6–7 years, produced by the Mediterranean inflow via the Dardanelles undercurrent. Dissolved oxygen concentration declines with depth, from saturated levels at 30–50 m, being nearly exhausted in sub-halocline waters during August and September (Beşiktepe *et al.*, 1993). In the south-western Sea of Marmara, muddy bottoms are predominant, given the detrital inputs by rivers (e.g. Algan *et al.*, 2004).

The North Aegean Sea is separated from the South Aegean by the Cyclades Islands. It is characterized by a wide shelf in

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Table 1. Sampling stations and hauls characteristics, with total number of species (S), abundance (A; individuals/km²) and biomass (B; kg/km²) of pelagic and demersal fish caught during the five surveys developed in the south-western Sea of Marmara (SM) and the north-eastern Aegean Sea (AS).

Area	Surveys	Latitude (N)	Longitude (E)	Swept area (km²)	Mean depth (m)	S	A	B
SM	July 2006	40°23′094	27°37′094	0.02	40	14	109,900	1619
SM	July 2006	40°26′200	28°03′520	0.02	43	13	247,667	3858
SM	July 2006	40°36′000	27°44′480	0.01	63	17	225,444	4604
SM	July 2006	40°33′240	27°31′180	0.02	71	19	50,313	1737
SM	October 2006	40°24′326	27°36′289	0.01	40	16	203,556	9350
SM	October 2006	40°25′350	28°03′820	0.02	43	14	40,889	904
SM	October 2006	40°36′000	27°44′480	0.02	61	19	63,800	2992
SM	October 2006	40°33′840	27°31′140	0.02	72	18	77,563	5009
SM	March 2007	40°21′318	27°42′535	0.02	38	19	166,087	4772
SM	March 2007	40°25′899	28°02′475	0.02	44	22	69,500	2176
SM	March 2007	40°35′654	27°43′545	0.02	58	19	73,813	2452
SM	March 2007	40°33′289	27°25′994	0.02	72	22	29,870	3379
SM	June 2007	40°25′350	28°03′820	0.02	42	16	110,318	2746
SM	June 2007	40°24′326	27°36′289	0.02	42	24	79,864	1897
SM	June 2007	40°36′000	27°45′000	0.02	66	13	20,500	587
SM	June 2007	40°34′042	27°30′030	0.02	70	15	38,591	1977
AS	July 2006	40°34′606	26°33′204	0.01	68	29	81,308	9077
AS	July 2006	40°02′784	25°55′723	0.01	75	22	28,000	520
AS	July 2006	40°32′418	26°23′958	0.02	89	21	56,158	4872
AS	July 2006	40°29′792	26°23′673	0.01	386	17	34,429	1660
AS	October 2006	40°09′370	25°39′597	0.01	71	11	47,000	1129
AS	October 2006	40°35′258	26°35′482	0.01	77	17	50,500	1870
AS	October 2006	40°02′706	25°53′984	0.02	79	23	14,118	508
AS	October 2006	40°32′424	26°23′007	0.02	94	21	34,778	3465
AS	October 2006	40°29′932	26°19′559	0.01	224	20	154,850	4424
AS	March 2007	40°29′578	26°10′000	0.03	78	25	53,750	2768
AS	March 2007	40°02′931	25°56′087	0.02	78	24	13,565	1216
AS	March 2007	40°14′911	25°51′078	0.02	100	21	27,471	1048
AS	March 2007	40°30′348	26°21′147	0.03	177	23	79,345	13041
AS	March 2007	40°15′198	25°48′535	0.02	220	19	59,125	1722
AS	March 2007	40°13′636	25°41′219	0.02	322	23	24,087	1403
AS	June 2007	40°34′153	26°33′083	0.02	68	23	65,455	3910
AS	June 2007	40°02′931	25°56′087	0.02	72	11	8955	591
AS	June 2007	40°33′807	26°18′879	0.02	78	29	45,000	3796
AS	June 2007	40°33′340	26°22′250	0.02	88	29	42,636	2867
AS	June 2007	40°15′520	25°48′800	0.02	220	18	7591	237
AS	June 2007	40°12′529	25°38′487	0.02	325	23	10,364	400
AS	August 2007	40°10′197	25°22′142	0.04	344	20	16,927	454
AS	August 2007	40°17′403	25°52′300	0.06	354	19	23,700	1655
AS	August 2007	40°09′561	25°19′166	0.04	395	16	33,488	955

the northern part and the North Aegean Trough, which extends from south-west to north-east (Kourafalou & Barbapoulos, 2003) and reaches 1600 m depth. Black Sea waters, flowing from the Dardanelles, are the most significant water mass input into the North Aegean Sea. These massive waters of 8.8–25°C and 31.8–38.3 psu affect the uppermost layer (20–30 m depth) and are modified, moving westward and southward, by mixing with the intermediate waters of Levantine origin, a warm and highly saline water originating from the South Aegean to the Levantine basins, extending down to 350–400 m depth (Theocharis & Georgopoulos, 1993; Tokat, 2006; Pazi, 2008). Below there are very dense North Aegean Deep Waters (13.3°C and 39 psu). No anoxic events have been reported in this area. In the north-eastern Aegean Sea, biogenic and terrigenous sandy bottoms are dominant on the shelf, while the slope is characterized by silt and clay sediments (Sarı & Çağatay, 2001).

Table 2. Description of the redundancy analysis models used to test for the effects of explanatory variables. In all cases 999 unrestricted permutations were conducted to test the significance of the variables. DO, dissolved oxygen (mg/l).

	Variable tested	Covariables
Whole model	DO, D, T	
Effect of depth (D)	D	T, DO
Effect of temperature (T)	T	D, DO

Sampling

Data collection was carried out during five periods: June and October 2006, and March, June and August 2007. Fish were collected with a bottom trawl net, with a 16 mm cod-end mesh size and an estimated vertical and horizontal opening of about 2 and 19.4 m, respectively. During each haul, the physical and chemical parameters were recorded in the water column, using a CTD SBE-19 SEACAST Profiler equipped with oximeter.

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Table 3. Fish species caught in the south-western Sea of Marmara and north-eastern Aegean Sea. Total number of individuals (N), total weight (W, kg), depth-range (D, m), the frequency of appearance (F, percentage of hauls in which the species was captured within this depth-range), number of hauls (n). The asterisks indicate species removed for the analysis (*, species caught in only one sample; **, pelagic species).

Family	Species	Sea of Marmara					North Aegean Sea				
		N	W	D	F	n	N	W	D	F	n
Chimaeridae	*Chimaera monstrosa* Linnaeus, 1758						2	0.9	320–392	33	6
Scyliorhinidae	*Galeus melastomus* Rafinesque, 1810						389	7.4	210–401	89	9
	Scyliorhinus canicula (Linnaeus, 1758)	258	44.3	38–74	75	16	406	80.2	63–383	78	23
Triakidae	*Mustelus asterias* Cloquet, 1821*						1	5.0	170–183	100	1
Etmopteridae	*Etmopterus spinax* (Linnaeus, 1758)						149	3.3	320–401	50	6
Squalidae	*Squalus acanthias* Linnaeus, 1758	6	0.4	40–73	13	16	38	24.9	65–330	24	21
	Squalus blainvillei (Risso, 1826)						50	39.8	63–95	23	13
Oxidotidae	*Oxynotus centrina* (Linnaeus, 1758)	2	2.7	38–73	13	16	3	6.0	75–80	14	7
Squatinidae	*Squatina squatina* (Linnaeus, 1758)						1	0.02	320–330	33	3
Torpedinidae	*Torpedo marmorata* Risso, 1810	2	0.8	42–73	13	16	4	1.2	75–183	27	11
Rajidae	*Dipturus oxyrinchus* Linnaeus, 1758						10	10.7	65–401	21	24
	Raja asterias Delaroche, 1809*						1	0.6	75–80	14	7
	Raja clavata Linnaeus, 1758	110	145.4	38–73	88	16	25	24.4	63–356	55	22
	Raja miraletus Linnaeus, 1758	1	0.1	70–71	17	6	14	3.0	65–383	30	23
	Raja radula Delaroche, 1809						1	0.8	75–80	14	7
Dasyatidae	*Dasyatis pastinaca* (Linnaeus, 1758)	5	34.5	63–74	29	7	1	9.7	65–75	13	8
Myliobatidae	*Myliobatis aquila* (Linnaeus, 1758)	7	2.8	40–45	13	8	2	9.8	75–98	22	9
Congridae	*Conger conger* Linnaeus, 1758						6	2.7	75–324	31	16
Engraulidae	*Engraulis encrasicolus* Linnaeus, 1758**	2	0.02	60–61	25	4	35	0.9	72–95	25	12
Clupeidae	*Sardina pilchardus* Walbaum, 1792**	1	0.03	42–45	13	8					
	Sprattus sprattus (Linnaeus, 1758)**	2370	43.2	39–68	67	12					
Argentinidae	*Argentina sphyraena* Linnaeus, 1758						329	4.4	88–395	79	14
Chlorophthalmidae	*Chlorophthalmus agassizi* Bonaparte, 1840						23	0.2	210–383	67	9
Macrouridae	*Coelorinchus caelorhincus* (Risso, 1810)						1639	16.6	183–401	90	10
	Hymenocephalus italicus Giglioli, 1884						640	2.2	210–401	44	9
	Nezumia sclerorhynchus (Valenciennes, 1838)					11	0,04	320–392	33	6	
Merlucciidae	*Merluccius merluccius* (Linnaeus, 1758)	1123	138.4	38–74	100	16	1332	189.7	63–401	92	24
Phycidae	*Gaidropsarus biscayensis* (Collett, 1890)	14	0.3	42–68	25	12	1	0.005	320–330	33	3
	Phycis blennoides (Brünnich, 1758)						220	11.3	100–401	100	11
Gadidae	*Gadiculus argenteus* Guichenot, 1850						3020	17.9	170–401	42	19
	Merlangius merlangus (Linnaeus, 1758)	6808	238.4	38–74	100	16	636	30.5	65–383	17	23
	Micromesistius poutassou (Risso, 1826)						1438	356.9	170–401	70	10
	Molva dipterygia (Pennant, 1784)						16	1.4	170–401	50	10
	Trisopterus minutus (Linnaeus, 1758)						25	1.1	63–220	47	19
Ophidiidae	*Ophidion barbatum* Linnaeus,1758*						2	0.05	90–98	33	3
Lophiidae	*Lophius budegassa* Spinola, 1807	9	30.6	65–74	33	6	112	68.2	63–401	92	24
	Lophius piscatorius Linnaeus, 1758*						1	6.2	332–356	25	4
Trachichthyidae	*Hoplostethus mediterraneus* Cuvier, 1829						293	8.1	325–401	60	5
Zeidae	*Zeus faber* Linnaeus, 1758	24	1.4	40–73	31	16	26	9.0	63–237	39	18
Scorpaenidae	*Helicolenus dactylopterus* Delaroche, 1809						69	1.5	90–392	62	13
	Scorpaena notata Rafinesque, 1810						31	1.1	75–98	89	9
	Scorpaena porcus Linnaeus, 1758	3	0.3	38–45	25	8					
Triglidae	*Chelidonichthys cuculus* Linnaeus, 1758	107	2.6	40–74	13	16	12	0.5	75–330	20	20
	Eutrigla gurnardus Linnaeus, 1758	814	13.2	38–74	81	16	305	8.2	63–95	77	13
	Lepidotrigla cavillone Lacépède, 1801	255	4.8	40–73	44	16	1031	26.5	65–100	71	14
	Chelidonichthys lucernus Linnaeus, 1758	46	8.2	38–73	69	16	46	20.6	63–324	50	20
	Trigla lyra Linnaeus, 1758	5	0.7	42–73	25	16	251	34.5	63–401	75	24
	Trigloporus lastoviza (Brünnich, 1768)	1	0.05	42	13	8	120	5.1	63–98	62	13
Peristeiidae	*Peristedion cataphractum* Linnaeus, 1758						7	0.2	325–392	40	5
Pomatomidae	*Pomatomus saltatrix* (Linnaeus, 1766)**	226	11.8	38–74	31	16					
Serranidae	*Serranus cabrilla* (Linnaeus, 1758)						170	10.9	70–100	71	14
	Serranus hepatus (Linnaeus, 1758)	4977	75.8	38–74	100	16	1094	15.2	63–330	71	21
	Serranus scriba (Linnaeus, 1758)*						20	0.8	80–95	17	6
Sparidae	*Boops boops* Linnaeus, 1758						19	1.1	63–100	43	14
	Dentex dentex Linnaeus, 1758*						50	21.2	77–79	17	6
	Dentex macrophthalmus Bloch, 1791						31	3.9	77–95	22	9
	Dentex maroccanus Valenciennes, 1830						319	14.1	76–98	44	9
	Diplodus annularis Linnaeus, 1758	63	2.0	38–63	23	13					
	Pagellus acarne (Risso, 1826)						415	24.8	65–98	46	13
	Pagellus bogaraveo (Brunnich, 1768)						775	31.6	75–401	60	20

Continued

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Table 3. Continued

Family	Species	Sea of Marmara					North Aegean Sea				
		N	W	D	F	n	N	W	D	F	n
	Pagellus erythrinus (Linnaeus, 1758)						725	44.5	72–183	50	14
	Pagrus pagrus (Linnaeus, 1758)						39	2.8	75–98	44	9
Carangidae	*Trachurus trachurus* (Linnaeus, 1758)**	5683	90.3	38–74	69	16	231	7.8	63–324	65	20
Centracanthidae	*Centracanthus cirrus* Rafinesque-Schmaltz, 1810					2	0.1	80–95	14	7	
	Spicara maena (Linnaeus, 1758)**	515	19.1	38–73	69	16	52	2.8	65–330	24	21
	Spicara smaris (Linnaeus, 1758)**						34	1.2	63–73	20	5
Mullidae	*Mullus barbatus* Linnaeus, 1758	528	36.8	38–73	50	16	2505	74.3	63–330	86	21
	Mullus surmuletus Linnaeus, 1758	187	6.7	40–71	36	14	91	3.3	75–80	57	7
Cepolidae	*Cepola macrophthalma* Linnaeus, 1766	106	1.6	40–74	69	16	16	0.5	70–100	29	14
Trachinidae	*Trachinus draco* Linnaeus, 1758						41	5.4	63–100	64	14
	Echiichthys vipera (Cuvier, 1829)						6	1.3	63–79	20	10
Uranoscopidae	*Uranoscopus scaber* Linnaeus, 1758	30	7.2	38–73	44	16	6	0.6	65–82	25	12
Blennidae	*Blennius ocellaris* Linnaeus, 1758	19	0.7	40–73	38	16	14	0.4	63–100	57	14
Callionymidae	*Callionymus lyra* Linnaeus, 1758	50	1.9	38–74	75	16	1	0.09	65–70	25	4
	Callionymus maculatus Rafinesque-Schmaltz, 1810	13	0.1	70–73	67	3					
	Callionymus pusillus Delaroche, 1809	2	0.007	42	14	7	3	0.01	75–230	14	14
Gobiidae	*Deltentosteus quadrimaculatus* Valenciennes, 1837						3	0.03	65–95	38	8
	Gobius niger Linnaeus, 1758	1376	31.1	38–74	88	16	9	0.07	80–95	25	4
	Lesueurigobius friesii (Malm, 1874)	398	1.4	39–73	69	16	21	0.04	210–330	67	6
Trichiuridae	*Lepidopus caudatus* (Euphrasen, 1788)**						1	0.01	320–324	50	2
Scombridae	*Scomber scombrus* Linnaeus, 1758						2	0.2	100	100	1
Caproidae	*Capros aper* Linnaeus, 1758						75	0.5	100–383	80	10
Citharidae	*Citharus linguatula* Linnaeus, 1758	637	23.9	38–74	69	16	780	26.7	63–230	83	18
Scopthalmidae	*Lepidorhombus boscii* Risso, 1810						290	10.4	65–401	46	24
Bothidae	*Arnoglossus laterna* Walbaum, 1792	325	3.7	38–74	88	16	89	0.6	63–220	61	18
	Arnoglossus thori Kyle, 1913	3	0.01	42–45	13	8	41	0.3	72–82	30	10
Soleidae	*Buglossidium luteum* Risso, 1810*	14	0.1	40–44	13	8					
	Microchirus variegatus Donovan, 1808						12	0.4	63–80	27	11
	Monochirus hispidus Rafinesque, 1814*	1	0.01	39–41	13	8					
	Solea solea Quensel, 1806	12	1.1	38–44	25	8	28	3.4	63–80	45	11
Cynoglossidae	*Symphurus nigrescens* Rafinesque, 1810						18	0.1	65–330	33	21

A total of 40 hauls were conducted during daylight hours: 16 in the Sea of Marmara at depths of 38–74 m, and 24 in the Aegean Sea at depths of 63–401 m (Table 1). Trawl duration ranged from 15–60 minutes, and mean towing speed was about 2.4 knots. The position at the start and the end of each trawl was recorded using a Global Positioning System (GPS). All samples were sorted, counted, weighted and identified to species level. Catches were standardized to a swept area (km^2) in accordance with the methodology most commonly employed in studies of demersal megafaunal assemblages in the Mediterranean (e.g. Bertrand *et al.*, 2002).

Data analysis

A standardized abundance data matrix of demersal fish species was created. In this matrix, species appearing only in one sample or considered as pelagic (e.g. Fischer *et al.*, 1987) were removed (see Results). Data were log(x + 1) transformed, and cluster analysis and non-metric multidimensional scaling (MDS) were applied in order to identify fish assemblages. The Bray–Curtis index was used as a between-haul similarity measure. The unweighted pair-group method with arithmetic mean (UPGMA) was used as the clustering algorithm. Similarity percentage analysis (SIMPER) was used to determine which species characterize the groups detected. All these analyses were carried out using the PRIMER package (Clarke & Warwick, 2001).

The mean values of abundance (individuals.km^{-2}), biomass (kg.km^{-2}), mean fish weight (kg), species richness, Shannon–Wiener diversity index (H′; Shannon & Weaver, 1949) and evenness (J′; Pielou, 1969) were estimated for each assemblage detected in the cluster analysis. Differences between groups for these indices were examined using a *t*-test.

Measures of depth (m), temperature (°C), salinity (psu) and dissolved oxygen (mg/l) were taken for each haul location by conductivity–temperature–depth casts. Depth profiles were plotted for these variables. The environmental conditions near the bottom were estimated by considering the values of temperature, salinity and dissolved oxygen within the 5 m water column above the bottom. Multi-variate analysis of variance (MANOVA) was used to test for differences in these parameters between the continental shelves of the two study areas. A *t-test* was performed to identify which variables caused the differences. Prior to parametric tests, the data were checked for the assumptions of normality and homogeneity of variances. When these assumptions were not met, data were log-transformed.

Canonical analysis was used to explore the relationships between fish species and the environmental variables. The species included in the analysis were those appearing within the 75% of similarity contribution to the shelf assemblages detected in both the north-eastern Aegean and south-western Marmara Seas. Before the application of

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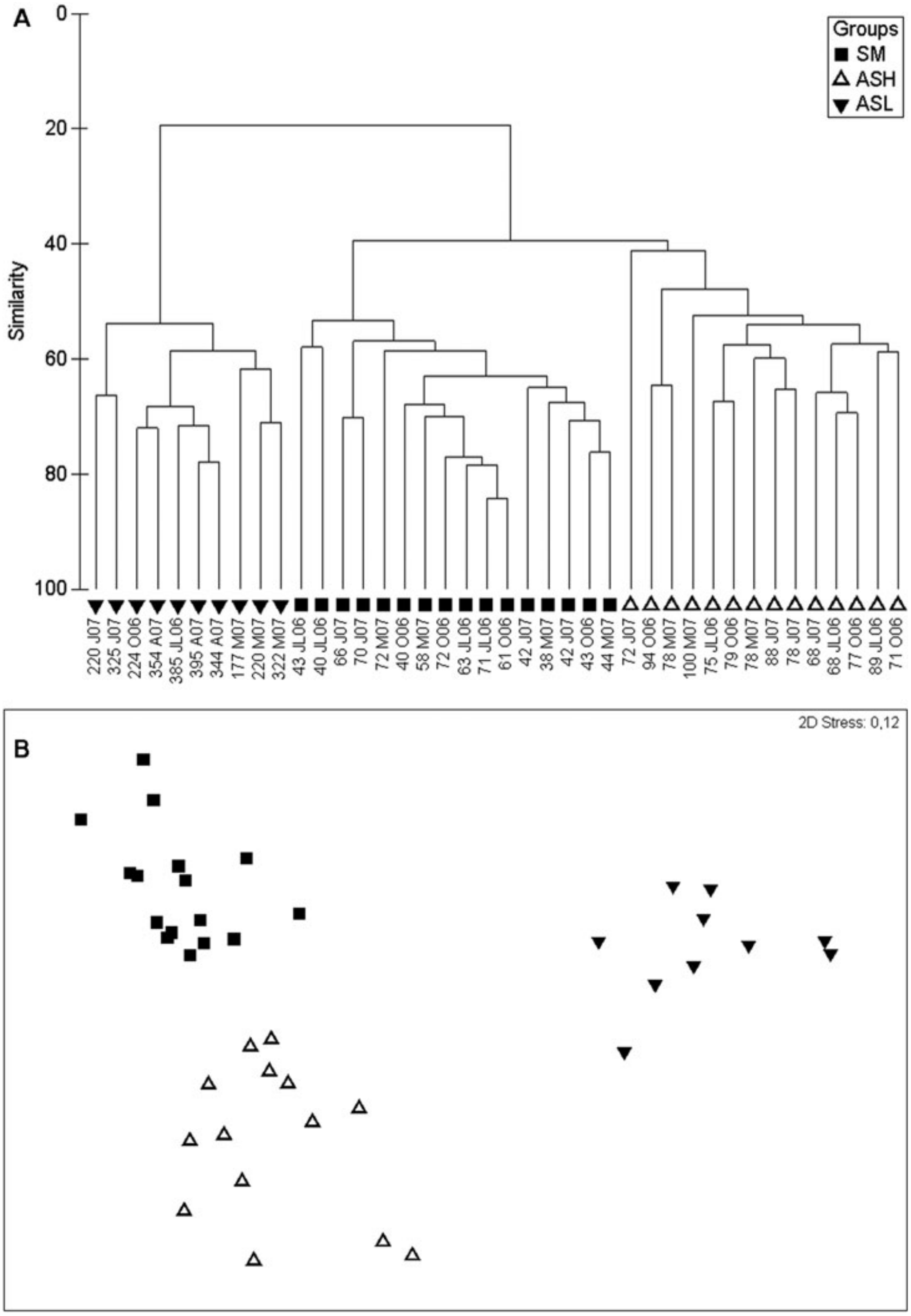

Fig. 2. Dendrogram (A) and two-dimensional non-metric multidimensional scaling ordination (B) based on fish standardized species abundance. Labels show the mean depths (m) and sampling period (JL06: July 2006; O06: October 2006; M07: March 2007; J07: June 2007 and A07: August 2007) for each sample. The samples were divided into three groups associated with bathymetric strata and areas. SM: 38-72 m in the south-western Sea of Marmara; ASH: 68-100 m in the north-eastern Aegean Sea; AS: 177-395 m in the north-eastern Aegean Sea.

direct gradient (canonical) analyses, the length of gradient of the response variables, which were the log-transformed standardized abundances per haul of selected fish species, was assessed by means of detrended correspondence analysis. The resulting gradients were short (below 2.5 SD units), and consequently a linear ordination method was used by applying redundancy analysis (RDA). The explanatory variables considered were depth, temperature, salinity and dissolved oxygen of water near the bottom. In RDA it is possible to specify co-variables (partial RDA), which allows testing of the effect of a particular explanatory variable after the variation explained by the co-variables is factored out. Details of the models used are found in Table 2. The significance of the explanatory variables was assessed by means of the Monte Carlo permutation-based test (Manly, 1991). A tri-plot diagram with species, samples and environmental variables was created for the partial RDA with depth as co-variable. Salinity was found to be not significant and was removed from the final model.

Table 4. Similarity percentage analysis results showing the mean abundance (A; individuals/km^2), average within-group similarity (SIM), the percentage contribution to the similarity (SIM%), standard deviation of similarity (SIM/SD), the percentage contribution to within-group similarity (SIM%), and the accumulated SIM% (ΣSIM%). SM, shelf in the south-western Sea of Marmara; ASH, shelf in the north-eastern Aegean Sea; ASL, upper slope in the north-eastern Aegean Sea.

SM SIM= 60.1	A	SIM	SIM/SD	SIM%	ΣSIM%
Merlangius merlangus	28844	8.91	6.15	14.66	14.66
Serranus hepatus	18054	7.64	3.74	12.58	27.24
Merluccius merluccius	4323	6.77	5.49	11.14	38.38
Gobius niger	4276	4.77	1.5	7.86	46.23
Arnoglossus laterna	1271	4.55	1.62	7.5	53.73
Eutrigla gurnardus	2726	3.98	1.3	6.56	60.29
Raja clavata	415	3.7	1.72	6.09	66.38
Citharus linguatula	2511	2.78	0.87	4.57	70.94
Lesueurigobius friesii	1427	2.73	0.86	4.49	75.43
ASH SIM= 52	**A**	**SIM**	**SIM/SD**	**SIM%**	**ΣSIM%**
Serranus hepatus	5011	6.57	4.93	12.64	12.64
Citharus linguatula	3707	5.17	2.24	9.95	22.59
Merluccius merlucius	3693	5.17	2.07	9.94	32.53
Mullus barbatus	8992	4.46	1.53	8.58	41.11
Lophius budegassa	194	3.01	1.48	5.8	46.91
Lepidotrigla cavillone	4729	2.95	0.96	5.66	52.58
Eutrigla gurnardus	1717	2.42	0.91	4.65	57.23
Serranus cabrilla	575	2.41	0.95	4.63	61.86
Scylorhinus canicula	826	2.31	0.96	4.44	66.3
Arnoglossus laterna	399	2.03	0.96	3.91	70.21
Raja clavata	80	1.4	0.78	2.68	72.89
Trachinus draco	190	1.38	0.79	2.66	75.55
ASL SIM= 61	**A**	**SIM**	**SIM/SD**	**SIM%**	**ΣSIM%**
Lepidorhombus boscii	992	5.08	6.58	8.46	8.46
Coelorinchus caelorhincus	6950	5.07	1.79	8.43	16.9
Phycis blennoides	678	4.75	6.55	7.9	24.8
Argentina sphyraena	1383	4.63	5.87	7.7	32.5
Lophius budegassa	253	4.54	8.87	7.56	40.06
Merluccius merluccius	1948	4.36	1.75	7.26	47.32
Trigla lyra	446	4.17	5.41	6.93	54.25
Pagellus bogaraveo	1332	4.15	1.83	6.9	61.15
Gadiculus argenteus	12957	3.77	1.22	6.27	67.42
Galeus melastomus	1307	3.28	1.2	5.45	72.87
Scylorhinus canicula	827	3.09	1.23	5.14	78.02

RESULTS

A total of 47, 940 individuals (2393.5 kg), belonging to 91 species (47 families) were collected from the 40 hauls analysed (Table 3). In the Sea of Marmara, a total of 44 species (27,138 ind., 1028.4 kg) were collected, of which *Merlangius merlangus, Merluccius merluccius* and *Serranus hepatus* were the most frequent species between 38 and 72 m depth, followed by *Raja clavata, Gobius niger* and *Arnoglossus laterna*. Catches in the Aegean Sea comprised 83 species, 20,802 individuals and 1365.0 kg. *Merluccius merluccius* and *Lophius budegassa* were the most frequent species, with large bathymetric ranges (63–401 m), while *Eutrigla gurnardus, Serranus cabrilla* and *Lepidotrigla cavillone* were most frequent in the shallower parts (<100 m depth) and *Phycis blennoides* and *Coelorinchus caelorhincus* abundant at depths >100 m.

Considering the whole catch, *M. merlangus* was the most important species in the Sea of Marmara, both in terms of number of individuals and weight, followed by *Trachurus trachurus* and *S. hepatus*, in terms of abundance, and by *R. clavata* and *M. merluccius*, in terms of biomass (Table 3). In the Aegean Sea, the most important species in terms of abundance were *Gadiculus argenteus*, *Mullus barbatus* and *C. caelorhincus*, whereas in terms of biomass they were *Micromesistius poutassou*, *M. merluccius*, *Scyliorhinus canicula*, *M. barbatus* and *L. budegassa* (Table 3).

Cluster analysis indicated that the samples could be attributed to three main groups (Figure 2A). The first discernible cluster comprised deep-water samples (177–395 m) from the Aegean Sea (ASL: Aegean Sea Slope). The remaining shallow water samples were distinct between the Aegean Sea (69–100 m depth, ASH: Aegean Sea Shelf) and Sea of Marmara (SM, 38–72 m). The MDS confirmed the presence of these three groups of samples (Figure 2B).

According to the results of the SIMPER analysis (Table 4), the average similarity of the SM group was 61%, with *M. merlangus*, *S. hepatus, M. merluccius*, *G. niger*, *A. laterna* and *E. gurnardus* the main contributors to this similarity. The average similarity of the ASH group was 52%, and *S. hepatus, Citharus linguatula, M. merluccius, M. barbatus, L. budegassa* and *L. cavillone* were the main contributors. The ASL group (the average similarity = 61%) comprised mainly *Lepidorhombus boscii, C. caelorhincus, P. blennoides, Argentina sphyraena, L. budegassa, M. merluccius* and *Trigla lyra*. The average dissimilarities between the three groups were as follow: 60.6% between SM and ASH; 82.7% between SM and ASL; 78.4% between ASH and ASL.

The comparisons for the ecological parameters between the assemblages detected revealed that the average values of abundance, biomass and mean fish weight were not significantly different. By contrast, mean species richness, diversity and evenness in SM were lower than in ASH (Table 5).

Table 5. Mean values and standard errors of the abundance (individuals/km^2), biomass (kg/km^2), fish weight (kg), species richness (number of species; total species richness also shown), diversity and evenness indices for shelf groups resulting from the cluster analysis, and results of the *t*-test. SM, shelf in the south-western Sea of Marmara; ASH, shelf in the north-eastern Aegean Sea; n.s., not significant; SE, standard error; $^*P < 0.01$; $^{**}P < 0.001$.

	SM	ASH	*t*-value	*Post-hoc*
Mean abundance	70846 ± 14202	39690 ± 5514	−1.939	n.s.
Mean biomass	2625.8 ± 539.8	2651.4 ± 623.2	0.031	n.s.
Mean fish weight	0.05 ± 0.02	0.06 ± 0.008	0.459	n.s.
Species richness	42	58		
Mean species richness	15.3 ± 0.9	20.4 ± 1.4	3.381^*	SM < ASH
Mean evenness J′	0.5 ± 0.04	0.7 ± 0.03	3.215^*	SM < ASH
Mean diversity H′	2.1 ± 0.2	2.9 ± 0.1	3.894^{**}	SM < ASH
Number of samples	16	14		

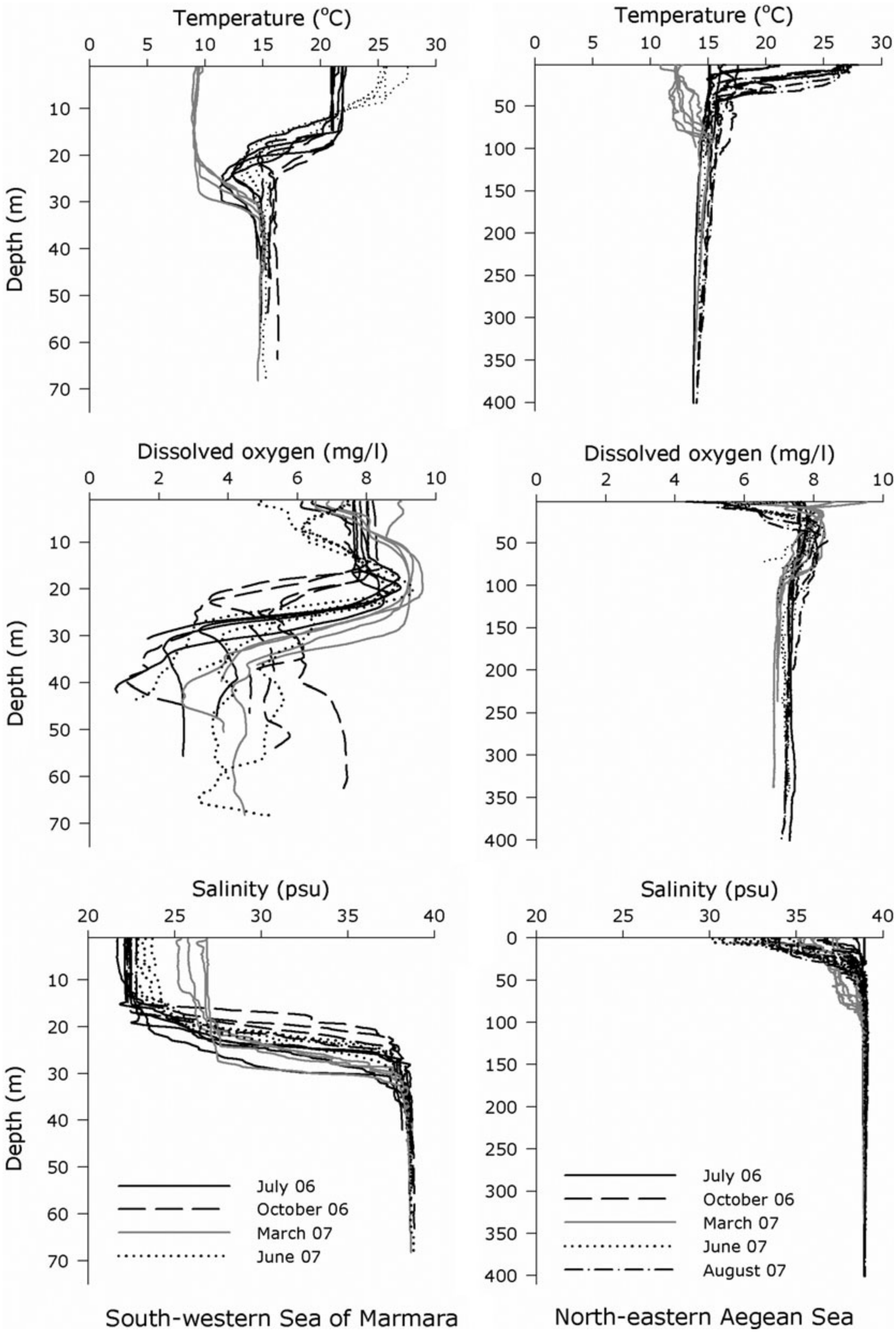

Fig. 3. The vertical profiles of the water temperature, salinity and dissolved oxygen for each sample from 38 to 72 m depth in the south-western Sea of Marmara, and from 68 to 395 m depth in the north-eastern Aegean Sea.

The vertical profiles showed that the variability of the values of temperature (T), dissolved oxygen (DO) and salinity (S) decreased with increasing depth, except in the case of DO in SM (Figure 3). The temperature near the bottom ranged from 14.4 to 16.3°C in the Sea of Marmara and from 13.7 to 16.2°C in the Aegean Sea, salinity from 37.9 to 38.8 psu in the Sea of Marmara and 38.6 to 39 psu in the Aegean Sea, and dissolved oxygen from 0.8 to 7.3 mg/l in the Sea of

Table 6. Total mean values (±standard error) of the environmental variables on the continental shelf areas, and their mean (±standard error), minimum and maximum values by sampling period. DO, dissolved oxygen (mg/l); T, temperature (°C); S, salinity (psu); D, depth (m).

Environmental variables		Sea of Marmara				Noth-eastern Agean Sea Shelf			
DO		3.6 ± 0.4				7.3 ± 0.07			
T		15.02 ± 0.1				14.9 ± 0.2			
S		38.5 ± 0.6				38.9 ± 0.04			
D		53.7 ± 3.6				79.4 ± 2.6			
		Jl06	O06	M07	Jn07	Jl06	O06	M07	Jn07
DO	Mean	2.01 ± 0.7	5.07 ± 0.8	4.2 ± 0.2	3.4 ± 0.8	7.4 ± 0.06	7.4 ± 0.05	7.2 ± 0.1	7.1 ± 0.2
	Minimum	0.8	3	3.8	1.3	7.3	7.3	7.1	6.5
	Maximum	3.7	7.3	4.8	5.2	7.5	7.6	7.4	7.7
T	Mean	14.6 ± 0.2	15.7 ± 0.2	14.8 ± 0.2	15 ± 0.09	14.7 ± 0.4	15.4 ± 0.3	14.5 ± 0.4	14.7 ± 0.1
	Minimum	14.4	15.3	14.6	14.7	14.2	15	13.7	14.5
	Maximum	14.9	16.3	15.1	15.3	15.4	16.2	15	14.8
S	Mean	38.3 ± 0.1	38.7 ± 0.07	38.5 ± 0.09	38.6 ± 0.09	38.9 ± 0.05	38.9 ± 0.06	38.7 ± 0.2	38.9 ± 0.04
	Mininimum	37.9	38.5	38.2	38.4	38.8	38.7	38.6	38.8
	Maximum	38.7	38.8	38.7	38.8	39	39	38.9	39

Marmara and from 6.5 to 7.7 mg/l in the Aegean Sea. MANOVA showed differences in the mean values of the environmental parameters between SM and ASH (Wilks' lambda = 0.237, $P < 0.001$) (Table 6). The *t*-test results showed that mean value of dissolved oxygen ($t = 7.707$, df = 28; $P < 0.001$) and salinity ($t = 4.740$, df = 28; $P < 0.001$) near the bottom, and depth ($t = 5.918$, df = 28; $P < 0.001$), were significantly higher in the ASH than in SM, whereas the mean values of temperature near the bottom were not significantly different between the two geographic areas studies ($t = -0.832$, df = 28; $P = 0.412$).

The RDA showed that dissolved oxygen, depth and temperature had a significant effect on the distribution of fish species. These variables explained 39.0% of the total variance of the selected species. Partial RDA models revealed that dissolved oxygen was the most important variable, and explained 10.4% of the total variance, whereas temperature and depth explained 9.7% and 7.4% of the total variance, respectively (Table 7). The RDA tri-plot, with depth as co-variable, showed that samples were continuously distributed along the dissolved oxygen and temperature gradients (Figure 4), although for this last variable two high extreme value samples and one low extreme value sample were present. Most of species abundances were positively correlated with dissolved oxygen, whereas *M. merlangus*, *A. laterna*, *G. niger* and *Lesueurigobius friesii* were negatively correlated with this variable. On the other hand the abundances of *A. laterna*, *M. merlangius*, *R. clavata*, *C. linguatula*, *E. gurnardus* and *M. merluccius* were positively correlated with temperature, whereas *L. friesii*, *L. budegassa*, *S. cabrilla*, *Trachinus draco* and *S. canicula* were negatively correlated to this variable. The short length of the arrows for *S. hepatus* and *L. cavillone* indicated that the abundances of these species were poorly explained by the variables in the model.

Table 7. Results of the redundancy analysis model. The explained variance (EV%), the F statistic and the significance (*P* value) are indicated. DO, dissolved oxygen (mg/l); T, temperature (°C); S, salinity (psu); D, depth (m).

Tested variables	EV%	F statistic	*P* value
DO, T and D	39.0	5.691	0.002
DO	10.4	4.490	0.004
T	9.7	4.172	0.006
D	7.4	3.186	0.018

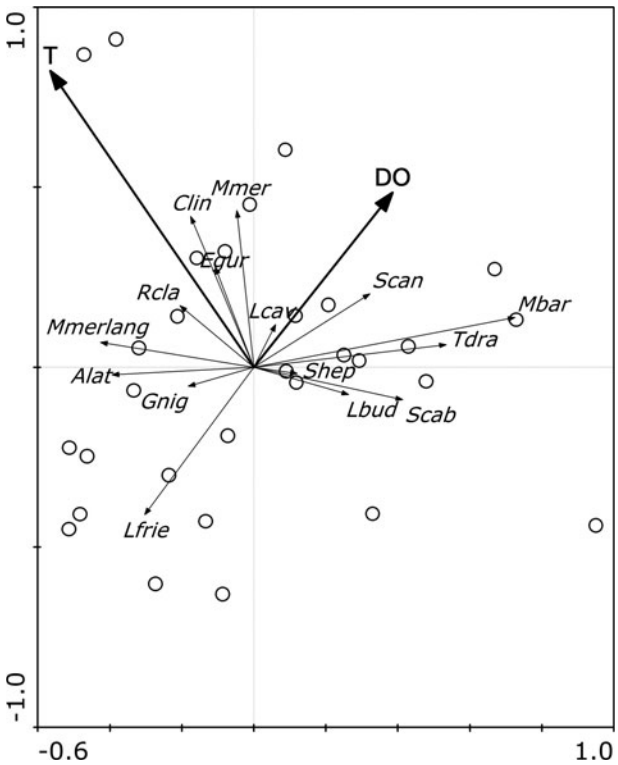

Fig. 4. Redundancy analysis tri-plot for fish species, samples and environmental variables. Alat, *Arnoglossus laterna*; Clin, *Citharus linguatula*; Egur, *Eutrigla gurnardus*; Gnig, *Gobius niger*; Lfrie, *Lesuerogobius friesii*; Lcav, *Lepidotrigla cavillone*; Lbud, *Lophius budegassa*; Mmerlang, *Merlangius merlangus*; Mmerluc, *Merluccius merluccius*; Mbar, *Mullus barbatus*; Shep, *Serranus hepatus*; Rcla, *Raja clavata*; Scan, *Scyliorhinus canicula*; Tdra, *Trachinus draco*. DO and T are the dissolved oxygen and temperature near the bottom, respectively.

DISCUSSION

The North Aegean Sea and the Sea of Marmara are among the major bio-geographical sectors in the northernmost Mediterranean Sea. A decrease in species richness has been reported between both areas, from west to east (Garibaldi & Caddy, 1998; Bianchi, 2007). This is due to the barrier effect of different topography, morphology and hydrological conditions along the Turkish Straits System (Dardanelles, Sea of Marmara and Bosphorus). The high contrast of temperature and salinity between the North Aegean Sea and the Sea of Marmara and the existence of a two-layer flow structure of water masses along the Turkish Straits System, with sharp horizontal and vertical temperature and salinity contrasts, very strong vertical mixing and hydraulic adjustment processes along this system and oxygen stress (Beşiktepe *et al.*, 1994), restrict the expansion of some Mediterranean species into the Sea of Marmara, more than the south-western expansion of Black Sea species. In this sense, 12 out of the 47 endemic species from the Black Sea are also present in the Sea of Marmara, whereas only 6 reach the Aegean Sea.

Our results support these biogeographical considerations, as clear differences were observed in the demersal fish species richness between both areas (83 in the Aegean Sea and 44 in the Sea of Marmara). Although almost all the species are also common in the rest of the Mediterranean Sea, *M. merlangus* and *S. sprattus*, two abundant species in the Black Sea which are considered as cold water relics originating from North Atlantic (Zaitsev & Öztürk, 2001), were more abundant in the Sea of Marmara.

Many studies have reported depth as the main factor determining faunal changes in the Mediterranean (e.g. Kallianiotis *et al.*, 2000, 2004; Labropoulou & Papaconstantinou, 2000; Masutí & Reñones, 2005; Moranta *et al.*, 2008). In the present study, depth and also area appeared as important factors. Samples carried out on the upper slope were separated from those on the shelf, and within this last depth stratum, two geographical groups could be defined corresponding to samples carried out in the Aegean Sea and the Sea of Marmara. Fish assemblages from the continental shelf and slope from the North Aegean Sea were more similar to those in the Thracian Sea and the Central Aegean Sea, than to those in the southern part of the North Aegean trough (Kallianiotis *et al.*, 2004; Labropoulou & Papaconstantinou, 2004), whereas the shelf of the Sea of Marmara was more similar to the Black Sea (Eryılmaz & Meriç, 2005).

Oceanographic characteristics, especially temperature and salinity, and bottom type play an important role for structuring assemblages on the continental shelf of the Aegean Sea (Stergiou *et al.*, 1997). In the present study, dissolved oxygen and temperature have been identified as important factors affecting fish assemblages on the shelf areas. However, salinity did not show any influence, probably due to a common effect of the Mediterranean waters below 40 m depth for both areas. *Merlangius merlangus* and the small-sized species *S. hepatus, L. friesii, G. niger* and *A. laterna* were more abundant in the south-western Sea of Marmara, in which dissolved oxygen was lower than in the north-eastern Aegean Sea. *Merlangius merlangus* can tolerate low levels of oxygen saturation (Pihl 1989; Baden *et al.*, 1990; Petersen & Phil, 1995) and in some areas its distribution has been fround to be negatively correlated with dissolved oxygen (Marshall & Elliott, 1998). In the Black Sea, this species is distributed between 35 and 100 m depth (Çiloğlu *et al.*, 2002), being more abundant at 40–90 m depth, where it finds enough dissolved oxygen and a suitable temperature (Kara *et al.*, 1999). Moreover, the population of *M. merlangus* was mostly composed of small specimens (mean fish weight was 48 and 35 g for the Aegean and Marmara Seas). The apparent affinity for hypoxia of these small-sized species and small individuals of large ones could be interpreted in terms of a sheltering strategy, as it seems that larger and potential predator species try to avoid such hypoxic areas (most of them being positively correlated to dissolved oxygen concentration). For example, the tolerance to hypoxia of coral gobies has been related to a reduced risk of predation and the potential losing of vital habitat space (Nilsson *et al.*, 2004). The type of bottom could be another factor affecting the composition of fish assemblages in the two continental shelf areas. Fish inhabiting the south-western Sea of Marmara were species characteristic of muddy bottoms (e.g. *L. friesii*), while those in the north-eastern Aegean Sea have been related to sandy or muddy–sand bottoms (Demestre *et al.*, 2000; Calloca *et al.*, 2003; Ordines & Massutí, 2009).

The mean abundance, biomass and mean fish weight of the two shelf assemblages did not show significant differences. However, diversity was significantly lower in the south-western Sea of Marmara than in the north-eastern Aegean Sea, and the inverse pattern was observed for evenness, revealing that the demersal ichthyfauna of the south-western Sea of Marmara was less homogeneous than that in the north-eastern Aegean Sea. In this sense, in the south-eastern Sea of Marmara, two species (*M. merlangus* and *S. hepatus*) accounted for nearly half of the total demersal fish abundance.

Diversity can be affected by different factors, such as the decrease of water quality (Guidetti *et al.*, 2002 and references therein), hypoxia (Keister *et al.*, 2000) and fishing pressure (i.e. Jennings *et al.*, 1999; Labropoulou & Papaconstantinou, 2005), among others. The fishing exploitation can also affect the size-structure of these communities, by harvesting larger individuals and increasing the relative importance of small ones in the fish populations (Pauly *et al.*, 1998). The illegal fishing exploitation has dramatically reduced the abundance of commercial fish species during the last decades (Zengin & Mutlu, 2000) and degenerated ecological conditions in the Sea of Marmara (Okuş *et al.*, 1997). Hence, fishing pressure could be another reason to explain the lower diversity and higher importance of small-sized species and small individuals of large ones in the south-western Sea of Marmara with respect to the north-eastern Aegean Sea, where also some zones banned for bottom trawling have been established (e.g. Saros Bay; see Figure 1). This last area is important as reproduction and nursery grounds for demersal and pelagic resources (Coker *et al.*, 2008), thus contributing to maintain more equilibrium in structured shelf assemblages.

As the main conclusion, our study supported the biogeographical differences between the Sea of Marmara and the Aegean Sea, in terms of demersal fish assemblages in the continental shelf areas, as a consequence of different geomorphological, oceanographic and fishing impact conditions. The identification of these assemblages, and the main environmental causes affecting them, can be of great importance for fisheries management and the sustainability of regional fisheries in the area.

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REFERENCES

Abelló P., Carbonell A. and Torres P. (2002) Biogeography of epibenthic crustaceans on the shelf and upper slope off the Iberian Peninsula Mediterranean coasts: implications for the establishment of natural management areas. *Scientia Marina* 66 (Supplement 2), 183–198.

Algan O., Balkıs N., Çağatay M.N. and Sarı E. (2004) The sources of metal contents in the shelf sediments from the Marmara Sea, Turkey. *Environmental Geology* 46, 932–950.

Baden S.P., Loo L.O., Pihl L. and Rosenberg R. (1990) Effects of eutrophication on benthic communities including fish: Swedish west coast. *Ambio* 19, 113–122.

Bertrand J.A., de Sola L.G., Papaconstantinou C., Relini G. and Souplet A. (2002) The general specifications of the MEDITS Surveys. *Scientia Marina* 66, 9–17.

Beşiktepe S., Ozsoy E. and Unluata U. (1993) Filling of the Marmara Sea by the Dardanelles lower layer inflow. *Deep-Sea Research I* 40, 1815–1838.

Beşiktepe S.T., Sur H.I., Ozsoy E., Latif M.A., Oguz T. and Unluata U. (1994) The circulation and hydrography of the Marmara Sea. *Progress in Oceanography* 34, 285–334.

Bianchi G. (1992) Study of the demersal assemblages of the continental shelf and upper slope off Congo and Gabon, based on the trawl surveys of the RV 'Dr Fridtjof Nansen'. *Marine Ecology Progress Series* 85, 9–23.

Bianchi C.N. (2007) Biodiversity issues for the forthcoming tropical Mediterranean Sea. *Hydrobiologia* 580, 7–21.

Biagi F., Sartor P., Ardizzone G.D., Belcari P., Belluscio A. and Serena F. (2002) Analysis of demersal assemblages off the Tuscany and Latium coast (north-western Mediterranean). *Scientia Marina* 66 (Supplement 2), 233–242.

Caddy J.F. (1999) Fisheries management in the twenty-first century: will new paradigms apply? *Reviews in Fish Biology and Fisheries* 9, 1–43.

Carney R.S. (2005) Zonation of deep biota on continental margins. *Oceanography and Marine Biology: an Annual Review* 43, 211–278

Çiloğlu E., Şahin C., Gözler A.M. and Verep B. (2002) Vertical distribution and ratio of whiting fish (*Merlangius merlangus euxinus* Nordmann, 1840) in the total catch on the Eastern Black Sea Coasts. *Ege University Journal of Fisheries and Aquatic Sciences* 19, 303–309.

Clarke K.R. and Warwick R.M. (2001) *Change in marine communities: an approach to statistical analysis and interpretation*. 2nd edition. Plymouth: PRIMER-E.

Coker T., Turkoglu M. and Satilmis H.H. (2008) Seasonal distribution of some fish eggs and larvae, and potential contribution of some large scale pelagic fish Species in Saros Bay, Turkey. *Çanakkale Values Symposiums (ÇIDS), Gelibolu Bulletin Book, 27–28 August 2008. Gelibolu, Çanakkale, Turkey*. pp. 329–330. [In Turkish.]

Colloca F, Cardinale M, Belluscio A. and Ardizzone G.D. (2003) Structure and diversity of demersal assemblages in the central Mediterranean Sea. *Estuarine, Coastal and Shelf Science* 56, 469–480.

D'Onghia G., Tursi G., Maiorano P., Matarrese A. and Panza M. (1998) Demersal fish assemblages from the bathyal grounds of the Ionian Sea (middle-eastern Mediterranean). *Italian Journal of Zoology* 65 (Supplement), 287–192.

Demestre M., Sánchez P. and Abelló P. (2000) Demersal fish assemblages and habitat characteristics on the continental shelf and upper slope of the north-west Mediterranean. *Journal of Marine Biological Association of the United Kingdom* 80, 981–988.

Eryılmaz L.S. and Meriç N. (2005) Review of fish fauna of the Sea of Marmara. *Journal of the Black Sea/Mediterranean Environment* 11, 153–178.

Fischer W., Bauchot M.L. and Schneider M. (eds) (1987) *Fiches FAO d'identification des espèces pour les besoins de la pêche. Méditerranée et mer Noire. Zone de pêche 37, Vertébrés*. Rome: FAO 2, pp. 761–1529.

Gaertner J.C., Bertrand J.A., de Sola L.G., Durbec J.P., Ferrandis E. and Souplet A. (2005) Large spatial scale variation of demersal fish assemblage structure on the continental shelf of the NW Mediterranean Sea. *Marine Ecology Progress Series* 297, 245–257.

Garibaldi L. and Caddy J.F. (1998) Biogeographic characterization of Mediterranean and Black Sea faunal provinces using GIS procedures. *Ocean and Coastal Management* 39, 211–227.

Gislason H., Sinclair M., Sainsbury K. and O'Boyle R. (2000) Symposium overview: incorporating ecosystem objectives within fisheries management. *ICES Journal of Marine Science* 57, 468–475.

González M. and Sánchez P. (2002) Cephalopod assemblages caught by trawling along the Iberian Peninsula Mediterranean coast. *Scientia Marina* 66, 199–208.

Guidetti P., Fanelli G., Fraschetti S., Terlizzi A. and Boero F. (2002) Coastal fish indicate human-induced changes in the Mediterranean littoral. *Marine Environmental Research* 53, 77–94.

Haedrich R.L., Rowe G.T. and Polloni P.T. (1980) The megabenthic fauna in the deep sea south of New England, USA. *Marine Biology* 57, 165–179.

Jennings S., Greenstreet S.P.R. and Reynolds J.D. (1999) Structural changes in an exploited fish community: a consequence of differential fishing effects on species with contrasting life histories. *Journal of Animal Ecology* 68, 617–627.

Kallianiotis A., Sophronidis K., Vidoris P. and Tselepides A. (2000) Demersal fish and megafaunal assemblages on the Cretan continental shelf and slope (NE Mediterranean): seasonal variation in species density, biomass diversity. *Progress in Oceanography* 46, 429–455.

Kallianiotis A., Vidoris P. and Sylaios G. (2004) Fish species assemblages and geographical sub-areas in the North Aegean Sea, Greece. *Fisheries Research* 68, 171–187.

Kara O.F., Kaya M., Benli H.A. and Mater S. (1999) The productivity and hydrographic properties of the trawl areas of the Middle and Eastern Black Sea. In Güven K.C.(ed.) *The Black Sea Symposium Ecological Problems and Economical Prospects, 16–18 September 1999 Istanbul, Turkey*. Istanbul: The Black Sea Foundation, pp 205–222.

Keister J.E., Houde E.D. and Breitburg D.L. (2000) Effects of bottom-layer hypoxia on abundances and depth distributions of organisms in Patuxent River, Chesapeake Bay. *Marine Ecology Progress Series* 205, 43–59.

Kourafalou V.H. and Barbopoulos K. (2003) High resolution simulations on the North Aegean Sea seasonal circulation. *Annales Geophysicae* 21, 251–265.

Labropoulou A. and Papaconstantinou C. (2000) Community structure of deep-sea demersal fish in the North Aegean Sea (Northeastern Mediterranean). *Hydrobiologia* 440, 281–296.

Labropoulou A. and Papaconstantinou C. (2004) Community structure and diversity of demersal fish assemblages: the role of fishery. *Scientia Marina* 68 (Supplement 1), 215–226.

Labropoulou A. and Papaconstantinou C. (2005) Effects of fishing on community structure of demersal fish assemblages. *Belgian Journal of Zoology* 135, 191–197.

Madurell T., Cartes J.E. and Labropoulou M. (2004) Changes in the structure of fish assemblages in a bathyal site of the Ionian Sea (eastern Mediterranean). *Fisheries Research* 66, 245–260.

Manly B.F.J. (1991) *Randomization and Monte Carlo methods in biology*. New York: Chapman & Hall.

Marshall S. and Elliott M. (1998) Environmental influences on the fish assemblage of the Humber estuary, UK. *Estuarine, Coastal and Shelf Science* 46, 175–184.

Massutí E., Gordon J.D.M., Moranta J., Swan S.C., Stefanescu C. and Merrett N.R. (2004) Mediterranean and Atlantic deep-sea fish assemblages: differences in biomass composition and size-related structure. *Scientia Marina* 68, 101–115.

Massutí E. and Reñones O. (2005) Demersal resource assemblages in the trawl fishing grounds of the Balearic Islands (western Mediterranean). *Scientia Marina* 69, 167–181.

Moranta J., Quetglas A., Massutí E., Guijarro B., Hidalgo M. and Diaz P. (2008) Spatiotemporal variations in deep-sea communities off the Balearic Islands (western Mediterranean). *Journal of Marine Systems* 71, 346–366.

Nilsson G.E., Hobbs J-P., Munday P.L. and Östlund-Nilsson S. (2004) Coward or braveheart: extreme habitat fidelity through hypoxia tolerance in a coral-dwelling goby. *Journal of Experimental Biology* 207, 33–39. doi:10.1242/jeb.00713.

Okuş E., Yüksek A., Uysal A. and Orhon V. (1997) *Marmara Denizi'nde ekonomik demersal balıklarının stok tayini projesi 1992–1995 Kesin Raporu*. İ.Ü. Deniz Bilimleri İşletmeciliği Enstitüsü, TÜBİTAK-DEBAG-116/G, 206 pp. [In Turkish.]

Ordines F. and Massutí E. (2009) Relationships between macro-epibenthic communities and fish on the shelf grounds of the western Mediterranean. *Aquatic Conservation: Marine and Freshwater Ecosystems* 19, 370–383.

Pauly D., Christensen V., Dalsgaard J., Froese R. and Torres Jr. F.C. (1998) Fishing down marine food webs. *Science* 279, 850–863.

Pazi I. (2008) Water mass properties and chemical characteristics in the Saros Gulf, Northeast Aegean Sea (Eastern Mediterranean). *Journal of Marine Systems* 74, 698–710.

Petersen J.K. and Pihl L. (1995) Responses to hypoxia of plaice, Pleuronectes platessa, and dab, *Limanda limanda*, in the south-east Kattegat: distribution and growth. *Environmental Biology of Fishes* 43, 311–321

Pielou E.C. (1969) *An introduction to mathematical ecology*. New York: John Wiley & Sons.

Pihl L. (1989) Effects of oxygen depletion on demersal fish in coastal areas of the south-east Kattegat. In Rylands J.S. and Tyler P.A. (eds) *Proceedings of the 23rd European Marine Biology Symposium Swansea, Wales, 5–9 September, 1998, School of Biological Sciences, University of Wales*. Fredensborg, Denmark: Olsen & Olsen, pp. 431–439.

Sarı E. and Çağatay M.N. (2001) Distributions of heavy metals in the surface sediments of the Gulf of Saros, NE Aegean Sea. *Environment International* 26, 169–173.

Shannon C.E. and Weaver V. (1949) *A mathematical theory of communication*. Urbana, IL: University of Illinois Press.

Stergiou K.I. and Pollard D.A. (1994) A spatial analysis of the commercial fisheries catchesfrom the Greek Aegean Sea. *Fisheries Research* 20, 109–135

Stergiou K.I., Christou E.D., Georgopoulos D., Zenetos A. and Souvermezoglou C. (1997) The Hellenic Seas: physics, chemistry, biology and fisheries. *Oceanography and Marine Biology: an Annual Review* 35, 415–538.

Theocharis A. and Georgopoulos D. (1993) Dense water formation over the Samothraki and Limnos plateaux in the North Aegean Sea (Eastern Mediterranean Sea). *Continental Shelf Research* 13, 919–939.

Tokat E. (2006) *Saros Körfezi Hidrolojik ve Biyolojik Su Özellikleri (*Hydrological and biological water properties of the Saros Bay*)*. MSc thesis Dokuz Eylül University, İzmir, Turkey. [InTurkish.]

Ungaro N., Marano C.A., Vlora A. and Martino M. (1998) Space–time variations of demersal fish assemblages in the south-western Adriatic Sea. *Vie et Milieu* 48, 191–201.

Ungaro N., Marano C.A., Marsan R., Martino M., Marzano M.C., Strippoli G. and Vlora A. (1999) Analysis of demersal species assemblages from trawl surveys in the south Adriatic sea. *Aquatic Living Resources* 12, 177–185.

Zaitsev Y. and Öztürk B. (2001) *Exotic fish species in the Marmara, Black, Azov and Caspian Seas*. İstanbul, Turkey: Turkish Marine Research Foundation.

and

Zengin M. and Mutlu C. (2000) Marmara Denizi'ndeki Balıkçılığın Son Durumu ve Stokların Geleceğine İlişkin Öneriler (The resent state of the fisheries and suggestions related to the future of the stocks at the Marmara Sea). In Öztürk B., Kadıoğlu M. and Öztürk H. (eds) *Marmara Denizi 2000 Sempozyumu Bildiriler Kitabı, İstanbul,11–12 Kasım 2000*. TÜDAV 5, pp 441–425. [InTurkish.]

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