

## Population biology and habitat associations of benthic fish species in the shallow areas of a Mediterranean coastal lagoon (SE Iberian Peninsula)

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**SUMMARY:** The present study investigates the seasonal variation in fish abundance, fish biomass, reproductive status and population structure of four dominant benthic fish species, *Salaria pavo*, *Pomatoschistus marmoratus*, *Gobius cobitis* and *Gobius niger*, in the shallow and littoral areas of the Mar Menor coastal lagoon. In addition, the seasonal habitat associations of each species were studied by assessing environmental variables related to the habitat structure: submerged vegetation cover, submerged vegetation density, water depth and substrate composition. The temporal variations in fish density, standing stock and size frequency distributions of these species can largely be attributed to the seasonality of their breeding and juvenile recruitment periods. Moreover, habitat associations for these species were similar to those obtained in other Mediterranean and Atlantic coastal lagoons.

**Keywords:** Mar Menor, shallow habitats, Gobiidae, Bleniidae, fish density, gonadosomatic index.

**RESUMEN:** BIOLOGÍA POBLACIONAL Y ASOCIACIONES CON EL HÁBITAT DE LAS ESPECIES DE PECES BENTÓNICAS EN LAS ÁREAS SOMERAS DE UNA LAGUNA COSTERA MEDITERRÁNEA (SE PENÍNSULA IBÉRICA). – En el presente estudio se investigaron las variaciones estacionales de la abundancia, la biomasa, status reproductor y la estructura de la población de cuatro especies de peces bentónicos dominantes, *Salaria pavo*, *Pomatoschistus marmoratus*, *Gobius cobitis* y *Gobius niger*, en las zonas someras y litorales de la laguna costera del Mar Menor. Además, se estudiaron las asociaciones con las variables del hábitat: cobertura y densidad de la vegetación subacuática, profundidad y tipo de sustrato, para cada una de las especies y en cada estación del año. Las variaciones estacionales en la abundancia, la biomasa y la estructura por tallas de estas especies pueden ser atribuidas a sus periodos de reproducción y el reclutamiento de juveniles. Las asociaciones con las variables del hábitat para todas las especies fueron similares a las encontradas en otras lagunas costeras Mediterráneas y Atlánticas.

**Palabras clave:** Mar Menor, hábitats someros, Gobiidae, Bleniidae, densidad de peces, índice gonadosomático.

### INTRODUCTION

Coastal lagoons and estuaries play an important role and have great value for fish communities as spawning, nursery and feeding areas, pathways in diadromous migrations and even essential habitats for threatened fish species (Elliott *et al.*, 2007). Within these areas fish assemblages usually vary seasonally

and spatially according to their life-history strategies and habitat requirements (Drake *et al.*, 2002; Akin *et al.*, 2005; Pombo *et al.*, 2005; Pérez-Ruzafa *et al.*, 2007).

Unfortunately, these systems are among the most vulnerable aquatic environments in the world, being subject to considerable anthropogenic pressures that usually lead to changes in their biological well-being

(Costa *et al.*, 2007; Viaroli *et al.*, 2007). Knowledge of the structure and functioning of fish communities within these systems is thus important for management purposes and habitat enhancement (Vasconcelos *et al.*, 2007).

In temperate coastal lagoons Gobiidae and Blennidae families make up an important group of benthic fishes in terms of both species richness and abundance (Pérez-Ruzafa *et al.*, 2004; Koutrakis *et al.*, 2005; Malavasi *et al.* 2005; Franco *et al.*, 2006; Ribeiro *et al.*, 2006). In the Mar Menor coastal lagoon, the benthic fish assemblage is dominated by these families and, at specific level, *Pomatoschistus marmoratus* (Risso, 1810) (marbled goby), *Gobius cobitis* Pallas, 1814 (giant goby), *Gobius niger* L., 1758 (black goby) and *Salaria pavo* (Risso, 1810) (peacock blenny) are among the most abundant species (Barcala, 1999; Pérez-Ruzafa *et al.*, 2006). Although these resident species are an important component of the ichthyofauna of the shallow littoral areas in the Mar Menor coastal lagoon (Oliva-Paterna *et al.*, 2006), little is known about their population biology traits in these areas and only studies of condition indices have been published recently (Verdiell-Cubedo *et al.*, 2006a,b; Verdiell-Cubedo *et al.*, 2007).

Since the 1970s the Mar Menor has undergone strong environmental changes following widening of the channels that connect it to the Mediterranean sea, which has caused a decrease in salinity from 50-52 to the present levels of 39-45. Moreover, regular and intermittent watercourses flow into the lagoon, draining a large intensive agricultural area and leading to an high input of agrochemicals. Commercial fisheries are supported by the lagoon, which is also subject to intensive tourist development (Pérez-Ruzafa *et al.*, 2005). Its coastline is densely populated and affected by a variety of human activities (urban development, the construction of marinas, artificial beaches, etc.), although there are still some associated wetlands (industrial salt ponds and natural marshlands) that have an important ecological and natural value and have been given international and national protection status (Martínez *et al.*, 2005; Velasco *et al.*, 2006).

As part of a wider study to examine fish communities of the shallow littoral areas of the Mar Menor coastal lagoon, the objectives of this paper were (1) to examine seasonal and spatial variations in fish abundance, fish biomass, reproductive status and population structure of these benthic fish species

and (2) to analyse the relationship between fish species density and environmental variables related to habitat structure.

Apart from the scientific value of such a study, there is an urgent need to gain quantitative information on the population biology of fish communities and their relationships with environmental factors in coastal lagoons, in order to obtain appropriate evaluations and recommendations for potential recovery management programmes and, in the long run, to determine whether habitat enhancement measures make sense or environmental quality control of pollution inputs will have to be dealt with as a management priority.

## MATERIALS AND METHODS

### Study area

The Mar Menor is a hypersaline coastal lagoon located in a semiarid region in the southeast of the Iberian Peninsula (Fig. 1). It is one of the largest coastal lagoons in the Mediterranean basin, with a surface area of 135 km<sup>2</sup> and an average depth of 3-4 m. It is separated from the Mediterranean Sea by a 22 km-long sand bar called La Manga with three narrow channels connecting it to the open sea. The lagoon shows a salinity range of 39-45 and the temperature varies from 10°C in winter to 32°C in summer (Pérez-Ruzafa *et al.*, 2004). Its bottom is principally covered by dense meadows of the invasive macroalga *Caulerpa prolifera*, although the shallowest areas are covered by scarce patches of the phanerogame *Cymodocea nodosa* (Pérez-Ruzafa *et al.*, 2005). The lagoon maintains a diverse fish community due to its environmental heterogeneity: unvegetated sandy and muddy bottoms, rocky bottoms and seagrass beds composed of homospecific and heterospecific meadows of *C. nodosa* and *C. prolifera* (Pérez-Ruzafa *et al.*, 2006).

Shallow littoral areas (maximum depth  $\leq 1$  m) of the lagoon are characterised by soft substrates (principally muddy and sandy bottoms) and isolated patches of submerged vegetation (heterospecific and homospecific meadows of *C. nodosa* and *C. prolifera*). The sampling sites were located along the whole coastline of the lagoon to represent the diversity of shoreline habitats within it: artificial or natural sandy beaches associated with littoral urbanised areas and shallow littoral areas, which still show an important

degree of naturalness, associated with the adjacent coastal wetlands protected by law (San Pedro industrial salt ponds, La Hita salt marsh, El Carmolí salt marsh and Lo Poyo salt marsh) (Pérez-Ruzafa *et al.*, 2006; Conesa and Jiménez-Cárceles, 2007).

### Sampling methods

The sampling was carried out on a seasonal basis, during the summer (July) and autumn (October) of 2003, and the winter (February) and spring (May) of 2004. A total of 16 sampling sites were selected in the shallow littoral areas of the lagoon (Fig. 1). Samples were collected using a 10 m-long beach seine (2 mm mesh size), which allowed the capture of juvenile fishes and adults of small-sized species. We collected three to six replicates at each of the 16 sampling sites by hauling 20 m reaches of shoreline at each site, the area covered by each haul being approximately 160 m<sup>2</sup> (minimum hauled area per sampling site = 480 m<sup>2</sup>), with a total number of 263 samples taken.

After being anaesthetised, fish were preserved in 10% formalin solution and identified at species level in the laboratory following Whitehead *et al.* (1986) and Arias and Drake (1990).

The abundance and biomass of each species at each sampling site within season was recorded and expressed as fish density (number of individuals per 100 m<sup>2</sup>) and fish standing stock (grams of fish biomass per 100 m<sup>2</sup>), respectively.

A total of 2706 individuals were measured for total length (TL) to the nearest mm (905 specimens of *Salaria pavo*, 653 of *Gobius cobitis*, 460 of *G. niger* and 588 of *Pomatoschistus marmoratus*). Total weight (TW  $\pm$  0.01 g), eviscerated weight (EW  $\pm$  0.01 g) and gonad weight (GW  $\pm$  0.001 g) were measured in random sub-samples. The reproductive status of each species, as revealed by gonadosomatic index, was studied by analysing the variation in this index ( $GSI = 100 \text{ GW} / \text{TW}$ ).

According to the typical body size at maturity of each species in the Mar Menor (Barcala, 1999; unpublished data), fish were classified into two groups: juveniles (sexually immature) and adult fishes. *S. pavo* fish larger than 4.5 cm, *G. cobitis* fish larger than 6.0 cm, *G. niger* fish larger than 4.0 cm and *P. marmoratus* fish larger than 2.4 cm were considered as adult fishes.

Each sampling site was characterised by four environmental variables (quantified in each replicate

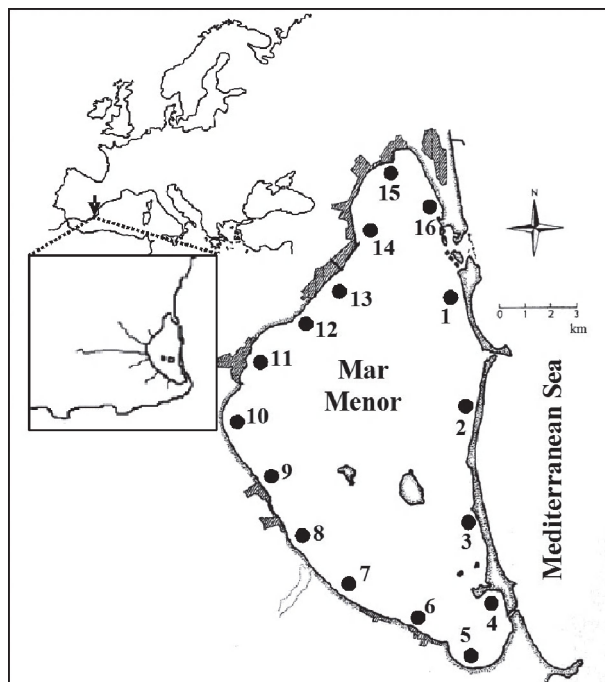


FIG. 1. – Geographical location of the Mar Menor coastal lagoon and location of sampling sites in the shallow littoral areas.

of each sampling site) related to habitat structure: water depth (cm), submerged vegetation cover (%), submerged vegetation density and substrate composition (mud, sand, gravel, pebble and boulder). The assessment of submerged vegetation cover and submerged vegetation density was made visually, the former recorded as the area percentage covered by submerged vegetation in each replicate and the latter as an ordinate categorical variable from 0 (low density of meadows) to 5 (high density of meadows). Substrate types were categorised according to Bain (1999) [mud (<0.06 mm), sand (0.06-1 mm), gravel (2-15 mm), pebble (16-63 mm) and boulder (>64mm)] and were estimated as percentage coverage within each replicate. The mean values of the environmental variables in each sampling site are given in Table 1.

### Statistical analyses

Two-way factorial analysis of variance (ANOVA) was used to test for differences in the fish density and standing stock among sampling sites and seasons. Both independent variables were considered as fixed factors. Fish density and standing stock data were transformed to  $\ln(x + 1)$  in order to reduce the heterocedasticity of the data. The level of significance was set at  $p \leq 0.01$  to minimise the chances of

TABLE 1. – Mean  $\pm$  S.E. of the measured environmental variables at each sampling site during the study period in the shallow areas of the Mar Menor coastal lagoon.

Sampling site	Depth (cm)	Submerged vegetation cover (%)	Submerged vegetation density	Mud (%)	Sand (%)	Gravel (%)	Pebble (%)	Boulder (%)
1 (La Chanta)	54.5 $\pm$ 4.5	28.5 $\pm$ 10.6	1.4 $\pm$ 0.5	1.7 $\pm$ 0.9	87.0 $\pm$ 1.6	11.0 $\pm$ 1.1	0.3 $\pm$ 0.3	0
2 (Tomás Maestre)	60.7 $\pm$ 5.0	14.0 $\pm$ 7.2	0.9 $\pm$ 0.4	0	82.2 $\pm$ 3.6	12.2 $\pm$ 3.0	3.6 $\pm$ 1.9	2.0 $\pm$ 1.1
3 (Los Aliseos)	48.0 $\pm$ 4.7	8.7 $\pm$ 6.2	0.6 $\pm$ 0.3	1.0 $\pm$ 1.0	79.0 $\pm$ 7.6	15.0 $\pm$ 5.5	3.7 $\pm$ 1.5	1.3 $\pm$ 1.3
4 (El Vivero)	37.1 $\pm$ 4.5	13.6 $\pm$ 6.3	0.7 $\pm$ 0.3	8.8 $\pm$ 2.5	74.8 $\pm$ 3.7	11.0 $\pm$ 1.4	4.0 $\pm$ 1.5	1.4 $\pm$ 0.7
5 (Playa Arsenal)	48.2 $\pm$ 5.2	12.7 $\pm$ 4.1	0.9 $\pm$ 0.2	11.5 $\pm$ 7.2	70.3 $\pm$ 7.7	12.1 $\pm$ 1.5	4.6 $\pm$ 1.8	1.5 $\pm$ 0.8
6 (Las Lomas)	64.7 $\pm$ 5.6	10.6 $\pm$ 6.8	0.7 $\pm$ 0.5	3.0 $\pm$ 1.9	74.3 $\pm$ 5.5	13.7 $\pm$ 3.9	6.7 $\pm$ 4.3	2.3 $\pm$ 1.2
7 (Los Nietos)	54.6 $\pm$ 3.8	16.8 $\pm$ 8.1	0.8 $\pm$ 0.4	16.0 $\pm$ 5.0	69.0 $\pm$ 5.5	10.7 $\pm$ 2.1	4.0 $\pm$ 1.7	0.3 $\pm$ 0.3
8 (Lo Poyo)	37.4 $\pm$ 3.5	25.7 $\pm$ 7.1	1.5 $\pm$ 0.3	40.0 $\pm$ 5.3	50.0 $\pm$ 4.6	9.0 $\pm$ 0.9	1.0 $\pm$ 0.3	0
9 (Punta Brava)	39.7 $\pm$ 4.8	30.5 $\pm$ 7.8	1.6 $\pm$ 0.4	29.2 $\pm$ 7.6	60.2 $\pm$ 8.0	9.8 $\pm$ 2.0	0.8 $\pm$ 0.6	0
10 (El Carmolí)	30.4 $\pm$ 4.7	25.0 $\pm$ 10.2	1.6 $\pm$ 0.7	39.2 $\pm$ 7.2	48.3 $\pm$ 2.8	8.3 $\pm$ 3.0	4.2 $\pm$ 1.4	0
11 (Cartagonovo)	42.8 $\pm$ 2.0	48.0 $\pm$ 15.0	2.8 $\pm$ 0.8	31.5 $\pm$ 9.0	41.7 $\pm$ 5.9	17.7 $\pm$ 3.8	7.3 $\pm$ 2.2	1.8 $\pm$ 1.8
12 (Los Alcázares)	51.9 $\pm$ 6.4	25.5 $\pm$ 11.8	1.2 $\pm$ 0.6	22.0 $\pm$ 14.7	71.7 $\pm$ 15.1	5.0 $\pm$ 0.7	1.3 $\pm$ 0.7	0
13 (La Hita)	35.3 $\pm$ 3.9	27.9 $\pm$ 7.5	1.4 $\pm$ 0.3	51.3 $\pm$ 9.5	37.5 $\pm$ 7.7	9.4 $\pm$ 2.2	1.8 $\pm$ 0.8	0
14 (Tres Marías)	52.8 $\pm$ 3.8	60.2 $\pm$ 7.5	3.1 $\pm$ 0.2	43.3 $\pm$ 13.3	44.2 $\pm$ 14.2	11.7 $\pm$ 1.8	0.8 $\pm$ 0.8	0
15 (Lo Pagán)	51.0 $\pm$ 3.8	10.3 $\pm$ 5.5	0.7 $\pm$ 0.3	6.0 $\pm$ 2.2	88.3 $\pm$ 2.1	5.2 $\pm$ 0.4	0.5 $\pm$ 0.2	0
16 (San Pedro)	46.6 $\pm$ 5.7	38.5 $\pm$ 8.7	2.0 $\pm$ 0.4	15.1 $\pm$ 3.5	66.3 $\pm$ 4.1	12.3 $\pm$ 2.7	3.8 $\pm$ 1.5	2.5 $\pm$ 1.2

Type I errors occurring (Underwood, 1997). Tukey's test was used for *post hoc* season comparisons when significant differences were detected ( $p \leq 0.01$ ).

To explore patterns of association among the environmental variables of the sampling sites, a principal component analysis (PCA) was applied to the correlation matrix for each sampling period separately. To establish species-habitat relationship the factors extracted by PCA were correlated (Pearson's correlation test) with fish density values for each studied species (Quinn and Keough, 2002). The correlation coefficients between the scores for each sampling site and the fish density make it possible to represent the fish density for each species as passive variables on a scatterplot, together with the environmental variables originally included in the PCA. Hence, this representation allows the fish density variable to be characterised in relation to the variables included in the analysis.

Prior to PCA, submerged vegetation cover and substrate variables were arc-sine transformed. Only those principal components (factors) with eigenvalues  $> 1$  were interpreted. The statistical analyses were performed using the SPSS® statistical package.

## RESULTS

A total of 25078 individuals of the studied species were caught in the shallow areas of the lagoon. The most abundant species, in terms of fish density, was *Pomatoschistus marmoratus*, which represented 89.96% (mean fish density for the study period

$\pm$  S.E.: 53.59  $\pm$  4.35 individuals/100 m<sup>2</sup>) of the total catch. This species was followed by *Salaria pavo* with 6.88% (mean fish density for the study period  $\pm$  S.E.: 4.10  $\pm$  0.80 individuals/100 m<sup>2</sup>) of the total catch, while *Gobius cobitis* and *G. niger* represented 1.63% (mean fish density for the study period  $\pm$  S.E.: 0.97  $\pm$  0.23 individuals/100 m<sup>2</sup>) and 1.54% (mean fish density for the study period  $\pm$  S.E.: 0.92  $\pm$  0.17 individuals/100 m<sup>2</sup>) of the total catch, respectively. As regards standing stock, *P. marmoratus* was also the dominant species, representing 70.03% (mean standing stock for the study period  $\pm$  S.E.: 17.06  $\pm$  1.29 g/100 m<sup>2</sup>) of the total catch, while *S. pavo*, *G. niger* and *G. cobitis* represented 13.83% (mean standing stock for the study period  $\pm$  S.E.: 3.37  $\pm$  0.54 g/100 m<sup>2</sup>), 10.55% (mean standing stock for the study period  $\pm$  S.E.: 2.57  $\pm$  0.51 g/100 m<sup>2</sup>) and 5.59% (mean standing stock for the study period  $\pm$  S.E.: 1.35  $\pm$  0.28 g/100 m<sup>2</sup>), respectively.

Studied species density and standing stock varied considerably across the 16 sampling sites (Table 2). The sampling site effect was responsible for significant differences in fish density and fish standing stock for all species (Tables 3 and 4).

Figure 2 shows the mean seasonal fish density and mean seasonal fish standing stock for each species. The Tukey test revealed that for *S. pavo* and *G. cobitis* their density and standing stock were significantly higher in summer (Tables 3 and 4). The *G. niger* density and standing stock did not differ between autumn and spring, or between summer and winter, although the first two seasons showed significantly higher values than the latter (Tables 3



TABLE 2. – Mean  $\pm$  S.E. fish density (no. individuals/100 m<sup>2</sup>) and standing stock (g individuals/100 m<sup>2</sup>) of the species studied at each sampling site during the study period.

Samplig site	<i>Salaria pavo</i>		<i>Pomatoschistus marmoratus</i>		<i>Gobius cobitis</i>		<i>Gobius niger</i>	
	Fish density	Standing stock	Fish density	Standing stock	Fish density	Standing stock	Fish density	Standing stock
1 (La Chanta)	1.96 $\pm$ 1.05	1.48 $\pm$ 0.5	67.71 $\pm$ 12.29	18.35 $\pm$ 3.16	0.21 $\pm$ 0.10	0.25 $\pm$ 0.12	0.33 $\pm$ 0.15	1.43 $\pm$ 0.73
2 (Tomás Maestre)	0.94 $\pm$ 0.28	1.91 $\pm$ 0.76	60.04 $\pm$ 10.24	20.45 $\pm$ 4.43	2.99 $\pm$ 0.93	3.19 $\pm$ 0.75	0.28 $\pm$ 0.17	0.49 $\pm$ 0.33
3 (Los Alíseos)	1.88 $\pm$ 0.83	1.93 $\pm$ 0.94	127.5 $\pm$ 23.48	33.98 $\pm$ 6.79	2.29 $\pm$ 1.18	1.95 $\pm$ 0.90	0.71 $\pm$ 0.27	1.46 $\pm$ 0.64
4 (El Vivero)	5.42 $\pm$ 3.24	3.78 $\pm$ 2.18	37.71 $\pm$ 7.81	14.56 $\pm$ 3.57	4.94 $\pm$ 2.41	6.22 $\pm$ 2.56	0.39 $\pm$ 0.13	1.02 $\pm$ 0.37
5 (Playa Arsenal)	1.11 $\pm$ 0.39	1.64 $\pm$ 0.64	44.81 $\pm$ 12.54	11.21 $\pm$ 2.28	0.38 $\pm$ 0.18	0.43 $\pm$ 0.19	0.98 $\pm$ 0.29	2.84 $\pm$ 1.13
6 (Las Lomas)	0.83 $\pm$ 0.31	3.80 $\pm$ 2.31	35.21 $\pm$ 20.5	9.00 $\pm$ 3.26	0.13 $\pm$ 0.09	0.73 $\pm$ 0.62	0.13 $\pm$ 0.09	0.22 $\pm$ 0.17
7 (Los Nietos)	2.38 $\pm$ 1.27	1.93 $\pm$ 0.83	53.04 $\pm$ 18.65	19.87 $\pm$ 5.91	0.33 $\pm$ 0.20	0.56 $\pm$ 0.31	1.75 $\pm$ 0.90	6.51 $\pm$ 3.21
8 (Lo Poyo)	0.58 $\pm$ 0.42	0.60 $\pm$ 0.44	71.67 $\pm$ 24.72	27.88 $\pm$ 7.81	0	0	1.00 $\pm$ 0.59	3.53 $\pm$ 1.97
9 (Punta Brava)	1.64 $\pm$ 0.78	1.66 $\pm$ 0.71	49.32 $\pm$ 11.34	19.33 $\pm$ 3.76	0.28 $\pm$ 0.26	0.75 $\pm$ 0.70	1.72 $\pm$ 0.94	5.11 $\pm$ 2.51
10 (El Carmolí)	0.42 $\pm$ 0.27	1.44 $\pm$ 0.93	13.23 $\pm$ 3.15	8.47 $\pm$ 2.30	0	0	5.37 $\pm$ 2.37	15.94 $\pm$ 7.13
11 (Cartagonovo)	17.44 $\pm$ 9.83	12.55 $\pm$ 6.45	22.94 $\pm$ 14.89	4.53 $\pm$ 2.02	0.25 $\pm$ 0.14	0.63 $\pm$ 0.35	1.13 $\pm$ 0.62	2.19 $\pm$ 1.18
12 (Los Alcázares)	12.50 $\pm$ 7.14	7.37 $\pm$ 3.01	30.76 $\pm$ 12.15	5.80 $\pm$ 1.60	0.22 $\pm$ 0.11	0.86 $\pm$ 0.53	0.58 $\pm$ 0.6	0.39 $\pm$ 0.19
13 (La Hita)	7.46 $\pm$ 3.94	4.95 $\pm$ 1.57	78.13 $\pm$ 28.14	28.38 $\pm$ 9.04	0.16 $\pm$ 0.12	0.19 $\pm$ 0.13	1.21 $\pm$ 0.46	2.01 $\pm$ 0.85
14 (Tres Marías)	38.42 $\pm$ 11.41	28.60 $\pm$ 10.77	8.54 $\pm$ 5.79	1.34 $\pm$ 0.80	0	0	0	0
15 (Lo Pagán)	1.88 $\pm$ 1.52	0.94 $\pm$ 0.62	72.84 $\pm$ 17.41	21.44 $\pm$ 4.92	0.03 $\pm$ 0.03	0.09 $\pm$ 0.09	0.03 $\pm$ 0.03	0.12 $\pm$ 0.12
16 (San Pedro)	0.97 $\pm$ 0.57	1.48 $\pm$ 0.99	40.56 $\pm$ 14.22	12.57 $\pm$ 4.28	1.41 $\pm$ 0.58	3.16 $\pm$ 1.64	0.09 $\pm$ 0.07	0.38 $\pm$ 0.27

TABLE 3. – Results of two-way factorial analysis of variance performed on the fish density [ln (no. individuals/100 m<sup>2</sup>)] of the studied species using season and sampling site as fixed factors. Results of Tukey (HSD) test for season comparisons are also shown (su = summer; au = autumn; wi = winter; sp = spring). Levels of significance: ns, not significant; \*\*p<0.01; \*\*\*p<0.001.

Species	df	F	Tukey (HSD)
<i>S. pavo</i>			
Season	3	61.96***	su > au = wi = sp
Sampling site	15	5.04***	
Season x Sampling site	41	1.93***	
Error	203		
<i>P. marmoratus</i>			
Season	3	3.18ns	
Sampling site	15	3.24***	
Season x Sampling site	41	1.75**	
Error	203		
<i>G. cobitis</i>			
Season	3	15.06***	su > au = wi = sp
Sampling site	15	5.44***	
Season x Sampling site	41	2.04**	
Error	203		
<i>G. niger</i>			
Season	3	36.56***	au = sp > su = wi
Sampling site	15	5.38***	
Season x Sampling site	41	2.50***	
Error	203		

and 4). Finally, *P. marmoratus* density did not differ between seasons, while its standing stock was significantly lower in summer (Tables 3 and 4).

The season x sampling site interaction was also significant for all cases, except for *S. pavo* density, which underlines the high spatial variability of fish density and fish standing stock across all seasons (Tables 3 and 4).

The GSI for *P. marmoratus* and *G. niger* peaked in spring, although *P. marmoratus* also showed a

TABLE 4. – Results of two-way factorial analysis of variance performed on the fish standing stock [ln (g individuals/100 m<sup>2</sup>)] of the studied species using season and sampling site as fixed factors. Results of Tukey (HSD) test for season comparisons are also shown (su = summer; au = autumn; wi = winter; sp = spring). Levels of significance: ns, not significant; \*\*p<0.01; \*\*\*p<0.001.

Species	df	F	Tukey (HSD)
<i>S. pavo</i>			
Season	3	31.22***	su > sp = au > wi
Sampling site	15	3.38***	
Season x Sampling site	41	1.42ns	
Error	203		
<i>P. marmoratus</i>			
Season	3	16.03***	au = wi = sp > su
Sampling site	15	3.11***	
Season x Sampling site	41	2.06**	
Error	203		
<i>G. cobitis</i>			
Season	3	6.04**	su > au = wi = sp
Sampling site	15	4.75***	
Season x Sampling site	41	1.91***	
Error	203		
<i>G. niger</i>			
Season	3	36.06***	au = sp > su = wi
Sampling site	15	5.46***	
Season x Sampling site	41	2.53***	
Error	203		

relatively high GSI during winter. On the other hand, *G. cobitis* showed a peak during winter and *S. pavo* during summer (Fig. 3).

It is worth pointing out the higher densities of *S. pavo*, *P. marmoratus* and *G. cobitis* juvenile fishes captured during summer (Fig. 4). In this season, juveniles represented 83.5% (1365 individuals), 46.3% (3978 individuals) and 94.7% (498 individuals) of total captures for each species, respectively. On the other hand, *G. niger* juveniles were present mainly

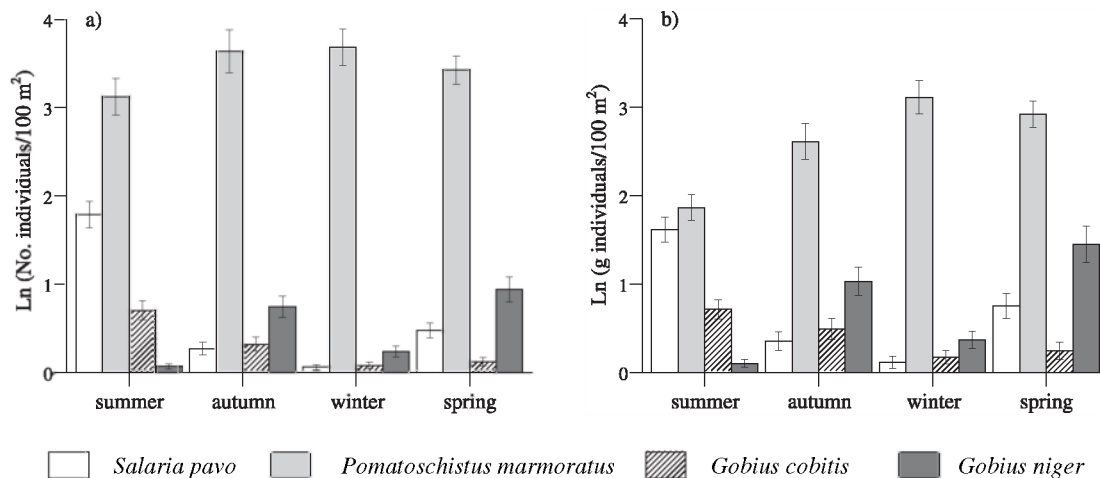


FIG. 2. – (a) Mean fish density  $\pm$  S.E. [ $\text{Ln (no. individuals/100 m}^2\text{)}$ ] and (b) mean fish standing stock  $\pm$  S.E. [ $\text{Ln (g individuals/100 m}^2\text{)}$ ] of the studied species within season.

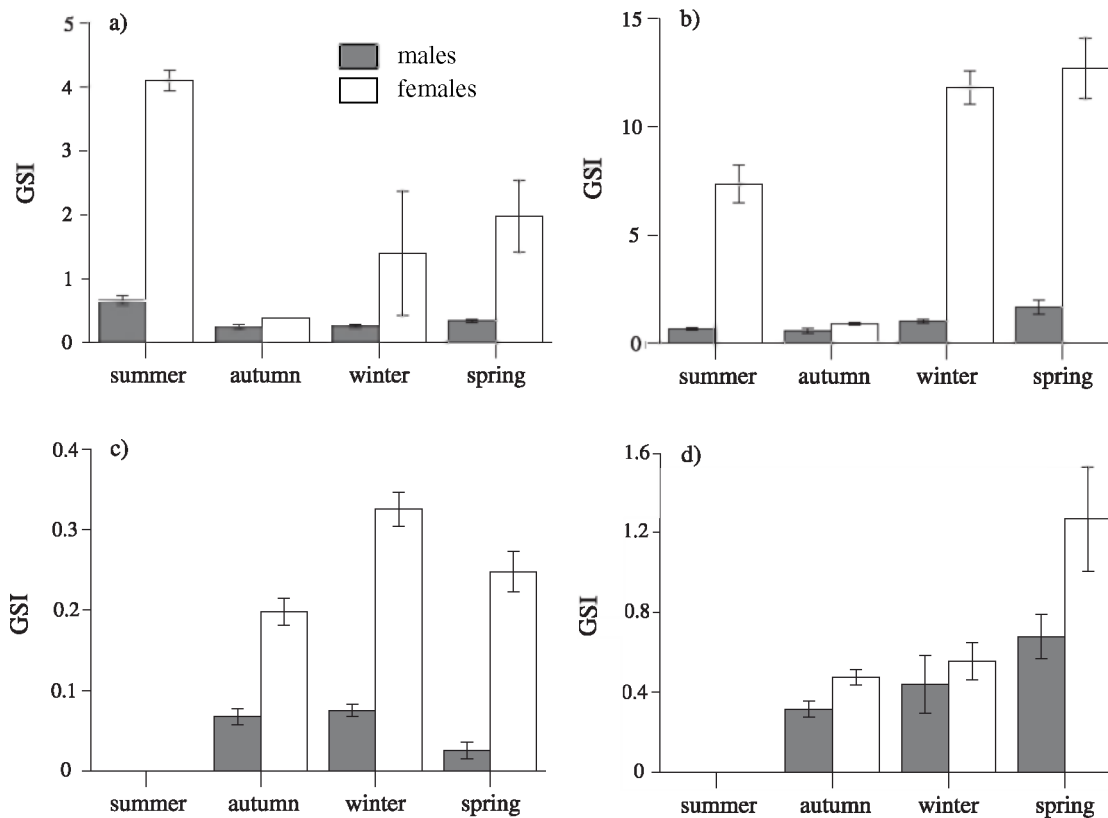


FIG. 3. – Seasonal mean  $\pm$  S.E. gonadosomatic index of males and females of the studied species: (a) *Salaria pavo* (males = 213, females = 137), (b) *Pomatoschistus marmoratus* (males = 116, females = 125), (c) *Gobius cobitis* (males = 59, females = 80), (d) *Gobius niger* (males = 84, females = 68).

during autumn, when they represented 24.1% (39 individuals) of total captures in this season for this species (Fig. 4).

Figure 5 shows the PCA analysis performed on the habitat variables for each season, and the position of the studied species according to the PCA scores. Each seasonal analysis determined two principal components, which explained 65.5–71.2% of

the variation in environmental variables. As shown in Figure 5, PC1 could be interpreted as a gradient from unvegetated sandy and deeper bottoms on the left part of the diagram, to shallow, muddy and well vegetated bottoms on the opposite side. PC2 was related to the presence of large substrate types (mainly pebbles and boulders). This situation changed in spring, when the right part of the diagram was re-

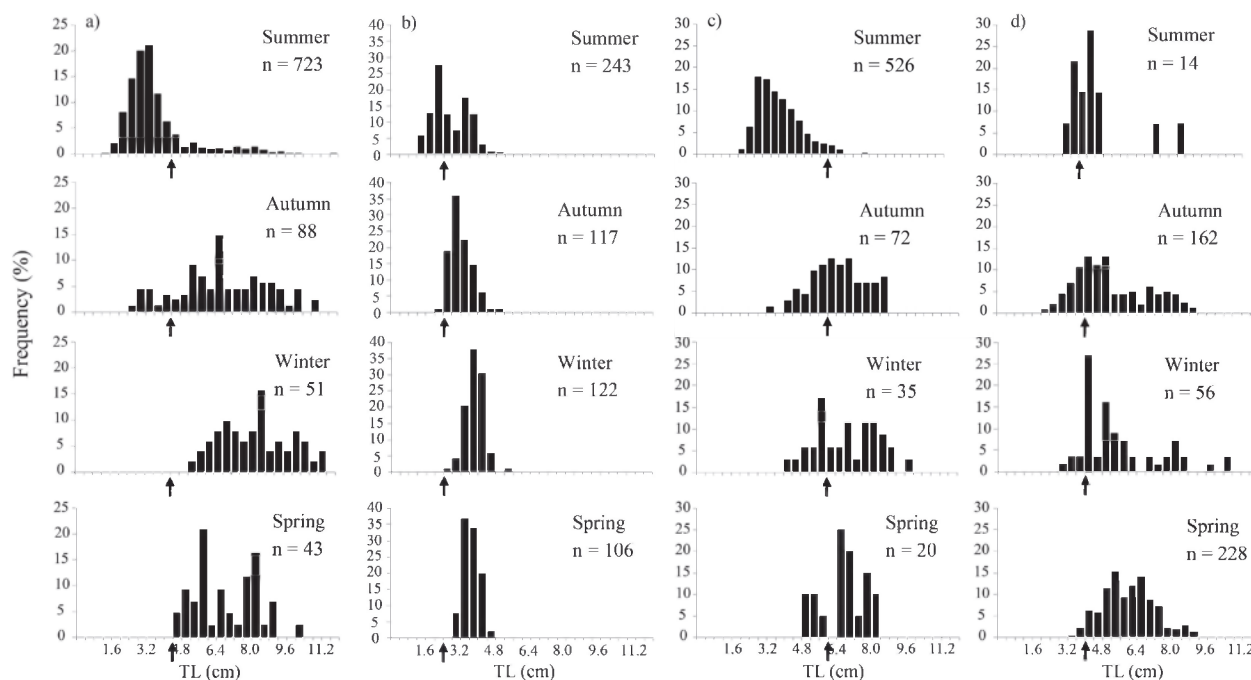


FIG. 4. – Size frequency distributions of the studied species within season: a) *Salaria pavo*, b) *Pomatoschistus marmoratus*, c) *Gobijs cobitis*, d) *Gobijs niger*. Arrows indicate the typical body size at maturity of each species.

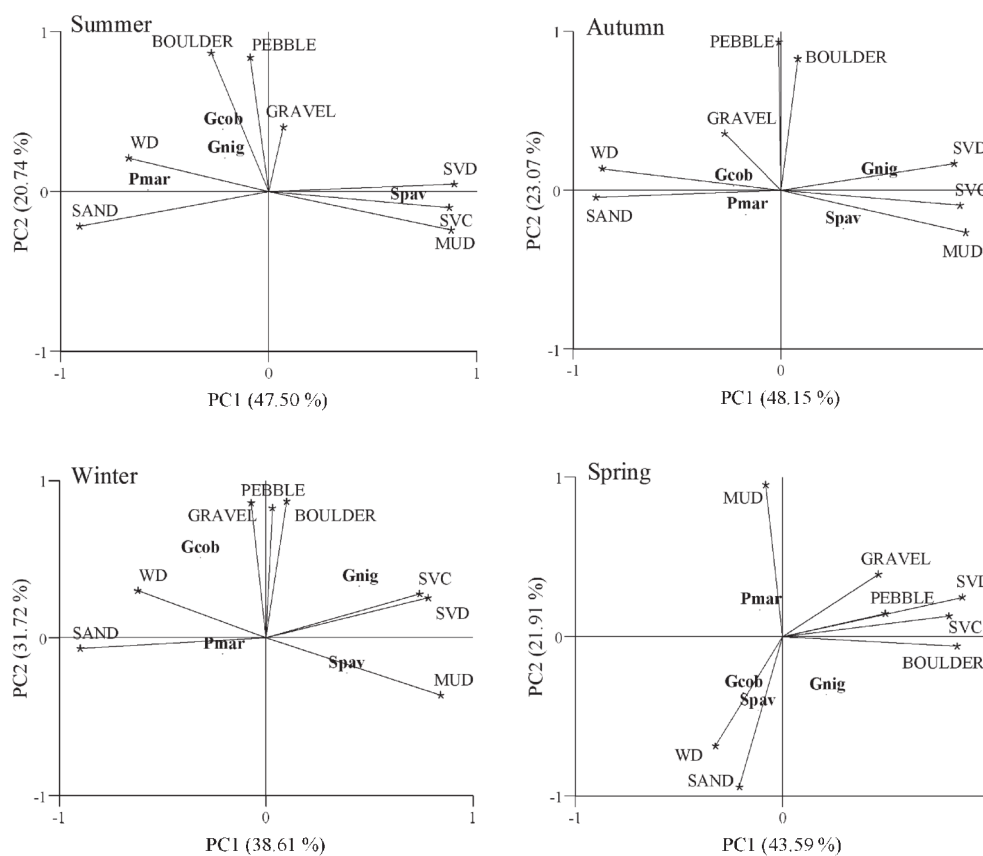


FIG. 5. – Results of the principal component analysis (PCA) and the position of studied species according to PCA scores. WD, water depth; SVC, submerged vegetation cover; SVD, submerged vegetation density; MUD, mud percentage; SAND, sand percentage; GRAVEL, gravel percentage; PEBBLE, pebble percentage; BOULDER, boulder percentage; Spav, *Salaria pavo*; Pmar, *Pomatoschistus marmoratus*; Gcob, *Gobijs cobitis*; Gnig, *Gobijs niger*.

lated to bottoms with high structural complexity and PC2 distinguished between sandy and muddy bottoms.

The density of *S. pavo* and *G. niger* was mainly positively correlated with PC1 in all seasons, with a significant relationship in summer ( $r_p = 0.67$ ,  $p < 0.001$ ) for *S. pavo* and for *G. niger* in autumn ( $r_p = 0.47$ ,  $p < 0.05$ ) and winter ( $r_p = 0.45$ ,  $p < 0.05$ ). The highest density of *S. pavo* during summer (38.44 individuals/100 m<sup>2</sup>) was obtained at the Tres Marías sampling site, which showed a well-developed mixed meadow of *Cymodocea nodosa* and *Caulerpa prolifera* and muddy bottoms (Table 1). *Gobius niger* densities were highest at shallow sampling sites with muddy and well-vegetated bottoms (Table 1). El Carmolí and Cartagonovo sampling sites showed the highest values with 10.21 individuals/100 m<sup>2</sup> and 1.56 individuals/100 m<sup>2</sup> during autumn and winter, respectively.

Conversely, *G. cobitis* density was mainly positively correlated with PC2, with a significant relationship in summer ( $r_p = 0.39$ ,  $p < 0.05$ ) and winter ( $r_p = 0.51$ ,  $p < 0.05$ ). El Vivero and Las Lomas sampling sites showed coarse substrate types (Table 1) and the highest densities of *G. cobitis* during summer (14.27 individuals/100 m<sup>2</sup>) and winter (0.63 individuals/100 m<sup>2</sup>), respectively. It is worth noting the absence of *G. cobitis* at Lo Poyo, El Carmolí and Tres Marías sampling sites during the study period and, conversely, the higher abundance of this species at the sampling sites located in La Manga: Tomás Maestre, Los Alíseos and El Vivero (Table 2).

In general, *P. marmoratus* was located around the origin of the axes in all seasons and showed no significant correlation with any of the considered factors, except in summer when this species showed a negative and significant relationship with PC1 ( $r_p = -0.58$ ,  $p < 0.001$ ). During this season the highest density of *P. marmoratus* (170.21 individuals/100 m<sup>2</sup>) was obtained at Los Alíseos sampling site, which was characterised by relatively unvegetated and deeper bottoms (Table 1).

## DISCUSSION

*Pomatoschistus marmoratus* was clearly the dominant species in terms of fish density and standing stock in the shallow areas of the lagoon, which agrees with other studies on fish assemblages in Mediterranean coastal lagoons and estuaries (Fouda

*et al.*, 1993; Berrebi *et al.*, 2005; Koutrakis *et al.*, 2005; Malavasi *et al.*, 2005) and with recent work on the Mar Menor lagoon (Pérez-Ruzafa *et al.*, 2006), where this species was seen to be very important in the make-up of benthic fish assemblages. As suggested by Berrebi *et al.* (2005) and Malavasi *et al.* (2005), the higher abundance of *P. marmoratus* in the Mar Menor could be explained by its sedentary nature and low level of habitat preferences. Moreover, it could be favoured by the relatively stable and higher salinity of the lagoon (>40) (Berrebi *et al.*, 2005; Malavasi *et al.*, 2005). This species showed a relatively homogeneous density throughout the study period, although the lower standing stock values observed in summer could be related to its recruitment period and the presence of smaller and juvenile individuals.

In contrast, the rest of the species studied showed a significant seasonal variation in their density and standing stock. A similar seasonal variation in fish density and standing stock was recognisable for *Salvia pavo* and *Gobius cobitis* (although *S. pavo* was more abundant than *G. cobitis*), both species showing higher values during summer, mainly due to the recruitment of juvenile fishes, and very low values during the other seasons. These results coincide with those presented by Malavasi *et al.* (2005) and Franco *et al.* (2006) for the Venice lagoon, and suggest that these species mainly use the shallow and littoral areas of the lagoon as recruitment and refuge grounds for juvenile individuals.

The temporal patterns of *G. niger* in the shallow areas also coincide with observations made in the Venice lagoon and the Ria de Aveiro lagoon, the increase in density and standing stock in autumn being related to the recruitment season and the second peak (spring) to the breeding period (higher GSI values) (Arruda *et al.*, 1993; Malavasi *et al.*, 2005; Franco *et al.*, 2006). Unlike *S. pavo* and *G. cobitis*, *G. niger* seems to use the shallow areas of the lagoon for reproductive purposes. This situation was probably due to the habitat requirements for reproduction of this species: males build nest under stones and defend and take care of the eggs deposited by the females (Barcala, 1999). The presence of a dense monospecific meadow of the invasive macroalga *Caulerpa prolifera*, which covers the whole central area of the lagoon, could force *G. niger* breeding individuals to migrate toward littoral shallow areas in search of suitable bottoms for reproduction.

The temporal variation in GSI suggests a pro-



longed breeding period for *P. marmoratus*, with maximum GSI values in spring, which agrees with other studies on this species (Malavasi *et al.*, 2005) and contrasts with results presented by Fouda *et al.* (1993) in Lake Timsah (Egypt), where the highest GSI values were obtained in winter. The GSI values of *G. cobitis* peaked in winter and decreased slightly in spring, its breeding season being slightly earlier than Atlantic populations, which reproduce in late spring (Gibson, 1970). These intraspecific variations in GSI were probably due to differences in water temperature to which the different populations were exposed (Gill *et al.*, 1996). The breeding period of *Salaria pavo* was shifted to summer, which is consistent with the results presented by Patzner (1983) and Almada *et al.* (1994) in Mediterranean and Atlantic populations, respectively.

The results concerning habitat associations in the shallow areas of the lagoon are similar to those obtained in other coastal lagoons, where *S. pavo* and *G. niger* are typical species of the seagrass meadows and *G. cobitis* of the unvegetated sandy bottoms (Malavasi *et al.*, 2005; Franco *et al.*, 2006; Ribeiro *et al.*, 2006). They also agree with those obtained by Pérez-Ruzafa *et al.* (2006) in the Mar Menor, where *S. pavo* and *G. niger* were more frequent on bottoms covered by *Caulerpa prolifera* meadows, while *G. cobitis* was more frequent on natural rocky bottoms and breakwaters. The absence of *G. cobitis* at Lo Poyo, El Carmolí and Tres Marias sampling sites and, conversely, the higher abundance of this species at the sampling sites located in La Manga can be attributed to the absence of artificial structures (rocky breakwaters and dikes) at the former sampling sites and its higher abundance and the presence of coarse substrate types (pebbles and boulders) at the latter, which could favour colonisation by *G. cobitis* (Pérez-Ruzafa *et al.*, 2006).

Malavasi *et al.* (2005) showed that *P. marmoratus* was, in terms of habitat requirements, a generalist species. The results presented here point to a similar situation except in summer, when this species showed a strong association with unvegetated sandy and deeper bottoms. This abundance pattern coincides with results presented by Pérez-Ruzafa *et al.* (2006) and Franco *et al.* (2006), who showed that *P. marmoratus* was more abundant on sparsely and unvegetated sandy bottoms. As suggested by Malavasi *et al.* (2005), this situation was probably due—in addition to its morphological adaptations—to the competitive effects of the territorial and aggressive

behaviour of individuals of larger goby species. In summer, the shallow areas of the Mar Menor are inhabited by high densities of juvenile fishes of *G. cobitis* and *S. pavo*, so competition with such species could force *P. marmoratus* individuals to search for unvegetated and deeper bottoms. In fact, recent studies dealing with the somatic condition of this species suggest that interspecific competition can negatively affect *P. marmoratus* individuals (Verdiell-Cubedo *et al.*, 2007).

In conclusion, the temporal patterns of variation in fish density and standing stock of the species studied in the shallow and littoral areas of the Mar Menor can be attributed, for the most part, to the seasonality of their breeding and juvenile recruitment periods. In addition, habitat associations for these species were similar to those obtained in other Mediterranean and Atlantic coastal lagoons.

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