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The effects of competitors on fitness of marbled goby *Pomatoschistus marmoratus* (Pisces, Gobiidae) in the Mar Menor coastal lagoon (SE Iberian Peninsula)

D. VERDIELL-CUBEDO*, F. J. OLIVA-PATERNA & M. TORRALVA

Department of Zoology, University of Murcia, Murcia, Spain

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Abstract
We investigated the relationship, at local level, between fitness (measured as fish condition) of *Pomastoschistus marmoratus* and environmental variables of shallow areas in the Mar Menor lagoon (Spain, Mediterranean Sea): water temperature (°C), water salinity (‰), depth (cm), submerged vegetation cover (%), submerged vegetation volume, substrate size, substrate heterogeneity, fish species richness, potential competitor fish species abundance, potential competitor fish species biomass, *P. marmoratus* abundance and *P. marmoratus* biomass. The mass–length relationships were used to test differences in fish condition between nine sampling sites. The ecological variable that accounted for most of the variation in condition was the abundance of potential competitor fish species, wich was related to interspecific fish interactions. The condition of *P. marmoratus* populations may be a good indicator of fish density interactions in coastal lagoons and could be considered when such populations are subjected to recovery plans or any other management programmes.

Keywords: Pomatoschistus marmoratus, *fish condition, mass–length relationship, environmental assessment, fish competition effects*

Introduction

Pomatoschistus marmoratus (Risso, 1810) is a resident benthic fish in the Mar Menor coastal lagoon. The marbled goby inhabits sandy and shallow bottoms in inshore, coastal lagoons and estuarine areas. Its geographical distribution ranges from the southwest Atlantic coast of Iberian Peninsula to Mediterranean and Black Seas (Miller 1986). Reproduction occurs in spring and summer, males build nests under mussel shells and defend and take care of the eggs deposited by the females (Mazzoldi & Rasotto 2001). Their food prey consists of small crustaceans, polychaetes and chironomid larvae (Miller 1986).

Gobies are an important component of fish assemblages in temperate estuaries and coastal lagoons (Arruda et al. 1993; Salgado et al. 2004; Malavasi et al. 2005). *P. marmoratus* is the most abundant benthic fish in sandy shallow habitats of some estuaries and costal lagoons of the Mediterranean Sea (Koutrakis et al. 2000, 2005; Malavasi et al. 2004; Berrebi et al. 2005). In terms of abundance and biomass, both larval and adult fish are dominant in fish assemblages in the Mar Menor (Pérez-Ruzafa et al. 2004).

Abundant literature concerning other *Pomatoschistus* spp. species is available, although few studies exist on the biology and ecology of *P. marmoratus*. To date, two studies about biology of this fish were done from the Suez Canal (eastern Mediterranean), Egypt (Fouda et al. 1993; Fouda 1995). More recently, new data have been published on the genetic, reproductive biology and distribution of this species in Italian and French coastal lagoons (Arculeo et al. 1999; Mazzoldi & Rasotto 2001; Berrebi et al. 2005). However, no data about southwest Mediterranean populations of *P. marmoratus* have been published.

In the management of fish populations it is common to measure individual, cohort (e.g. age or size groups) and population fitness (Jakob et al.

*Correspondence: David Verdiell-Cubedo, Department of Zoology, University of Murcia, 30100 Murcia, Spain. Tel: +34 968364961. Fax: +34 968363963. Email: verdiell@um.es

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1996). Such measurements are indicators of tissue energy reserves and may characterize components of the environment in which the fish live (e.g. food and habitat availability, competition, predation, physical factors and pollution) (Jackson et al. 2002; Copp 2003; Lloret & Planes 2003; Oliva-Paterna et al. 2003). These measurements reflect what is generally known as fish condition. A low fish condition can negatively affect growth, survival, first maturity and reproductive effort in subsequent phases of fish life history (Rätz & Lloret 2003; Hoey & McCormick 2004; Morgan 2004; Lloret et al. 2005).

Fish assemblages of coastal lagoons can be classified by reference to functional guilds, defined as a group of species that exploit the same class of environmental resources in a similar way (Root 1967). In this sense, fish species could show an overlap in resource utilization in time and space and, at certain times and/or sites, this could produce inter- and intraspecific competition events (Rice 2005).

The study of fish condition together with the investigations concerning the habitat characteristics allow for a better understanding of the biology and ecology of fish populations. Therefore, the aim of this work was to examine spatial variations in condition, estimated from the mass–length relationship, of *P. marmoratus*. More specifically, our aim was to study the relationship between fish condition and several environmental variables such as: water temperature (°C), water salinity (‰), depth (cm), submerged vegetation cover (%), submerged vegetation volume, substrate size, substrate heterogeneity, fish species richness, potential competitor fish species abundance, potential competitor fish species biomass, *P. marmoratus* abundance and *P. marmoratus* biomass.

Materials and methods

Study area

The Mar Menor is a hypersaline coastal lagoon located in a semiarid region in the south-east of the Iberian Peninsula (Figure 1). It is one of the largest coastal lagoons in the Mediterranean region and Europe, with a surface area of 135 km^2 and an average depth of 3–4 m. It is separated from the Mediterranean Sea by a 22 km-long sand bar with three narrow channels connecting it with the sea. The lagoon shows a salinity range of 39–45‰ and the temperature varies from 10°C in winter to 32°C in summer. Its bottom is principally covered by dense meadows of the invasive macroalga *Caulerpa prolifera*, although shallow areas are covered by meadows of *Cymodocea nodosa* (Pérez-Ruzafa et al. 2005).

Since the 1970s, the Mar Menor has suffered strong environmental changes following widening of the connecting channels, which has caused a decrease in salinity from 50–52‰ to the present levels. Moreover, regular and intermittent watercourses flow into the lagoon, draining a large intensive agricultural area and leading to an important input of agrochemicals. Finally, the Mar Menor coastal lagoon supports important commercial fisheries and is subject to intensive tourist development (Pérez-Ruzafa et al. 2005).

Sampling methods

The catches were carried out during July 2002 as part of a wider study to examine the effects of human activities on fish communities of the coastal lagoon. A total of nine sampling sites were selected in the perimeter shallow coastal areas. Samples were collected using a 10 m-long bag seine net and 0.5 mm mesh size, which allowed the collection of juvenile fish and adults of small-sized species. We collected three quantitative replicates at each sampling site by nearby (separated by approximately 50 m) 20 m reaches of shoreline at each site. In each reach, the bag seine was hauled offshore parallel to the shoreline in water <1.0 m for the whole length of the reach. The area covered by each haul was approximately 160 m^2 (quantitative sampling).

Additionally, one bag seine haul and five quadrangular (40×40 cm) hand net sweeps (non-quantitative samplings) were made along the shoreline in each sampling area. Our goal was to sample all shoreline habitats to detect species richness in a given sampling site.

Thus, three replicate samples were obtained at each of the nine sampling sites, enabling us to assess variance within sites and the efficiency of seining.

Fish from each of the three reaches (quantitative samplings) and non-quantitative samplings were preserved in separate jars in 7% formaldehyde, before being removed and identified at species level in the laboratory (Whitehead et al. 1986; Arias & Drake 1990).

Relative abundance was expressed as catch per unit effort (CPUEs) and biomass per unit effort (BPUEs):

$$\text{CPUEs} = \text{fish number}/\text{haul area covered}\ \left(160\ \text{m}^2\right)$$

$$\text{BPUEs} = \text{fish biomass (g)}/\text{haul area covered}\left(160\,\text{m}^2\right)$$

Each sampling site was characterized by 12 environmental variables and indices (quantified in each reach of every sampling site) related to water

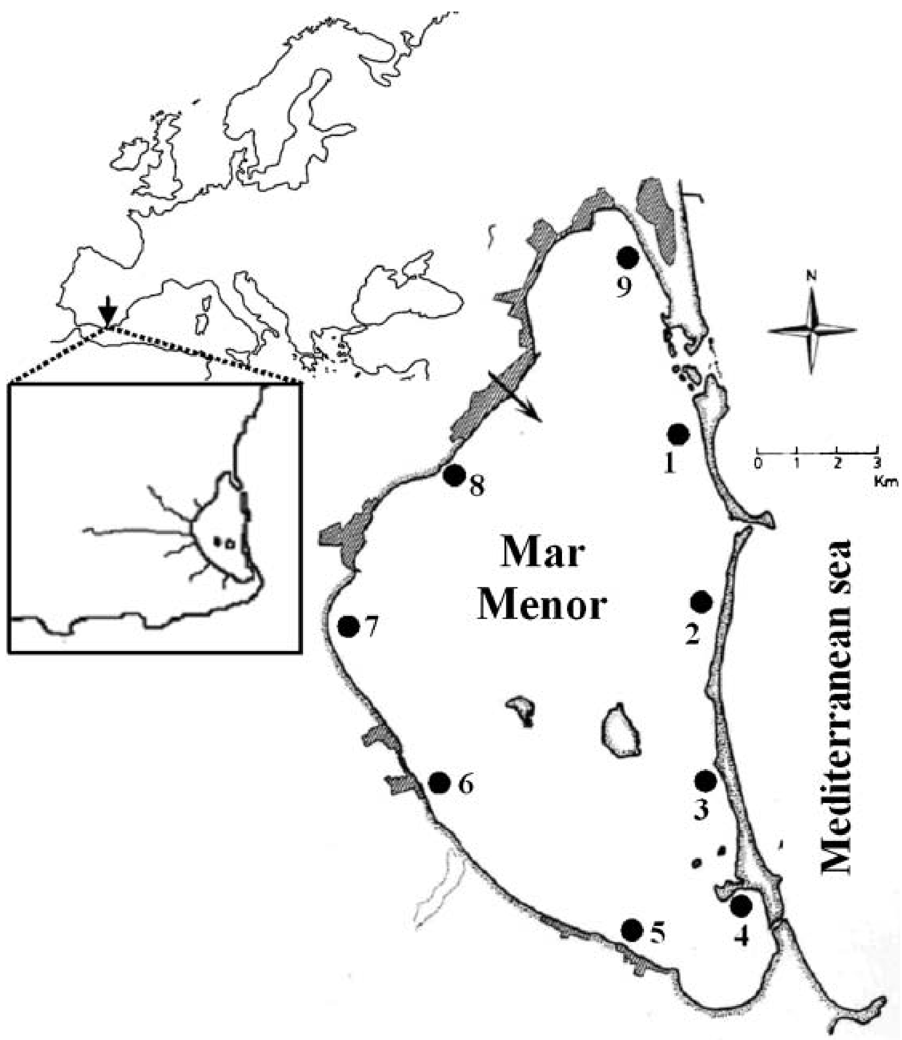

Figure 1. Geographical location of the Mar Menor coastal lagoon and location of sampling sites.

quality (weekly mean values), habitat structure (local level), possible resources exploited by fish populations and inter and intraspecific fish interactions: water temperature (°C), water salinity (‰), depth (cm), submerged vegetation cover (%), submerged vegetation volume, substrate size, substrate heterogeneity, fish species richness, potential competitor fish species abundance, potential competitor fish species biomass, *P. marmoratus* abundance and *P. marmoratus* biomass (Table I).

Water temperature (± 0.1°C) and salinity (± 0.1) were measured three times using an universal pocket meter WTW® Multi340i. The assessment of submerged vegetation cover and submerged vegetation volume was made visually, the first recorded as the area percentage covered by submerged vegetation in each reach and the second as an ordinate categorical variable from 0 (low density of meadows) to 5 (high density of meadows). We classified substrate *sensu* Bain (1999) [mud (1), sand (2), gravel (3), pebble (4) and boulder (5)] and assessed the substrate size (SS; average in each sampling site) and substrate heterogeneity (SH, standard deviation in each sampling site) by making at least 10 visual designations in each reach. The mean values of the abovementioned environmental variables were assessed at each sampling site. Fish species richness was evaluated as the total number of fish species at each sampling site.

Lipophrys dalmatinus, *Salaria pavo*, *Gobius niger*, *Gobius paganellus*, *Callionymus pusillus*, *Diplodus sargus sargus* (juveniles; total length $\leqslant 7.0$ cm) and *Solea solea* (juveniles; total length $\leqslant 7.0$ cm) were considered as potential competitor fish species due to their benthic habitat and dietary preferences (Dumay et al. 2004; Malavasi et al. 2004). In this way, potential competitor fish species and *P. marmoratus* relative abundance and biomass were

Table I. Mean values ± SD of variables in each sampling site: water temperature; water salinity; depth; submerged vegetation richness; submerged vegetation cover; submerged vegetation volume: 0 (low density) to 5 (high density); substrate size (SS; mean value); substrate heterogeneity (SH; mean value); fish species richness; potential competitor fish species abundance; potential competitor fish species biomass.

Sampling site	Water temperature (°C)	Salinity (‰)	Depth (cm)	Submerged vegetation cover (%)	Submerged vegetation volume	SS	SH	Fish species richness	Potential competitor fish species abundance (CPUEs)	Potential competitor fish species biomass (CPUEs)	*P. marmoratus* abundance (CPUEs)	*P. marmoratus* biomass (BPUEs)
La Chanta (1)	23.1 ± 0.8	40.2 ± 0.1	57 ± 3	5 ± 9	0.7 ± 0.6	2.1 ± 0.0	0.2 ± 0.0	13 ± 3	14.7 ± 22.0	6.5 ± 9.3	23.4 ± 30.0	35.0 ± 19.7
Las Brisas (2)	24.2 ± 0.4	41.5 ± 0.0	72 ± 4	10 ± 8	0.7 ± 0.6	2.3 ± 0.1	0.8 ± 0.2	10 ± 2	13.0 ± 14.5	13.1 ± 8.0	80.8 ± 70.1	123.0 ± 45.1
El Casino (3)	23.5 ± 0.6	42.1 ± 0.1	48 ± 1	23 ± 16	1.7 ± 0.6	2.6 ± 0.3	0.9 ± 0.5	10 ± 1	2.3 ± 4.9	7.9 ± 11.5	41.1 ± 19.6	73.6 ± 10.0
El Ciervo (4)	24.6 ± 0.3	42.1 ± 0.0	28 ± 5	7 ± 3	1.0 ± 0.0	2.2 ± 0.2	0.8 ± 0.2	9 ± 1	1.0 ± 1.0	2.6 ± 4.3	13.6 ± 10.8	30.7 ± 2.8
Playa Honda (5)	25.6 ± 0.9	41.5 ± 0.0	56 ± 4	18 ± 10	1.3 ± 0.6	2.4 ± 0.2	0.8 ± 0.3	13 ± 3	4.0 ± 4.0	14.5 ± 13.2	14.7 ± 19.7	32.7 ± 6.4
Los Urrutias (6)	28.2 ± 0.6	42.7 ± 0.2	18 ± 1	32 ± 23	2.7 ± 1.5	1.9 ± 0.3	0.8 ± 0.1	7 ± 1	0.0 ± 0.0	0.0 ± 0.0	8.3 ± 15.7	17.7 ± 7.3
El Carmolí (7)	23.7 ± 0.6	33.3 ± 1.0	22 ± 3	9 ± 7	1.3 ± 0.6	1.8 ± 0.2	0.7 ± 0.1	8 ± 1	1.0 ± 1.0	0.2 ± 0.2	25.1 ± 57.4	6.0 ± 17.6
Las Palmeras (8)	26.7 ± 0.2	43.2 ± 0.0	49 ± 9	13 ± 14	1.3 ± 0.6	2.1 ± 0.1	0.6 ± 0.2	7 ± 1	0.7 ± 1.2	1.7 ± 2.9	6.1 ± 33.4	38.0 ± 5.4
La Calcetera (9)	26.2 ± 0.6	41.7 ± 0.1	31 ± 8	23 ± 14	2.0 ± 0.0	2.4 ± 0.3	0.9 ± 0.3	6 ± 1	1.0 ± 1.0	5.2 ± 4.5	9.8 ± 13.2	20.3 ± 6.2

assessed as mean CPUEs and BPUEs, respectively, at each sampling site.

A total of 325 individuals of *P. marmoratus* (with total lengths ranging from 27 to 53 mm) from nine sampling sites were measured for total length (TL, ±1 mm), standard length (SL, ±1 mm), total mass (TM, ±0.01 g) and eviscerated mass (EM, ±0.01 g). In addition, a subsample of potential competitor fish species were measured for total length (TL, ±1 mm): *Lipophrys dalmatinus* (n=37), *Salaria pavo* (n=19), *Gobius niger* (n=15), *Gobius paganellus* (n=21), *Callionymus pusillus* (n=22), *Diplodus sargus sargus* (n=89) and *Solea solea* (n=20).

Statistical analyses

The statistical analysis used to compare fish condition was based on that used in previous studies (Vila-Gisbert & Moreno-Amich 2001; Oliva-Paterna et al. 2003) and proposed by García-Berthou & Moreno-Amich (1993). The method applies univariate analysis of covariance (ANCOVA) using eviscerated mass as the dependent variable and total length as the covariate. The relationship between eviscerated mass and length was clearly non-linear, but was linear after log-transformation. The homogeneity of the regression coefficients (slopes) was tested with an ANCOVA design that analysed the pooled covariate-by-factor interaction. If the covariate-by-factor interaction (homogeneity of slopes) was not significant ($P>0.05$), standard ANCOVA was applied to test differences in the parameter a (fish condition) between sampling sites.

A stepwise multiple regression analysis was performed to determine the amount of variation in parameter a (fish condition) associated with environmental variables. This regression procedure first selects the most correlated independent variable, and then removes the variance in the dependent variable. It then selects the second independent variable which most correlates with the remaining variance in the dependent variable, and so on until selection of an additional independent does not increase the r^2 by a significant amount ($P \leqslant 0.05$).

Statistical analyses were performed with SPSS® software package and a significance level of $P \leqslant 0.05$ was accepted.

To explore patterns of association among the environmental variables of the nine sampling sites, the principal component analysis (PCA) was applied to the correlation matrix. A Varimax rotation of the resulting matrix was performed (Visauta-Vinacua 1997).

Results

Juvenile and adult individuals of 17 fish species were captured: *Aphanius iberus*, *Atherina boyeri*, *Pomatoschistus marmoratus*, *Gobius niger*, *Gobius paganellus*, *Callionymus pusillus*, *Salaria pavo*, *Lypophrys dalmatinus*, *Solea solea*, *Diplodus sargus sargus*, *Sarpa salpa*, *Liza aurata*, *Liza saliens*, *Liza ramado*, *Hippocampus guttulatus*, *Syngnathus abaster* and *Belone belone*.

The size frequency distribution for the potential competitor fish species is shown in Figure 2.

Coefficients of the mass–length relationship of sampling sites are presented in Table II and the results of the ANCOVA are shown in Table III. There was significant homogeneity between sampling sites on the slope (parameter *b*) of the EM–TL relationships (Preliminary design, Table III), although the *y*-intercept (parameter *a*) varied significantly between sampling sites (Final design, Table III). As a result, sampling sites could be compared according to the values of parameter *a* of the EM–TL relationships. The La Chanta (1) sampling site showed the lowest fish condition value, and El Ciervo (4) showed the highest fish condition value.

A stepwise multiple regression model indicated that only potential competitor fish species abundance accounted for the variation between sampling sites (60.7%) of parameter *a* in the EM–TL relationships (Table IV), pointing to a negative effect on the condition of *P. marmoratus*.

The first two factors extracted by PCA explained 52% of total variance (factor 1, 32.3%; factor 2, 19.7%). Inspection of Figure 3 supports the following conclusions: there was a positive correlation of the first factor with *P. marmoratus* abundance and biomass, depth and potential competitor fish species abundance. Moreover, water temperature was negatively correlated with the first factor. Secondly, fish species richness was the variable associated most strongly with factor 2.

Discussion

In the investigation of intra- and interpopulation variations in fish condition, mass–length regressions provide a good alternative to relative mass indices (ratio-related techniques), assuming that the slope does not vary between nearby sampling sites or that the slope is homogeneous for population on a local level (Sutton et al. 2000). Relative mass indices do not normally fulfil these underlying assumptions and have been criticized on statistical grounds (Jakob et al. 1996).

Our results showed that the condition of *P. marmoratus* differed between the sampling sites studied. Any differences in parameter *a* of the EM–TL relationship were probably caused by differences in ecological condition. Although fish size could be an important factor affecting fish condition (Pope & Willis 1996), the homogeneity of the slopes of the mass–length relationship obtained for the sampling sites studied indicated that condition was independent of fish body form (Winters & Wheeler 1994).

In our site level analysis of habitat-fish condition relationships, potential competitor fish species abundance was the ecological variable that best correlated with *P. marmoratus* condition. Sampling sites with higher values of potential competitor fish abundance (La Chanta and Las Brisas) provided the lowest values for parameter *a* of the EM–TL relationship, demonstrating a poorer fish condition.

It is known that Mediterranean shallow coastal lagoons are environments that exhibit very high variability in biotic and abiotic parameters, at both temporal and spatial level (Malavasi et al. 2004; Koutrakis et al. 2005). In gobiid populations inhabiting these areas, environmental variability can lead to different degrees of competition, predation and mortality (Pampoulie et al. 2000, 2001; Pampoulie, 2001).

Fish population densities vary in time and space, and there may be strong seasonal variations in the effects of competitors (Steele & Forrester 2002).

In the warm season (June to September), the shallow areas of the Mar Menor are inhabited by high densities of juvenile fishes of different species (gobiidae and bleniidae principally), which use these areas as nursery sites. So, during the sampling period (July) the size structure of the fish community was very similar (see Figure 2). Moreover, *Pomatoschistus marmoratus* abundance was positively correlated with the abundance of potential competitor fish species.

In such situation, competition for prey resources (due to trophic overlap) and/or for refuge from predators was probably higher. Competition for food and space, both within and between species, has been considered an important factor in the structuring of fish communities (Elliot & Hemingway 2002). Although no data about prey resources in the Mar Menor are available, it is certain that the sampling sites presented a relatively low substrate size (sand–gravel) and low submerged vegetation cover, so competition for refuge was likely higher.

Density-dependent processes, such as competition and aggression among individuals of the same or different species, can be an influential factor in fitness, growth, reproduction and survival (Wootton

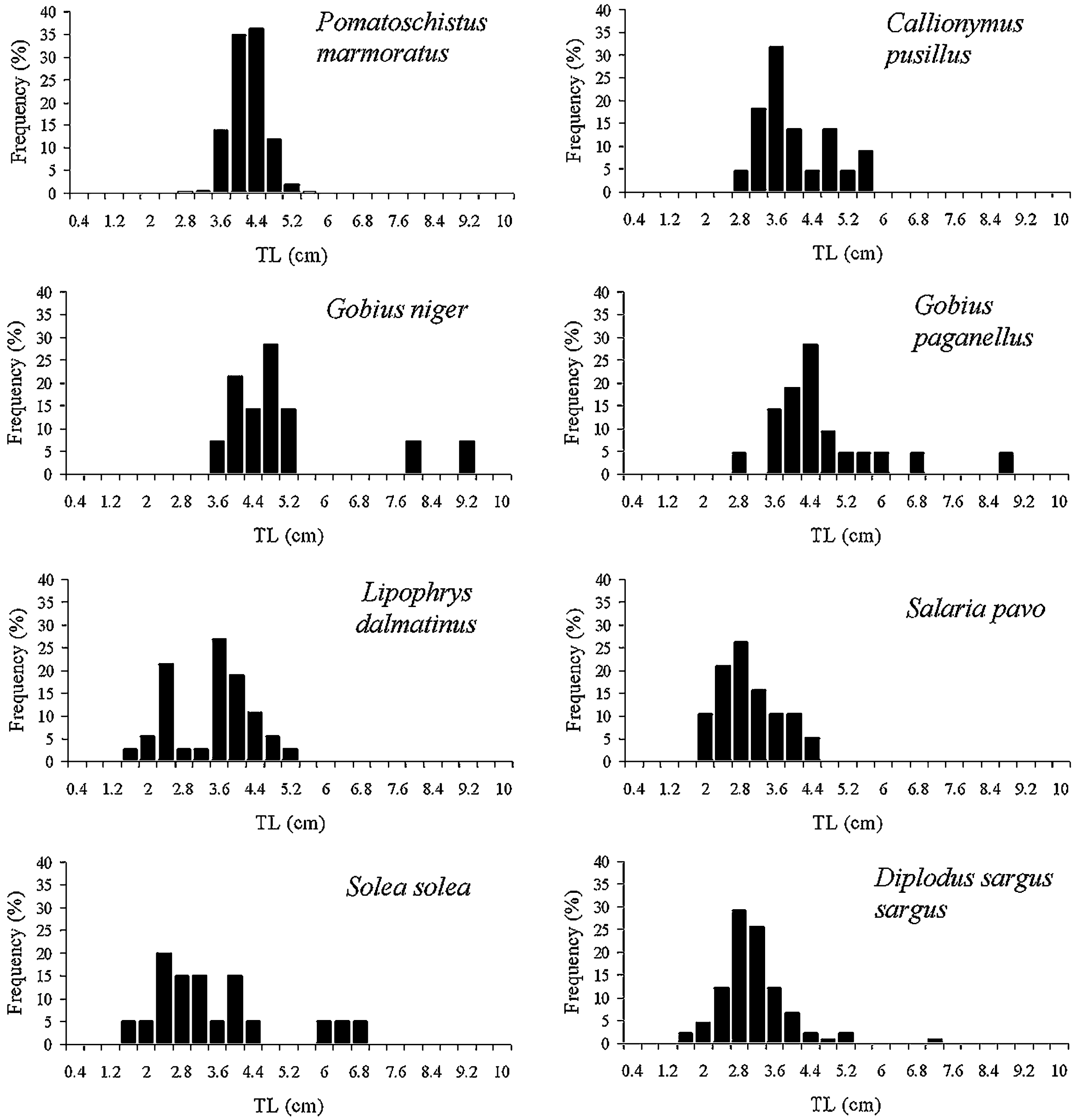

Figure 2. Size frequency distributions for *Pomatoschistus marmoratus* and potential competitor fish species in the Mar Menor coastal lagoon.

1998; Hensor et al. 2005). In addition, Jackson et al. (2002) concluded that a reduction in prey availability for *P. microps* reduced their condition and, consequently, their fitness and nest quality.

In another scenario, the competitive superiority of larger individuals may reduce the availability of resources for smaller individuals, with the result that the dominant fish show a higher condition value than subordinate fish (Adams et al. 1998; Sloman et al. 2001). In sampling sites with a higher abundance of potential competitor fish species, it is very probable that the territorial and aggressive behaviour of larger individuals (see Figure 2) of *Gobius niger* and *G. paganellus* denies *P. marmoratus* access to prey resources. Indeed, Malavasi et al. (2005) suggested that the distribution of smaller gobies such as *P. marmoratus* and *P. microps* in the shallow areas of Venice lagoon could be related to the competitive and predation pressure due to the presence of larger gobies (e.g. *G. niger*).

Table II. Regression coefficients (*a, b*) ±SD and determination coefficients (r^2) of the log-transformed mass–length relationship.

Sampling site	*n*	*b* (slope)	*a* (the y-intercept)	Adjusted r^2	*P*
La Chanta (1)	50	3.06±0.15	−10.38±0.69	0.89	<0.0005
Las Brisas (2)	38	2.81±0.20	−9.23±0.95	0.84	<0.0005
El Casino (3)	36	2.67±0.20	−8.62±0.95	0.83	<0.0005
El Ciervo (4)	32	2.52±0.24	−7.92±1.13	0.77	<0.0005
Playa Honda (5)	37	2.78±0.18	−9.10±0.81	0.87	<0.0005
Los Urrutias (6)	37	2.77±0.19	−9.07±0.88	0.85	<0.0005
El Carmolí (7)	40	2.61±0.24	−8.34±1.13	0.75	<0.0005
Las Palmeras (8)	18	2.61±0.17	−8.39±0.79	0.93	<0.0005
La Calcetera (9)	37	2.67±0.18	−8.59±0.87	0.85	<0.0005

Hence, a high abundance of potential competitor fish species produces an important level of stress in *P. marmoratus* individuals, which is reflected in a decrease of its somatic condition.

We found no relationships between the other variables of habitat structure and fish condition, probably due to the number of sampling sites or perhaps because any relationship was clouded by the very complexity of the ecological interactions (e.g. a nonlinear relationship between these variables). To a certain extent, this demonstrates the need for more investigation into the relationships between habitat characteristics, environmental variations and fish condition in the study area.

In conclusion, our results suggest that, at least in the study period, interspecific fish competition in the shallow areas of the Mar Menor can be an influential factor in the somatic condition of *P. marmoratus* individuals. This situation can affect the subsequent phases of its life history traits such growth and reproduction.

Table III. ANCOVA analyses of the mass–length relationship in *Pomatoschistus marmoratus*. All variables (dependent and covariate) were log-transformed. Total length is the covariate.

Source of variation	*F*	df	*P*
Preliminary design (test for interaction)			
TL	1558.02	1, 324	<0.0005
Sampling site	0.84	8, 324	0.567
TL × Sampling site	0.87	8, 324	0.546
Final design (no interaction)			
TL	1803.37	1, 324	<0.0005
Sampling site	8.95	8, 324	<0.0005

Table IV. Stepwise multiple regression model used to predict condition (a) of *Pomatoschistus marmoratus* from environmental variables.

	Regression equation	Adjusted r^2	*F*	df	*P*
Model	*a*=−8.417 − 0.810 (potential competitor fish species abundance)	0.607	13.336	1, 8	<0.05

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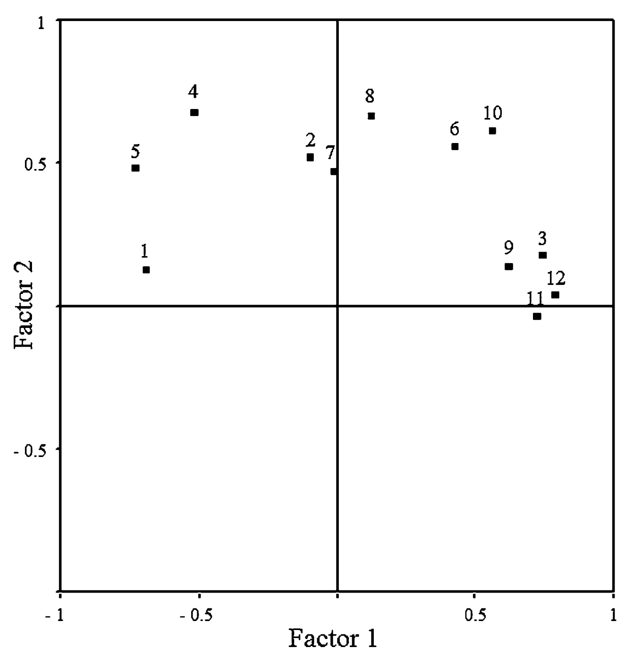

Figure 3. Result of the principal component analysis that includes the following variables: 1, water temperature; 2, salinity; 3, depth; 4, submerged vegetation cover; 5, submerged vegetation volume; 6, substrate size; 7, substrate heterogeneity; 8, fish species richness; 9, potential competitor fish species abundance; 10, potential competitor fish species biomass; 11, *Pomatoschistus marmoratus* abundance; 12, *P. marmoratus* biomass.

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