Biomass response to environmental factors in two congeneric species of *Mullus*, *M. barbatus* and *M. surmuletus*, off Catalano–Levantine Mediterranean coast of Spain: a preliminary approach

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Abstract
Biomass response to environmental factors in two congeneric species of Mullus, M. barbatus *and* M. surmuletus*, off Catalano–Levantine Mediterranean coast of Spain: a preliminary approach.*— We analyzed the influence of some abiotic variables in the biomass distribution of these species using survey data collected over four years (2006–2009) in the Catalano–Levantine coast of Spain. The preliminary results show that variables such as time (year) and latitude feebly affect the biomass distribution of these species. Depth, by itself, is not as significant as believed, masking the influence of other variables. *M. barbatus* biomass distribution seems to be especially influenced by salinity and, to a lesser extent, by temperature, while only temperature seems to have a significant effect on the *M. surmuletus* biomass distribution. These results are consistent with the bathymetric distribution of both species, with *M. barbatus* showing affinity for low salinity waters and *M. surmuletus* for warmer waters, which may contribute to the segregation of the species.

Key words: *Mullus*, Biomass, Abiotic factors, Western Mediterranean.

Resumen
Respuesta de la biomasa a factores ambientales en dos especies congenéricas, M. barbatus *y* M. surmuletus*, en aguas catalano–levantinas de la costa Mediterránea española: planteamiento preliminar.*— Se ha analizado la influencia de algunos factores abióticos en la distribución de las biomasas de las especies utilizando datos de campaña recogidos a lo largo de cuatro años (2006–2009) en la costa catalano–levantina de España. Los resultados preliminares muestran que las distribuciones de la biomasa de las dos especies se ven afectadas débilmente por la época del año y la latitud. La profundidad no resulta tan significativa como se esperaba, enmascarando la influencia de otras variables. La distribución de la biomasa de *M. barbatus* está especialmente afectada por la salinidad y, en menor medida, por la temperatura; y en el caso de *M. surmulentus*, parece que únicamente la temperatura tiene un efecto significativo en la distribución de la biomasa. Estos resultados son consistentes con la distribución batimétrica de ambas especies, mostrando una afinidad por aguas de salinidad reducida en el caso de *M. barbatus*, y por aguas cálidas en el caso de *M. surmuletus*, que puede contribuir a la segregación de las especies.

Palabras clave: *Mullus*, Biomasa, Factores abióticos, Mediterráneo occidental.

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Introduction

The red mullet (*Mullus barbatus* L., 1758) and the striped red mullet (*Mullus surmuletus* L., 1758) are common demersal fishes of the Mediterranean Sea that appear distributed all around the Mediterranean basin and the North–Western Atlantic, mostly at depths less than 200 m in the shelf. *M. barbatus* inhabits sandy and muddy bottoms, while *M. surmuletus* is generally found on bottoms with heterogeneous granulometry and often on *Posidonia* beds. They show bathymetric habitat partitioning and clear niche segregation in relation to the bottom type that constitutes their habitat (Margalef, 1980; Hureau, 1986; Lombarte et al, 2000).

Both species are among the most valuable resources for fisheries, being fished simultaneously or sequentially using a number of gears that vary over the year (Martin et al., 1999). In the Spanish Mediterranean, the trawl fleets generate 80% of the *Mullus* landings, with *M. barbatus* representing ≈ 70% of this fraction. However, in small–scale fisheries that account for the remaining 20% of the total landings, *M. surmuletus* represents 75% of the catch, and *M. barbatus* accounts for the remaining 25%. The mullet trammel nets are preferably used in areas where *M. surmuletus* concentrates, such as the coastal rocky bottoms and, more generally, at depths over 50 m or at the limit of the meadows of *Posidonia oceanica* (L.) Delile (1813), thus attaining higher yield in the bottoms (Baino et al., 1998), while avoiding any interference with trawl fishing (García–Rodríguez et al., 2006). Taking both fisheries together, the proportion of species in total landings is almost balanced, with a slight dominance (60/40) of *M. barbatus.* Inter–annual fluctuations in volume are high (Fernández, pers. com.) and are present despite fishing efforts remaining almost constant. This suggests that fluctuations do not depend only on fishing activities, but also on the environmental conditions. In this sense, some recent studies related sea–surface temperature with recruitment success for *M. barbatus* in the strait of Sicily (Levi et al., 2003), and Machias et al. (1998) established the ranges of bottom depth, temperature and salinity over which *M. surmuletus* is distributed in the Cretan shelf. In addition, generalised additive models (GAMs) have been applied to test the hypothesis that *M. barbatus* abundance is related to the bathymetry, spatial location and temperature variability of the NE Mediterranean (Maravelias et al., 2007).

To shed some light on this topic, we developed an exploratory study on the influence of several abiotic variables (year, latitude, depth, temperature and salinity) in the distribution of these two species in the Catalano–Levantine coast of Spain.

Material and methods

Sampling took place in the Catalano–Levantine coast of Spain (FAO–GFCM Geographic Sub Area 06, GSA 6). All samples were collected during the course of four consecutive MEDITS_ES International Spring Trawl Surveys (from 2006 to 2009) according to the international standard methodology (Relini et al., 2008). Sea depth, temperature and salinity were recorded using a CTD SBE–37 probe located in the mouth of the gear and represented *in situ* observations of the hydrological conditions associated with each catch. For each of the above variables, individual haul averages were estimated from the data recorded during the effective trawl (when the gear is in contact with the bottom) and included in the analyses as variables. Another variable included was latitude, while year of survey (2006–2009) was considered as a factor. Fish biomass per haul was calculated as the catch in weight by sweep area and expressed in kg/km^2. Some cartographic depictions of sea temperature, salinity and fish abundance (expressed as biomass captured per square kilometre) were obtained applying a geostatistical kriging model over the cumulated data collected in the study.

An exploratory scrutiny of the data was carried out by means of covariance analysis, linear regression and correlation (Pearson's correlation coefficient) to elucidate whether the above variables had any relationship to the biomass distribution of the two mullets during the study period. To clarify whether species had any 'preference' in their appearance, a *t*–test, an analysis of variance (ANOVA) and a Tukey test were performed over the data distribution, previously normalised by means of a logarithmic transformation, to test for significant differences in the mean values of the variables between samples with presence and samples without presence of each species.

Table 1. Main statistical values of the considered abiotic variables (depth, temperature and salinity) of total samples recorded over the 2006–2009 period in the Catalano–Levantine coast of Spain: D. Depth (m); T. Temperature (ºC); S. Salinity (0/00).

Tabla 1. Principales valores estadísticos de las variables abióticas consideradas (profundidad, temperatura y salinidad) del total de las muestras recogidas en el periodo 2006–2009 en las costas catalano–levantinas de España: D. Profundidad (m); T. Temperatura (ºC); S. Salinidad (0/00).

	D	T	S
Min.	33	12.81182	37.79290
Max.	816	16.72884	38.54560
Average	193.55	13.5469	38.2414
(± SD)	(± 188.26)	(± 0.71355)	(± 0.1727)
Range	783	3.917018	0.752704

Table 2. Main statistical values of abiotic variables considered (depth, temperature and salinity) in samples with *Mullus* occurrence.

Tabla 2. Principales valores estadísticos de las variables abióticas consideradas (profundidad, temperatura y salinidad) en las muestras con presencia de las especies de Mullus.

	Depth (m)	Temperature (ºC)	Salinity (0/00)	Biomass (kg/km^2)
M. barbatus				
Min.	33	12.8118	37.7929	0.36
Max.	535	16.7288	38.3913	658.53
Average	102.93	13.6990	38.1569	43.68
(± SD)	(± 68.34)	(± 0.8362)	(± 0.1176)	(± 86.73)
Range	502	3.9170	0.5984	658.16
M. surmuletus				
Min.	36	12.8118	37.9048	0.50
Max.	535	16.7288	38.5334	547.49
Average	126.71	13.7364	38.1922	19.04
(± SD)	(± 103.51)	(± 0.8792)	(± 0.1492)	(± 62.96)
Range	499	3.9170	0.6286	546.99

Finally, a generalized linear model (GLM) was also performed. Data were normalised by transforming biomass to Ln, and the relationship between the different factors and the species biomass was analysed by means of multiple regressions, applying a simple model without interactions and identity as a link:

$$\text{Ln}(\text{biomass}_{jklm}) = \mu + Yj + Lj + Dk + Tl + Sm + \varepsilon_{ijklm}$$

where: μ is overall mean; Yi, effect of year i; Lj, effect of latitude j; Dk, effect of depth stratum k; Tl, effect of temperature l, Sm, effect of salinity m; ε, error term assumed to be distributed normally.

A deviation analysis was carried out to evaluate the significance of the factor and variables in the model. Deviance represents the variation present in the data and its analysis results in a table that summarises the information related to the sources of variation of the data, in a similar way to an ANOVA. In this table, each variable copes with an amount of deviance that represents the amount of variation of the response explained by the variable. Statistical analysis was performed with the S–PLUS software (MathSoft, Seattle, WA, USA).

Results

Analyses comprised data from 293 hauls (33–816 m depth) collected over a period of four years (2006–2009). Table 1 shows the average and range of each of the studied abiotic variables. Depth showed negative and positive significant correlations with temperature (r^2 = 0.54; t = –0.916; p = 0.000) and salinity (r^2 = 0.75; t = 19.525; p = 0.000), respectively. Correlation between temperature and salinity was negative and significant (r^2 = 0.44; t = –8.335; p = 0.000). Thus, both salinity and temperature were highly correlated with depth, showing a gradient on both the continental shelf and the upper slope, with colder and saltier waters in deeper zones (fig. 1).

The average biomass of each species seemed to covariate positively with latitude and temperature and negatively with depth and salinity. Despite r^2 values being low (< 0.27), in the case of *M. barbatus* all relations were significant (latitude: t = 2.0658, p = 0.041; depth: t = –2.424, p = 0.0165; temperature: t = 3.564, p = 0.0005; and salinity: t = –3.248, p = 0.0014). In *M. surmuletus*, temperature was the only variable showing a significant relation with the fish biomass (r^2 = 0.218; t = 2.362; p = 0.01996). *M. barbatus* appeared in 161 hauls (55% of the total) comprising a depth range 502 m wide, with maximum biomass values in the 0–200 m depth interval decreasing abruptly thereafter. *M. surmuletus* appeared in 114 samples (39%), showing a depth range 499 m wide, with maximum values in the 0–50 m interval decreasing gradually with depth. Ranges and averages of variables in samples with presence of each species were moderately similar. Only average biomass was different, with *M. barbatus* being more abundant (twofold) than *M. surmuletus* (table 2).

Mean values and variance of variables in samples with presence of any of the mullet species were similar to those without it excepting depth, which showed evident differences (fig. 2). Latitude had no significance;

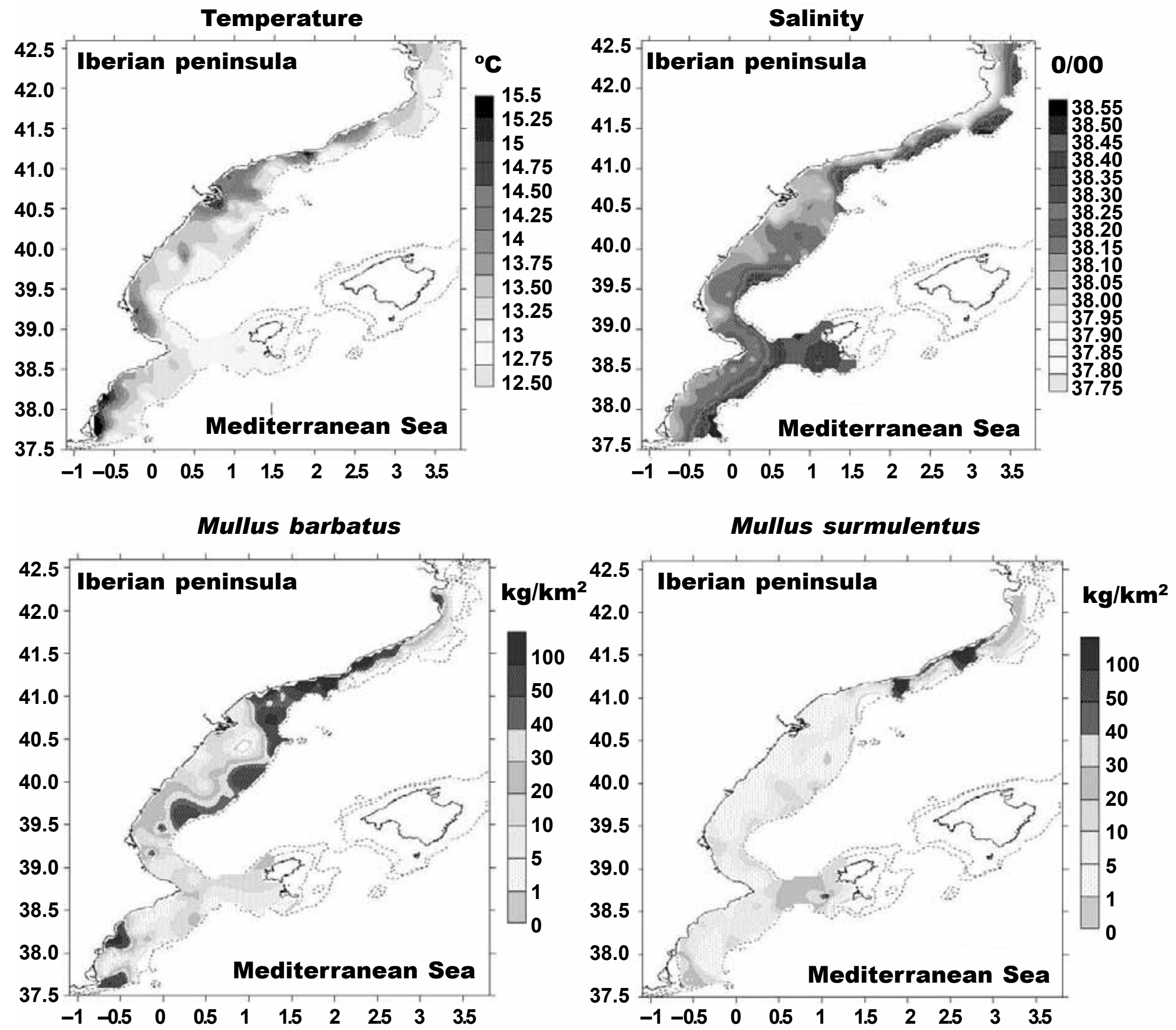

Fig. 1. Representation of the spring distribution of temperature and salinity, and *M. barbatus* and *M. surmuletus* biomasses in the studied area. Cumulated data for 2006–2009.

Fig. 1. Representación de la distribución en primavera de la temperatura y salinidad, así como las biomasas de M. barbatus *y* M. surmuletus*, en el área estudiada. Datos acumulados para el periodo 2006–2009.*

however, sea depth, temperature and salinity resulted in significant differences in all tests ($p < 0.05$), suggesting that biomass distribution of the species shows some 'preferences' regarding the selected variables. The mean values of depth of samples associated with the presence of biomass of both species were lower than means in samples where they were not found, in a similar way to salinity. On the other hand, temperature exhibited upper mean values related with species appearance. In a first interpretation, both species seem to 'prefer' shallow waters (well–known circumstance), characterised by low salinity and warmer temperature. Ranges (minimum and maximum) of variables in samples with species' appearance could be considered as ranges of distribution of the species in the sampled area.

Preliminary GLM analysis resulted in a strongly asymmetrical biomass distribution, with numerous extreme data. Logarithmic transformation of the data (biomass) partially solves this imbalance, reducing part of the extreme values for *M. barbatus* (fig. 3) as well as for *M. surmuletus* (fig. 4). The modelled biomasses exhibit moderate linearity, with some scattered data, and the total deviance explained by the models is scarce. The partial residuals of the variables, in relation to the response, indicates that the model corresponds with the data (fig. 5). The model explained 17% of

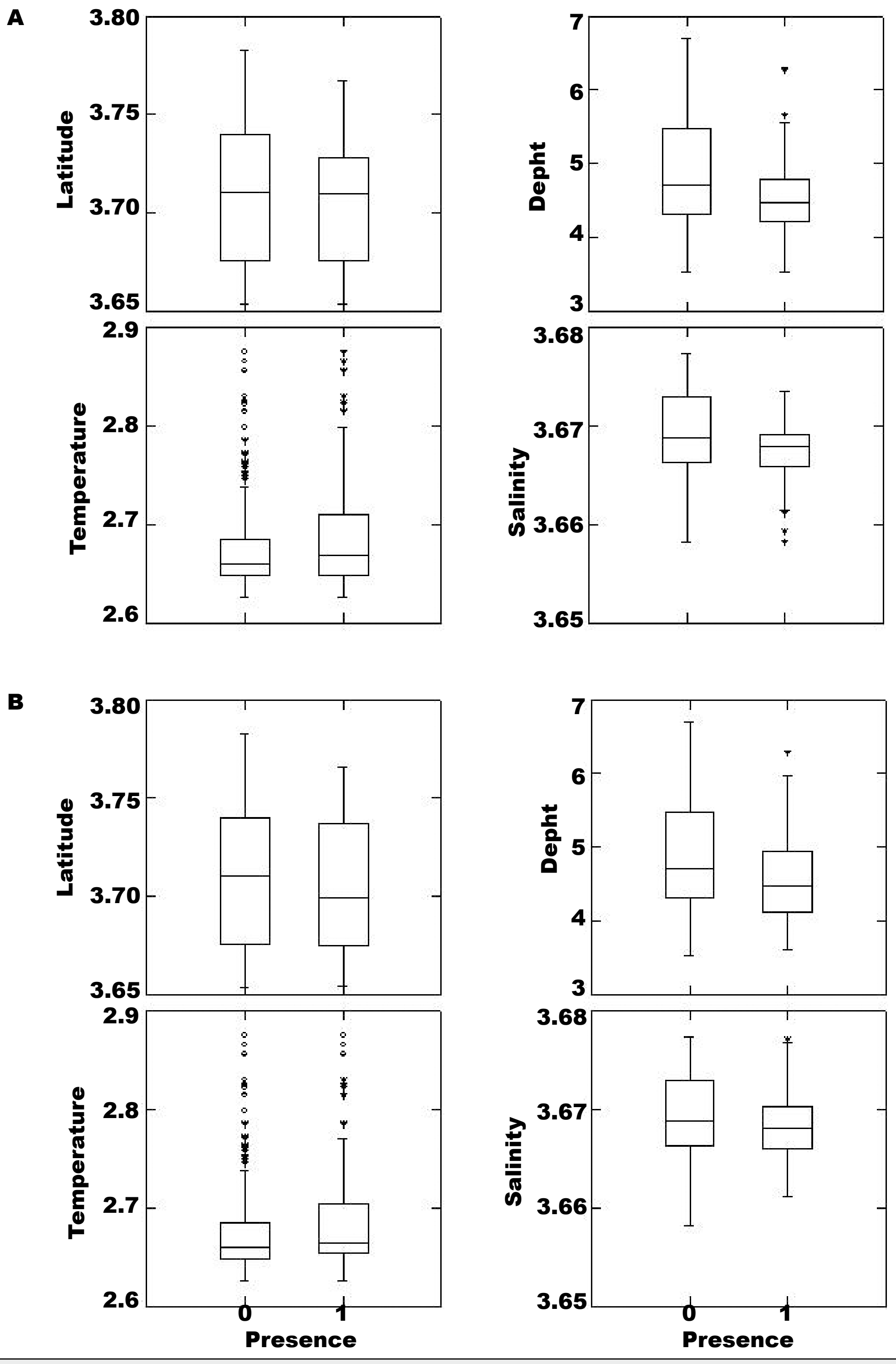

Fig. 2. Box plots for each of the studied abiotic variables (latitude, depth, temperature and salinity) in samples with absence (0) and occurrence (1) of: A. *M. barbatus;* B. *M. surmuletus*. (Means of depth, temperature and salinity in samples with species presence were significantly different from those without presence.)

Fig. 2. Diagramas de caja para cada variable estudiada (latitud, profundidad, temperatura y salinidad) en muestras con ausencia (0) o con presencia (1) de: A. M. barbatus; *B.* M. surmuletus. (*Las medias de profundidad, temperatura y salinidad de las muestras con presencia de la especie resultaron ser significativamente diferentes de las muestras sin presencia.)*

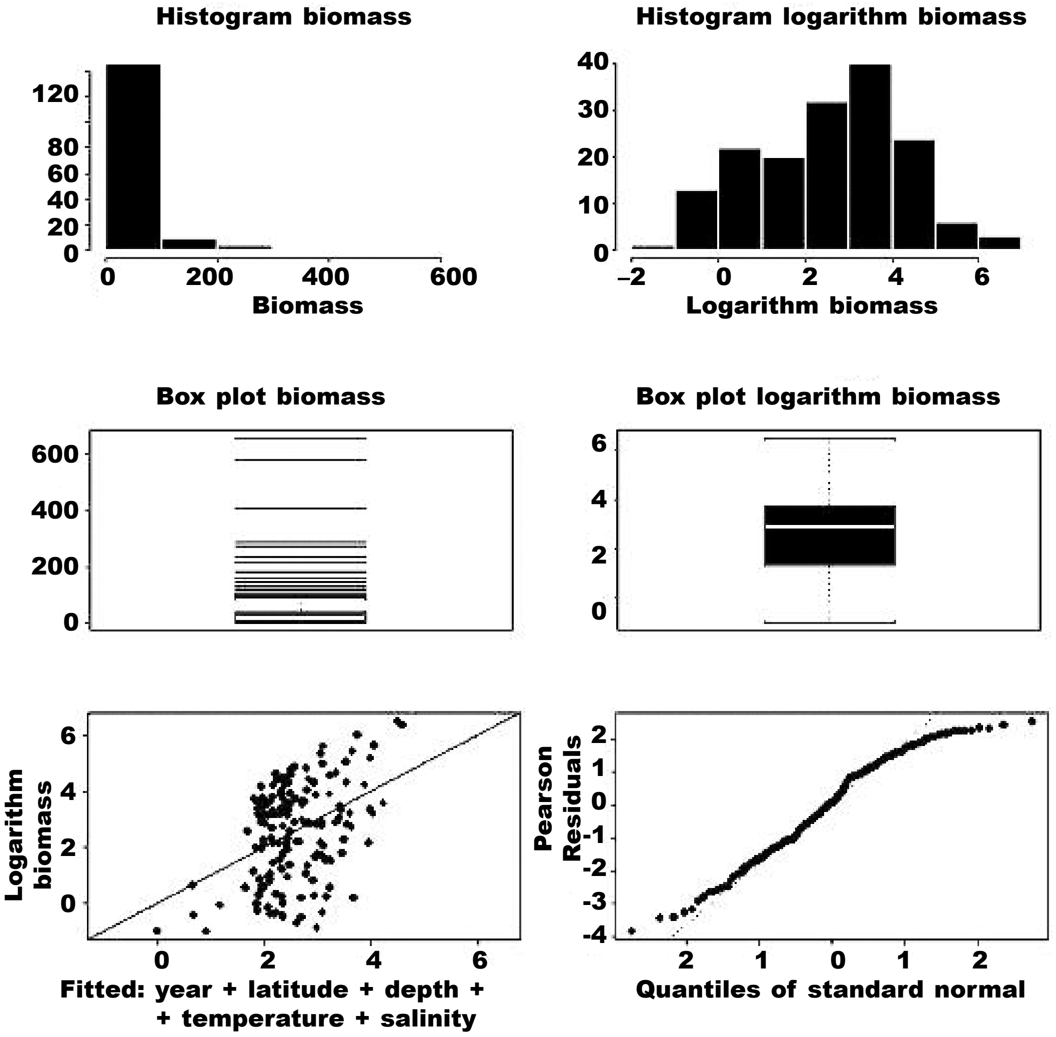

Fig. 3. Histograms and box plots of the *M. barbatus* biomass in the positive observations: raw data, top and middle left; and transformed data, top and middle right. Response of the adjusted variable (bottom left) and normal probability graphic of the Pearson residuals (bottom right) for the applied model are also included.

Fig. 3. Histogramas y diagramas de caja de la biomasa de M. barbatus *en las observaciones positivas: arriba y centro a la izquierda datos brutos; arriba y centro a la derecha datos transformados. Respuesta de la variable ajustada (abajo izquierda) y gráfico de probabilidad normal de los residuales de Pearson (abajo derecha) para el modelo aplicado.*

variance *in M. barbatus*, with salinity (7%) as the most explanatory factor, followed by temperature (3%). In the case of *M. surmuletus*, the model explained 8% of variance, with temperature (5%) as the main explanatory factor (table 3).

Although for both species the biomass decreased with increased depth, salinity and rise of temperature and the ranges of the analysed variables were quite similar, we found remarkable differences between the two in the specific effect of each variable. These results suggest that mullets have environmental preferences in their distribution, with an important and negative effect of salinity in *M. barbatus* biomass and a positive and less intense effect of temperature in the *M. surmuletus* case.

Discussion

Our results suggest that, in the studied area, the biomass contribution of each species is different, with lower values for *M. surmuletus*. This may be because

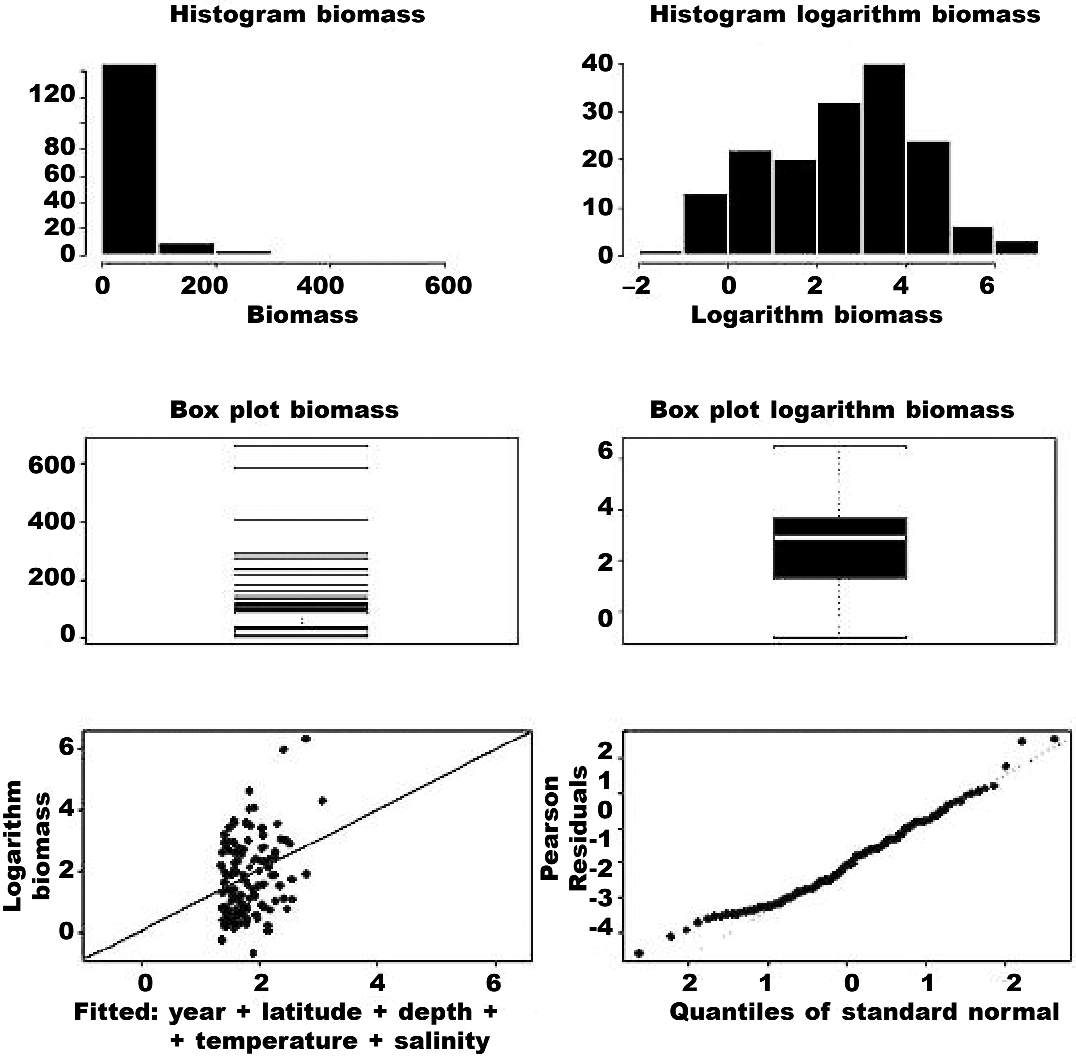

Fig. 4. Histograms and box plots of the *M. surmuletus* biomass in the positive observations: raw data, top and middle left; and transformed data, top and middle right. Response of the adjusted variable (bottom left) and normal probability graphic of the Pearson residuals (bottom right) for the applied model are also included.

Fig. 4. Histogramas y diagramas de caja de la biomasa de M. surmuletus *en las observaciones positivas: arriba y centro a la izquierda datos brutos; arriba y centro a la derecha datos transformados. Respuesta de la variable ajustada (abajo izquierda) y gráfico de probabilidad normal de los residuales de Pearson (abajo derecha) para el modelo aplicado.*

the gear used as sampler (bottom trawl net) can only be applied in smooth bottoms. Thus, *M. surmuletus* showed a clear preference for rough bottoms, while *M. barbatus* had a greater abundance on soft bottoms, being more accessible to the sampler. This difference in substrate preference was especially marked in young individuals (Lombarte et al., 2000), which inhabit very close to the shoreline. In addition, these results coincide with findings of Tserpes et al. (2002) for the Mediterranean shelf. With respect to the effect of time (year) on the biomass distribution, no significance was found, and only a diminishing trend could be identified in *M. barbatus* (fig. 5).

Both species had a relatively well–balanced distribution along the sampling area. Averaged biomass values for *M. barbatus* diminished slowly toward the north, while *M. surmuletus* increased slightly, but not in a significant way in any case (fig. 5).

Depth is assumed to have an important role in species distribution. In this study, this factor correlated

Table 3. Results of the GLM analysis of the considered variables, for *Mullus* biomass as response, showing the explained deviance for each variable and its significance. Df. Degree od freedom; % Dev. Percentage of total deviance explained by the variable; *F*. Values of Fisher's test; Pr(*F*). Probability at a 0.05 significance level.

Tabla 3. Resultados del análisis GLM de las variables consideradas, con la biomasa de Mullus *como respuesta, y mostrando la deviación explicada para cada variable y su significación: Df. Grados de libertad; % Dev. Porcentaje de la desviación total explicada por la variable;* F. *Valores del test de Fisher; Pr(*F*). Probalbilidad a un nivel de significación de 0,05.*

	Df	Deviance	Df	Deviance	% Dev	*F*	Pr(F)
M. barbatus		Null	160	464.7119			
Year	3	18.33183	157	446.3800	3.94	2.43524	0.0669743
Latitude	1	9.25879	156	437.1212	1.99	3.68987	0.0566035
Depth	1	4.97387	155	432.1474	1.07	1.98222	0.1611854
Temperature	1	14.83192	154	417.3155	3.19	5.91091	0.0162028
Salinity	1	33.40117	153	383.9143	7.19	13.31125	0.0003613
Total %					17.39		
M. surmuletus		Null	113	179.436			
Year	3	4.918596	110	174.5174	2.74	1.057042	0.3706481
Latitude	1	1.411066	109	173.1063	0.79	0.909745	0.3423521
Depth	1	0.260992	108	172.8453	0.15	0.168267	0.6824842
Temperature	1	8.153103	107	164.6922	4.54	5.256483	0.0238397
Salinity	1	0.280186	106	164.412	0.16	0.180642	0.6716835
Total %					8.37		

negatively with the biomass of both species, and the correlation was significant for *M. barbatus*. In the case of *M. surmuletus*, previous studies have shown a significant relationship between biomass and depth over the year in the Iraklion Gulf (Machias et al., 1998). However, our results were far from significant in this species. Although both species concentrates in the first 200 m depth of the shelf, with highest biomass values in the first 50 m and decreasing thereafter, *M. surmuletus* increases its average biomass in the 200–500 m depth interval, recovering the values showed in the 50–100 m depth interval (fig. 5). Until now, *M. surmuletus* was thought to have a wider bathymetric range than *M. barbatus* which, in contrast to *M. surmuletus*, never appeared below the 200 m depth in the Spanish Mediterranean (Lombarte et al., 2000), but reached the 328 m depth in the Ionian Sea (Mytilineou et al, 2005). In addition, the observed bathymetric distribution of *M. surmuletus* has increased with time. Thus, Hureau (1986) reported that *M. surmuletus* inhabits depths of less than 100 m and Macpherson & Duarte (1991) found a depth range of 12 to 182 m. More recently, Machias et al. (1998) found the species between 28 and 310 m depths in Crete, Mytilineou et al. (2005) expanded the range from 5 to 409 m depth in the Ionian Sea, and García–Rodríguez et al. (2007) found *M. surmuletus* down to 716 m off Castellón. In the present study, both species appeared in similar depth ranges, with *M. barbatus* achieving 535 m depth and *M. surmuletus* biomass recovered in the 200–500 m interval, mainly due to the occurrence of a small amount of big–sized individuals. Depth by itself only means barometric pressure, with the water masses being characterised by their physical characteristics and chemical composition, and has no significance in the GLM results (table 3). Consequently, we consider that bathymetric segregation is not as clear as believed to date as a function of depth, and could be attributed to other abiotic variables, highly correlated with depth, but possibly masked in their influence by depth.

Temperature is the most important physical characteristic of water masses. In this seasonal study (spring), temperature decreased with depth, and the observed range for temperature (3.92ºC) (table 1) was slightly wider than that observed by Machias et al. (2000) in the Cretan spring for *M. surmuletus* (2.8ºC). In both studies, temperature had a positive correlation with biomass, being significant only in the present study. Temperature was also one of the explanatory variables in the GLM models. In the case of *M. barbatus*, and despite temperature not being the most explanatory variable, it explains ≈ 3% of the observed deviance, while in *M. surmuletus*, temperature is the most important variable (table 3). Maravelias et al. (2007) found that the mean *M. barbatus* abundance in the Aegean Sea was consistently higher in areas with shallower

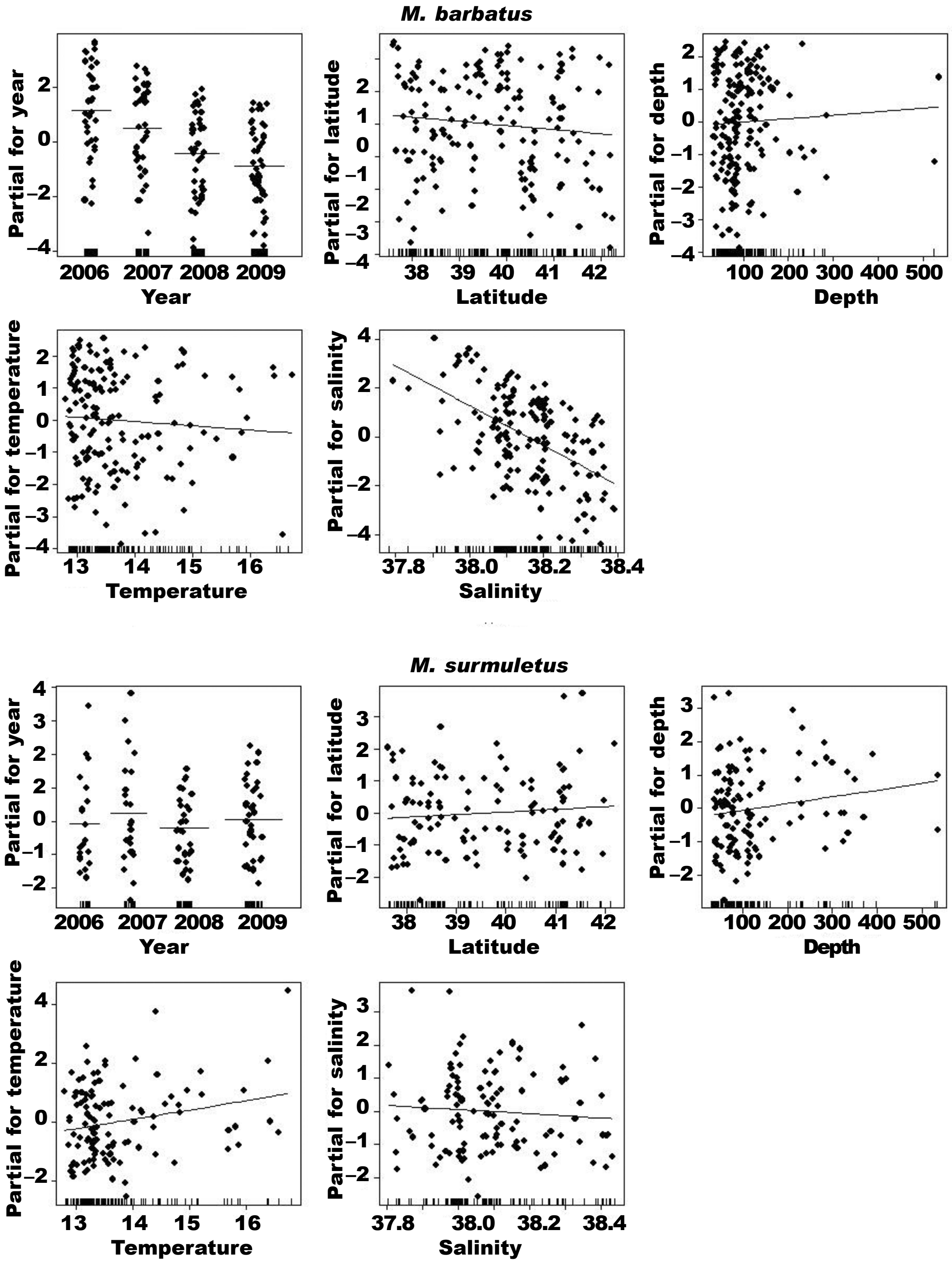

Fig. 5. Graphs showing partial residuals of variables in the model of *M. barbatus* and *M. surmuletus*. Points (●) represent the biomass values plotted against mean (year) or the adjusted regression line in variables. Bar width at the bottom of each figure is proportional to observations.

Fig. 5. Gráficas de los residuales parciales de las variables en el modelo para M. barbatus *y* M. surmuletus. *Los puntos (●) representan los valores de biomasa con respecto a la media (año) o a la recta de regresión ajustada en las variables. La anchura de las barras de la parte inferior de cada figura es proporcional a las observaciones.*

depths (35–60 m) and warmer bottom waters (19ºC) than in the central area, with deeper and colder waters. This species seems to avoid the cold bottom waters (< 16ºC) of the deeper regions (Maravelias et al., 2007). In the present study, *M. barbatus* biomass seems to be related to temperatures comprised in the range 12.81–16.73ºC and, although the relationship was positive, the temperatures we recorded were lower than those reported by Machias et al. (2000) in spring and by Maravelias et al. (2007) in summer. Besides, our results suggest that temperature is an explanatory variable for both species distribution, especially in the case of *M. surmuletus*, for whom it represents the main source of biomass variation (table 3, fig. 5).

Salinity is the main chemical characteristic of marine water and, in combination with temperature, it clearly defines the different water masses of any specific area. Some authors (Tsimenides et al., 1991; Machias et al., 2000) hold that salinity shows very small variation and it is considered not to have an effect on the fish distribution on the Cretan shelf. In this study, salinity increases with depth, showing a range of variation of 0.7527 psu, and is negatively correlated with the biomass of the studied species, a correlation that is significant in the case of *M. barbatus*. GLM results suggest that for *M. barbatus*, salinity is the main explanatory variable for the biomass distribution, followed in importance by temperature. In the case of *M. surmuletus*, the influence of salinity variations in its biomass distribution is negligible (table 3, fig. 5).

In conclusion, we observed that the biomass of both mullet species varied minimally over time, showing a uniform distribution in the studied area, with *M. barbatus* being more abundant. Depth seems to have a moderate influence by itself in the biomass distribution, and the observed variations can be attributed to other water characteristics highly correlated with depth. Thus, in the case of *M. barbatus*, biomass distribution is related with the T–S of the water masses, but this relation is mostly due to the water salinity. In contrast, *M. surmuletus* biomass seems to be significantly affected by the temperature of the water. These preliminary results are consistent with the similar bathymetric distribution shown by both species, with an affinity for waters with low salinity in the case of *M. barbatus*, and for warmer waters in the case of *M. surmuletus*, which can contribute, more clearly than depth, to the segregation of the species. Further analysis over an extended database, to improve accuracy, may support these interesting preliminary results.

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