

Effects of Shoreline Urban Modification on Habitat Structure and Fish Community in Littoral Areas of a Mediterranean Coastal Lagoon (Mar Menor, Spain)

**David Verdiell-Cubedo, Mar Torralva,
Asunción Andreu-Soler & Francisco
J. Oliva-Paterna**

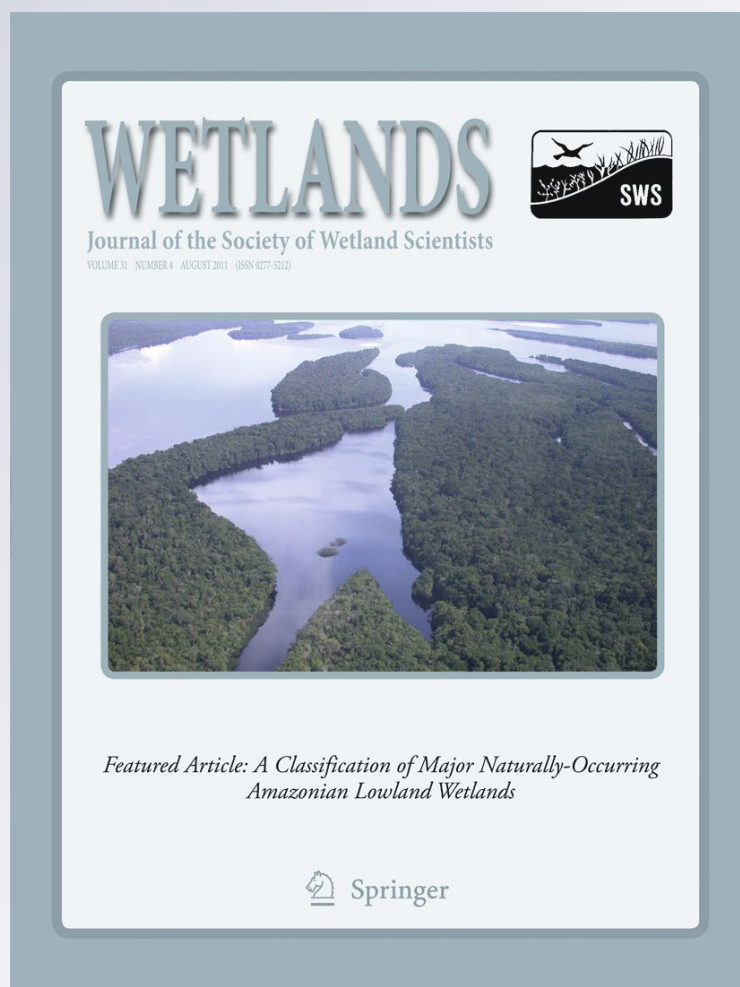
Wetlands

Official Scholarly Journal of the Society
of Wetland Scientists

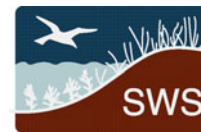
ISSN 0277-5212

Wetlands

DOI 10.1007/s13157-012-0296-6



Your article is protected by copyright and all rights are held exclusively by Society of Wetland Scientists. This e-offprint is for personal use only and shall not be self-archived in electronic repositories. If you wish to self-archive your work, please use the accepted author's version for posting to your own website or your institution's repository. You may further deposit the accepted author's version on a funder's repository at a funder's request, provided it is not made publicly available until 12 months after publication.



Effects of Shoreline Urban Modification on Habitat Structure and Fish Community in Littoral Areas of a Mediterranean Coastal Lagoon (Mar Menor, Spain)

David Verdiell-Cubedo · Mar Torralva ·
Asunción Andreu-Soler · Francisco J. Oliva-Paterna

Received: 11 October 2011 / Accepted: 28 February 2012
© Society of Wetland Scientists 2012

Abstract The shallow habitats of coastal lagoons play an invaluable role for fish communities as nursery areas and provide essential habitats for threatened fish species. Shoreline modification is an anthropogenic coastal stressor that can negatively affect aquatic communities through the modification of nearshore habitats. The aim of the present study was to quantify the effects of two types of shoreline conditions on habitat structure and fish community of littoral habitats. Unmodified shorelines adjacent to saltmarshes and recreational beaches in urbanised areas of the Mar Menor coastal lagoon were compared. The results showed that there were significant differences in habitat structure, fish community structure and fish species abundance by shoreline type. Recreational beaches were characterised by higher water depth and homogeneous substrata, while unmodified shorelines showed high substrata heterogeneity and supported well developed meadows of submerged vegetation. The latter shoreline type provided an important nursery habitat for marine species such as *Sparus aurata* and *Liza saliens*, and represented critical habitats for species of conservation concern such as *Aphanius iberus* and *Syngnathus abaster*. Littoral areas adjacent to modified shorelines were dominated by *Pomatoschistus marmoratus*. We suggest that urbanisation has impacted fish assemblages through degradation of habitat structure (loss of complexity and refuge areas).

Keywords Mediterranean Sea · Coastal lagoons · Shallow-water habitats · Coastal saltmarsh · Shoreline modification · Fish community

Introduction

Transitional waters, such as estuaries and coastal lagoons, play an invaluable role as spawning, nursery and feeding areas for fish communities and provide essential habitats for threatened fish species (Elliott et al. 2007; Rountree and Able 2007; Franco et al. 2008; França et al. 2009). These environments provide ample food resources (e.g. high abundance of invertebrates) and possess favourable habitat conditions (e.g. temperature, hydrodynamics, refuge) that enhance fish growth and survival (Baldó and Drake 2002; Attrill and Power 2004; Pombo et al. 2005; Franco et al. 2006).

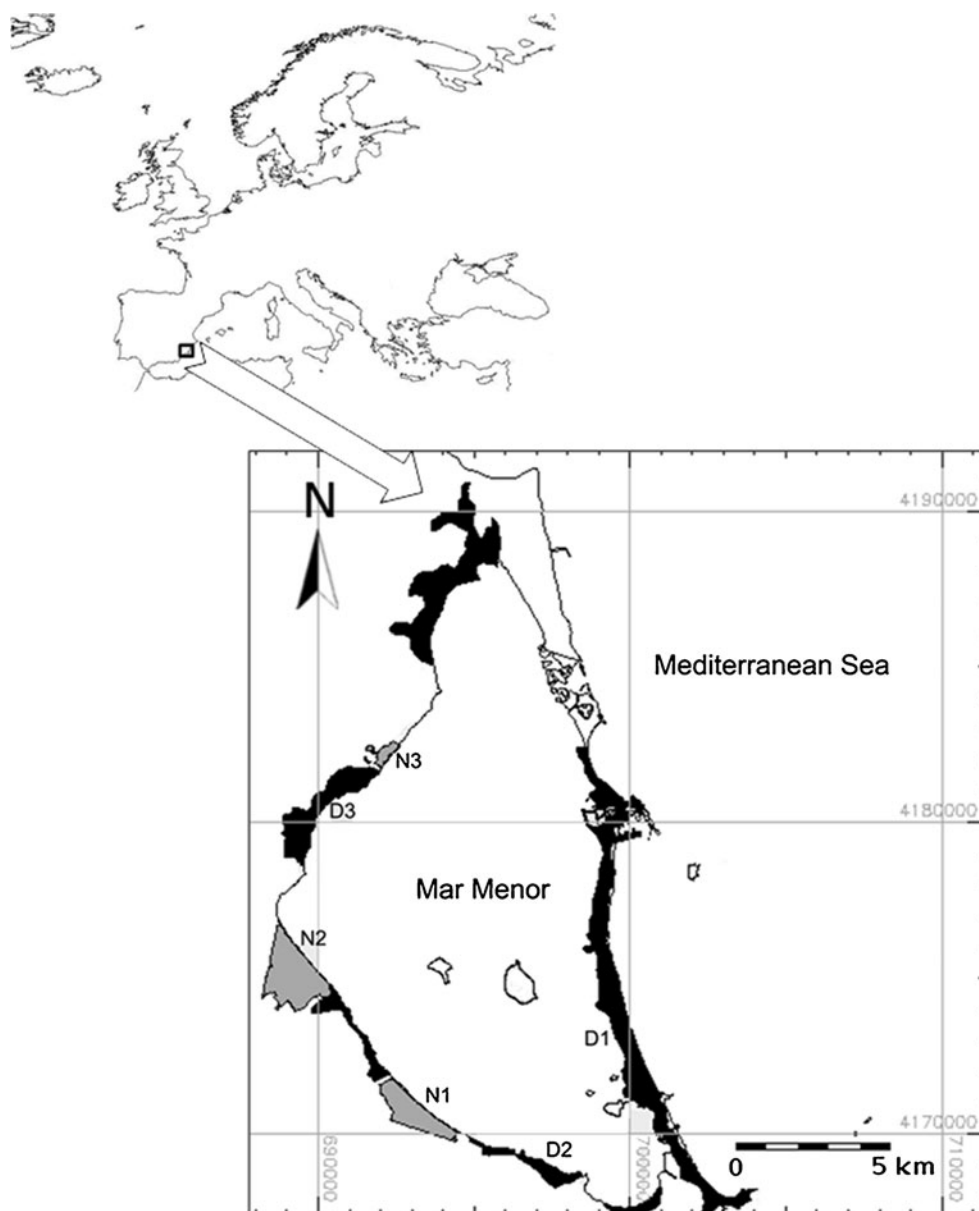
Despite their importance, these systems are among the most vulnerable aquatic environments in the world, and are subject to considerable anthropogenic pressures that usually lead to changes in their biological health (Vasconcelos et al. 2007; Courrat et al. 2009). Shoreline development is a significant anthropogenic coastal stressor that can negatively affect nearshore faunal communities through the alteration or loss of littoral habitats, increased pollutant inputs, loss of allocthanous material and changes in food availability (Peterson et al. 2000; Sanger et al. 2004; Seitz et al. 2006; Bilkovic and Roggero 2008). Since highly productive shallow littoral areas of coastal lagoons and estuaries serve as nursery and feeding grounds for numerous fish species, information on the effects of coastal development is a critical ecosystem management issue.

The Mar Menor, located on the southeastern Iberian Peninsula, is one of the largest coastal lagoons in the Mediterranean Sea (Fig. 1). Its coastline is densely populated

D. Verdiell-Cubedo (✉) · M. Torralva · F. J. Oliva-Paterna
Departamento de Zoología y Antropología Física,
Facultad de Biología, Universidad de Murcia,
30100 Murcia, Spain
e-mail: verdiell@um.es

A. Andreu-Soler
Laboratorio de Vertebrados, Facultad de Ciencias,
Universidad Autónoma de Baja California,
22800 Ensenada, Mexico

Fig. 1 Location of the Mar Menor coastal lagoon and distribution of sampling sites (N1-N3: unmodified shorelines; D1-D3: modified shorelines). Grey areas represent natural saltmarshes and black areas are urbanised areas with residential use



supporting a large tourist population during summer months of about 450000 people. During the last three decades, major changes to the lagoon environment have occurred as a result of increased nutrient inputs and development of tourism facilities, including urban development (Pérez-Ruzafa et al. 2005). Several studies have demonstrated that human activities surrounding the lagoon have negatively impacted biota and altered the functioning of the Mar Menor (Lloret et al. 2005; Martínez et al. 2005; Carreño et al. 2008). Pérez-Ruzafa et al. (2006) showed that coastal works during the 1980's (dredging and pumping sand to create artificial beaches and the installation of artificial rocky structures) in the Mar Menor had a negative impact on the distribution and abundance of benthic fish fauna.

Nevertheless, the lagoon and its adjacent wetlands (salt-pans and natural saltmarshes) have significant ecological

and natural value and have been given international and national protection status. The lagoon maintains a diverse fish community due to its environmental heterogeneity: unvegetated sandy and muddy bottoms, rocky bottoms and seagrass beds composed of the phanerogams *Cymodocea nodosa* (Ucria) Ascherson and *Ruppia cirrhosa* (Petagna) Grande (Pérez-Ruzafa et al. 2005). Moreover, the shallow littoral areas of the lagoon are highly productive and have been shown to serve as nursery and feeding grounds for many fish species (Oliva-Paterna et al. 2006; Verdiell-Cubedo 2009).

Therefore, the objective of the present study was to examine the influence of shoreline modification on habitat structure and the assemblage of small fish by comparing two types of shoreline conditions in the shallow littoral areas of the Mar Menor: shorelines adjacent to saltmarshes and

recreational beaches in urbanised areas with residential land use. We hypothesised that fish assemblages and habitat structure were not uniform across the lagoon's shoreline, and that fish assemblages and habitat structure were expected to differ between modified and unmodified shorelines.

Material 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 km² and an average depth of 3.6 m. It is separated from the Mediterranean Sea by a 22 km-long sand bar called La Manga, which has three narrow channels that connect it to the open sea. The lagoon shows a salinity range of 39–45 ppt and the temperature varies from 10 °C in winter to 32 °C in summer (Pérez-Ruzafa et al. 2005). Its bottom is principally covered by dense meadows of the invasive macroalga *Caulerpa prolifera* (Forsk.) Lamouroux, although the shallowest areas are covered by scarce patches of the phanerogames *C. nodosa* and *R. cirrhosa* (Lloret et al. 2005; Pérez-Ruzafa et al. 2005).

The importance of the lagoon and its saltmarshes in terms of biodiversity has been recognised in numerous international protection schemes: it has been a Ramsar International site since 1994; it is considered a Special Protected Area of Mediterranean Interest (SPAMI), established by the Barcelona Convention in 2001; and a Site of Community Importance (SCI) to be integrated in the Nature 2000 Network (EU Habitats Directive). This zone is also a Specially Protected Area (SPA) in relation to nest building, migration and over-wintering of aquatic birds, and is protected by European legislation (Birds Directive 79/409/CEE).

The lagoon also supports important commercial fisheries, primarily Anguillidae (*Anguilla anguilla*), Sparidae (*Sparus aurata* and *Diplodus* spp.), Mugilidae (*Mugil cephalus* and *Liza* spp.) and Atherinidae (*Atherina boyeri*) (Pérez-Ruzafa et al. 2005; Andreu-Soler et al. 2006). The mullets *Liza aurata* and *Liza saliens* and the gilthead bream *Sparus aurata* are among the most abundant migrant fish species that colonise these areas in their juvenile stages. As resident species that spend their life cycles in the lagoon, the endangered cyprinodontid *Aphanius iberus*, the pipefish *Syngnathus abaster*, the marbled goby *Pomatoschistus marmoratus* and the sand smelt *A. boyeri* are the most abundant short-lived fish species inhabiting such shallow littoral areas (Verdiell-Cubedo 2009).

Recreational beaches located in urbanised areas are subjected to seasonal maintenance operations, which comprise

sand replenishment during the months prior to summer and sand cleaning during summer months (June–September). In addition, these areas have been impacted by the construction of sport harbours and the installation of rocky breakwaters perpendicular to the coast (Pérez-Ruzafa et al. 2005, 2006). In contrast, shorelines adjacent to saltmarshes display natural conditions with high cover of supralittoral vegetation (shrubs and reedbeds of *Phragmites australis*) and sand bare grounds (Carreño et al. 2008). Moreover, the later shoreline types are characterised by the presence of seasonal water-course mouths that regularly deposit large quantities of sediments, nutrients and terrestrial organic matter (Lloret et al. 2005; Velasco et al. 2006).

Shallow littoral areas (water depth ≤ 1 m) of the lagoon are characterised by soft substrates (principally muddy and sandy bottoms) and isolated patches of submerged vegetation (mainly meadows of *C. nodosa* and *R. cirrhosa*).

Sampling Methods

Sampling was carried out during four sampling periods: July 2002 and 2003 (summer season) and February 2003 and 2004 (winter season). A total of six sampling sites were selected in the shallow littoral areas of the lagoon (Fig. 1): three in natural saltmarshes, Lo Poyo (N1), El Carmolí (N2) and La Hita (N3) and three in urbanised areas with recreational beaches: La Manga (D1), Los Nietos (D2) and Los Alcázares (D3). 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. Six replicates were collected during every sampling period at each of the six sampling sites by hauling 20 m reaches of shoreline at each replicate. The area covered by each haul was approximately 160 m² (standardised hauled area per sampling site=960 m²), with a total number of 122 samples taken: 63 samples in urbanised areas and 59 in natural saltmarshes (in some cases it was not possible to perform six replicates in each sampling site due to adverse weather conditions or massive proliferation of filamentous algae).

Fish were anaesthetised with benzocaine, fixed in neutralised formaldehyde (10 %) and identified at species level in the laboratory. The abundance of each species was recorded and expressed as number of individuals per 160 m².

Each sampling site was characterised by five environmental variables (quantified in each replicate of every sampling site) related to habitat structure: water depth (cm), submerged vegetation cover, submerged vegetation density, substrata grain size and substrata heterogeneity. Water depth was recorded three times at a central point in each replicate. Submerged vegetation cover and density were estimated by visual inspection, the former was recorded as the percentage area covered by submerged vegetation at each replicate and the latter as an ordinate categorical variable from 0 (low

meadow density) to 5 (high meadow density). Substrata was classified according to Bain (1999) [mud (1), sand (2), gravel (3), pebble (4) or boulder (5)] and substrata grain size (average in each sampling site) and substrata grain heterogeneity (standard deviation in each sampling site) were assessed by making at least 10 visual designations at each replicate.

Statistical Analysis

In order to reinforce the comparison of *a-priori* defined shoreline type, sampling sites were ordered using non-metrical multidimensional scaling (MDS), which was applied to a resemblance matrix based on the Euclidean distance generated on the mean seasonal normalised values of the environmental variables matrix. Sampling sites were classified into different shoreline types by hierarchical cluster analysis (Euclidean distance; group average link) (Clarke and Warwick 2001).

A two-way analysis of variance (two-way ANOVA) was used to test for differences between shoreline types and seasons on each selected fish species abundance (*A. iberus*, *A. boyeri*, *P. marmoratus*, *S. abaster*, *L. aurata*, *L. saliens* and *S. aurata*), total abundance of resident species (*A. iberus*, *S. abaster*, *P. marmoratus* and *A. boyeri*) and total abundance of migrant species (*L. aurata*, *L. saliens* and *S. aurata*). Both independent variables were considered as fixed factors.

Assumptions of normality and homogeneity of variance were checked with Kolmogorov-Smirnov's and Levene's tests, respectively. To meet these assumptions, fish abundance data were fourth-root transformed. In many cases, transformation did not produce homogeneous variances; nevertheless two-way ANOVA was used, as the F statistic is considered to be robust in relation to the assumption of heterogeneity. In order to compensate for the increased likelihood of a Type I error, the level of significance was set at $P \leq 0.01$ (Underwood 1997). When significant shoreline type x season interactions were detected in the two-way ANOVA, one-way ANOVA test was used to test for differences between shoreline type during each season and among seasons for each shoreline type ($P < 0.05$).

Differences in the structure of the fish community between shoreline types were assessed by a factorial design with shoreline type and season as fixed factors through the distance-based pseudo-F statistics, PERMANOVA (9999 permutations), using similarity matrices based on the Bray-Curtis similarity coefficient generated on abundance data (fourth-root transformed). Exploration of species contributions to describing dissimilarities between shoreline types was carried out with the SIMPER procedure. Principal coordinate analysis (PCO) on similarity matrices was then conducted to visualize PERMANOVA and SIMPER significant results.

Finally, a PCA was applied to explore patterns of association among the environmental variables of the sampling sites. To establish habitat-species associations the factors extracted by PCA were correlated (Pearson correlation test) with fish abundance values for each studied species (Quinn and Keough 2002). The correlation coefficients between fish species abundance and both PC1 and PC2 (+: significant positive, -: significant negative or 0: no correlation) make it possible to represent the fish abundance 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 abundance variable to be characterised in relation to the variables included in the analysis. Only components with eigenvalues larger than 1 were interpreted. Prior to PCA, submerged vegetation cover variable was arcsin (\sqrt{x}) transformed.

Statistical analyses were performed using the SPSS® statistical package (Version 15.0) and the PRIMER software (Version 6.1.7) (Clarke and Warwick 2001).

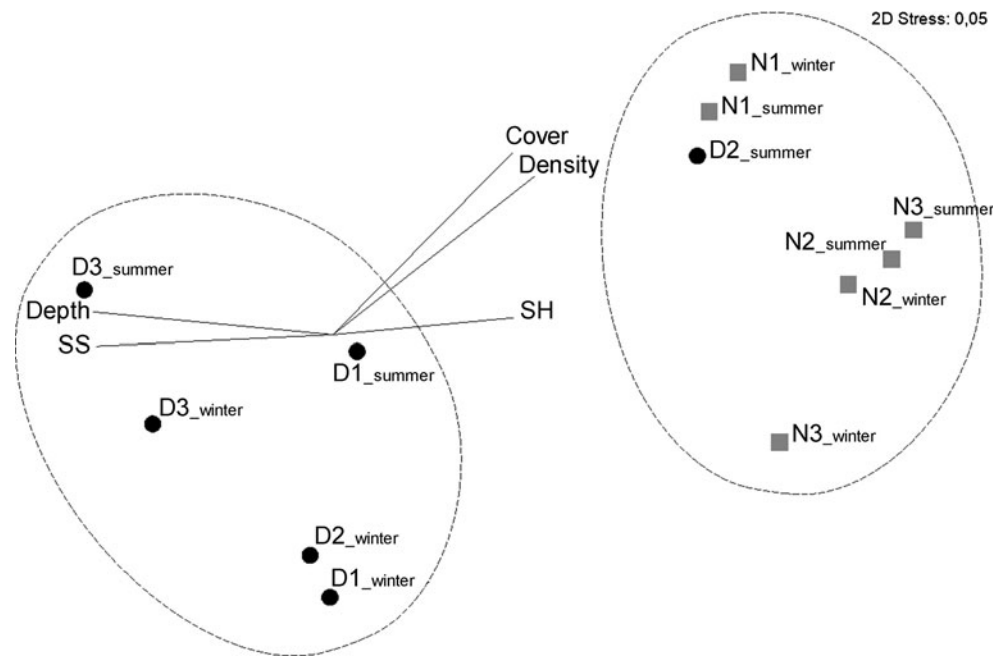
Results

Habitat Classification

Figure 2 presents the results of the MDS and cluster analyses and the seasonal classification of sampling sites into different shoreline types. The first axis (MDS1) was highly positively correlated with submerged vegetation volume ($\rho = 0.92$) and cover ($\rho = 0.87$), reflecting that MDS1 clearly separated between sampling sites with scarce development of submerged vegetation on the left part of the diagram and well-vegetated bottoms on the right. Additionally, MDS1 was positively correlated with substrata heterogeneity ($\rho = 0.66$) and negatively correlated with substrata size ($\rho = -0.85$) and water depth ($\rho = -0.82$). MDS2 was not significantly correlated with any environmental variables.

According to these results, the La Manga (D1_summer, D1_winter), Los Nietos (D2_winter) and Los Alcázares (D3_summer, D3_winter) sampling sites, located on the left part of the diagram, showed low values of submerged vegetation cover and volume, high substrata size (sandy bottoms) and water depth (Fig. 2 and Table 1). Conversely, the Lo Poyo (N1_summer, N1_winter), El Carmolí (N2_summer, N2_winter) and La Hita (N3_summer, N3_winter) sampling sites were represented by well-vegetated bottoms, high substrata heterogeneity, low substrata size and water depth (Fig. 2 and Table 1). The classification of D2_summer in the natural shoreline group was mainly due to the proliferation of filamentous algae and the phanerogam *R. cirrhosa* observed at this sampling site during summer (Table 1). Despite this heterogeneity, this sampling site was included in the modified shoreline group for later analysis of selected fish species abundance and fish community structure.

Fig. 2 Ordination and classification of sampling sites into different shoreline types according to the results of MDS and cluster analyses performed on the seasonal environmental variables matrix (N1-N3: unmodified shorelines; D1-D3: modified shorelines). Vectors represent the Pearson's correlation values between each environmental variable and the ordination scores (Cover: submerged vegetation cover; Density: submerged vegetation density; Depth: water depth; SS: substrata grain size; SH: substrata grain heterogeneity). Dashed lines represent clusters based on Euclidean distances of less than three



Fish Assemblages

A total of 24 fish species were collected during the study period. The five most abundant fish species were *L. saliens* (7551 individuals, 22.2 % of the total catch), *P. marmoratus* (7537 individuals, 22.1 % of the total catch), *L. aurata* (6541 individuals, 19.3 % of the total catch), *S. aurata* (4658 individuals, 13.7 % of the total catch) and *A. boyeri* (4581 individuals, 13.5 % of the total catch). *S. abaster* represented 2.1 % of the total catch (724 individuals) and *A. iberus* 1.5 % (513 individuals) (Table 2). These seven fish species comprised 94.4 % of the total catch.

There were significant differences in fish species abundance between shoreline types for *A. iberus*, *L. saliens* and *P. marmoratus* (Table 3). The former two species were more abundant at saltmarsh shorelines while *P. marmoratus* was more abundant in modified shorelines (Tables 2 and 3). The abundance of migrant fish species was significantly higher in unmodified shorelines (Tables 2 and 3). There were no such differences for abundance of *A. boyeri*, *L. aurata* and the total abundance of resident fish species (Tables 2 and 3).

The habitat x season interaction was significant for *S. aurata* and *S. abaster* (Table 3). There were only significant differences during winter between shoreline types; both species displayed significantly higher values in saltmarsh shorelines during this season (one-way ANOVA, $F=10.55$, $P<0.01$; one-way ANOVA, $F=7.69$, $P<0.01$, respectively) (Table 2). Considering seasonal fluctuations within shoreline types, *S. aurata* resulted in significantly higher abundance values during winter than summer in modified and unmodified shorelines (one-way ANOVA, $F=62.74$, $P<0.001$; one-way ANOVA, $F=82.48$, $P<0.001$, respectively)

(Table 2). *S. abaster* only showed significant seasonal differences in modified shorelines, with the highest abundances during summer (one-way ANOVA, $F=14.49$, $P<0.001$) (Table 2).

In regards to seasonal variation in abundance there was a significant difference for the resident species *A. boyeri*, which showed higher values during summer (Tables 2 and 3). The migrant species *L. aurata* showed significantly higher abundance during winter, as well as the total abundance of migrant fish species (Tables 2 and 3). *A. iberus* and *P. marmoratus* showed marginally seasonal differences ($P=0.038$ and $P=0.05$, respectively) in their abundance, the former being more abundant during summer and the latter in winter (Tables 2 and 3). *L. saliens* abundance and the total abundance of resident fish species did not show significant seasonal differences (Tables 2 and 3).

Fish community structure showed significant differences between shoreline types (PERMANOVA: pseudo- $F=2.67$, $P<0.05$), with no significant interaction between shoreline type and season (PERMANOVA: pseudo- $F=0.54$, $P>0.05$). The species contributing most to dissimilarities between shoreline types were *P. marmoratus* and *L. aurata*, which characterised the fish samples from modified shorelines (Table 4 and Fig. 3), and *S. aurata*, *L. saliens*, *A. iberus* and *S. abaster*, which typified assemblages from saltmarsh shorelines (Table 4 and Fig. 3).

Habitat-Species Associations

The first two axes of the principal component analysis (PCA) performed on the environmental variables matrix explained 72 % of variance (Fig. 4). There was a high level

Table 1 Mean seasonal values \pm 1 SE of the environmental variables at each sampling site

Variables	Modified shoreline						Unmodified shoreline					
	La Manga (D1)		Los Nietos (D2)		Los Alcázares (D3)		Lo Poyo (N1)		El Carmolí (N2)		La Hita (N3)	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
Submerged vegetation cover (%)	17.1 \pm 4.2	5.3 \pm 0.6	32.5 \pm 7.3	10.4 \pm 3.0	14.0 \pm 7.9	5.0 \pm 0.1	34.6 \pm 6.2	43.9 \pm 9.6	30.0 \pm 8.0	29.1 \pm 9.6	40.6 \pm 5.7	16.3 \pm 3.5
Submerged vegetation density (0-5)	1.2 \pm 0.2	0.8 \pm 0.2	2.1 \pm 0.4	0.8 \pm 0.2	1.0 \pm 0.4	0.6 \pm 0.2	2.2 \pm 0.3	2.2 \pm 0.3	2.5 \pm 0.4	1.8 \pm 0.4	1.9 \pm 0.3	1.4 \pm 0.3
Water depth (cm)	45.7 \pm 1.9	36.4 \pm 3.6	40.2 \pm 4.1	47.1 \pm 5.3	67.7 \pm 5.2	53.3 \pm 4.0	32.8 \pm 3.2	34.3 \pm 2.7	29.6 \pm 2.6	29.0 \pm 3.6	35.4 \pm 4.4	33.4 \pm 4.2
Substrata grain size (1-5)	2.28 \pm 0.06	2.15 \pm 0.02	1.69 \pm 0.11	1.95 \pm 0.02	2.35 \pm 0.14	2.34 \pm 0.18	1.85 \pm 0.06	1.86 \pm 0.03	1.84 \pm 0.06	1.86 \pm 0.12	1.62 \pm 0.11	1.59 \pm 0.08
Substrata grain heterogeneity	0.62 \pm 0.05	0.40 \pm 0.03	0.51 \pm 0.07	0.35 \pm 0.03	0.51 \pm 0.06	0.51 \pm 0.12	0.49 \pm 0.05	0.52 \pm 0.03	0.75 \pm 0.07	0.81 \pm 0.08	0.75 \pm 0.04	0.71 \pm 0.07

Table 2 Mean seasonal abundance (n individuals/160 m²) of the selected fish species at each sampling site. Resident species: *Aphanius iberus*, *Atherina boyeri*, *Pomatoschistus marmoratus* and *Syngnathus abaster*. Migrant species: *Liza aurata*, *Liza saliens* and *Sparus aurata*

Species	Modified shoreline						Unmodified shoreline					
	La Manga (D1)		Los Nietos (D2)		Los Alcázares (D3)		Lo Poyo (N1)		El Carmolí (N2)		La Hita (N3)	
	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter	summer	winter
<i>Aphanius iberus</i>	0	0	18.3 \pm 8.4	0	0.1 \pm 0.1	0.1 \pm 0.1	8.6 \pm 5.6	1.6 \pm 0.9	0.7 \pm 0.3	2.6 \pm 1.7	13.3 \pm 6.2	2.6 \pm 1.9
<i>Atherina boyeri</i>	4.4 \pm 1.3	4.7 \pm 4.1	65.3 \pm 18.9	8.3 \pm 5.6	10.2 \pm 3.3	24.0 \pm 16.9	17.5 \pm 11.8	4.9 \pm 3.6	61.6 \pm 14.0	10.7 \pm 5.3	148.5 \pm 63.1	6.3 \pm 4.3
<i>Pomatoschistus marmoratus</i>	112.6 \pm 26.8	135.0 \pm 28.1	49.3 \pm 22.6	67.8 \pm 17.2	63.6 \pm 49.9	26.7 \pm 8.6	7.5 \pm 1.8	62.1 \pm 25.9	44.3 \pm 22.8	17.5 \pm 4.8	39.4 \pm 15.1	112.5 \pm 45.6
<i>Syngnathus abaster</i>	5.3 \pm 2.3	0.3 \pm 0.2	17.7 \pm 6.3	6.3 \pm 4.6	1.7 \pm 1.3	0	6.2 \pm 2.6	3.4 \pm 1.1	0.4 \pm 0.2	2.9 \pm 1.9	23.9 \pm 12.5	2.4 \pm 0.8
<i>Liza aurata</i>	2.8 \pm 1.2	8.2 \pm 5.7	11.6 \pm 8.0	158.5 \pm 85.5	77.2 \pm 37.1	167.7 \pm 64.3	6.6 \pm 2.6	1.1 \pm 0.5	23.9 \pm 10.3	26.8 \pm 13.7	18.4 \pm 12.8	205.3 \pm 76.6
<i>Liza saliens</i>	1.9 \pm 1.2	28.1 \pm 27.9	25.2 \pm 16.8	2.3 \pm 1.5	21.9 \pm 16.9	14.0 \pm 7.9	52.5 \pm 23.1	19.4 \pm 9.4	41.6 \pm 26.0	31.1 \pm 20.1	60.0 \pm 23.2	531.5 \pm 270.4
<i>Sparus aurata</i>	0	5.1 \pm 2.7	0	36.0 \pm 13.8	0	10.9 \pm 6.7	0	4.2 \pm 1.9	0	217.5 \pm 72.7	0	208.6 \pm 68.9
Resident species	122.3 \pm 28.3	140.0 \pm 26.5	150.6 \pm 30.9	82.4 \pm 64.2	75.6 \pm 52.7	50.9 \pm 16.6	39.8 \pm 14.8	72.0 \pm 26.1	107.0 \pm 17.8	33.7 \pm 8.8	225.0 \pm 63.9	123.8 \pm 48.1
Migrant species	4.8 \pm 1.5	41.4 \pm 30.1	36.8 \pm 17.5	180.9 \pm 96.8	99.1 \pm 36.8	180.9 \pm 64.5	59.1 \pm 21.9	24.8 \pm 8.9	65.5 \pm 24.4	275.4 \pm 87.0	78.4 \pm 21.0	945.4 \pm 382.5

Table 3 Results of two-way ANOVA performed on the abundance [ln (n individuals/160 m²+1)] of selected fish species, with season and shoreline type as fixed factors. n.s. $P>0.01$, * $P<0.01$, ** $P<0.001$

Species	df	F	Species	df	F
<i>Aphanius iberus</i>			<i>Liza saliens</i>		
Shoreline type	1	12.71**	Shoreline type	1	21.89**
Season	1	4.42 _{n.s.}	Season	1	0.05 _{n.s.}
Shoreline type x season	1	0.53 _{n.s.}	Shoreline type x season	1	0.65 _{n.s.}
Error	118		Error	118	
<i>Atherina boyeri</i>			<i>Sparus aurata</i>		
Shoreline type	1	1.85 _{n.s.}	Shoreline type	1	11.14*
Season	1	42.02**	Season	1	171.02**
Shoreline type x season	1	0.71 _{n.s.}	Shoreline type x season	1	11.14*
Error	118		Error	118	
<i>Pomatoschistus marmoratus</i>			Resident species		
Shoreline type	1	9.47*	Shoreline type	1	2.93 _{n.s.}
Season	1	3.91 _{n.s.}	Season	1	1.69 _{n.s.}
Shoreline type x season	1	0.14 _{n.s.}	Shoreline type x season	1	0.48 _{n.s.}
Error	118		Error	118	
<i>Syngnathus abaster</i>			Migrant species		
Shoreline type	1	1.94 _{n.s.}	Shoreline type	1	15.35**
Season	1	9.76*	Season	1	19.46**
Shoreline type x season	1	8.92*	Shoreline type x season	1	0.08 _{n.s.}
Error	118		Error	118	
<i>Liza aurata</i>					
Shoreline type	1	0.01 _{n.s.}			
Season	1	9.71*			
Shoreline type x season	1	1.23 _{n.s.}			
Error	118				

of association between the first component (PC1) and submerged vegetation (cover and density) and substrata grain heterogeneity. Secondly, water depth and substrata grain size were strongly associated with component 2 (PC2) (Fig. 4). Therefore, two habitat gradients were defined in the study area following the PCA of habitat variables. PC1 (eigenvalue=2.19, 43.8 % of variance) could be interpreted

as a gradient from unvegetated bottoms with a homogeneous substrata on the left part of the diagram, to well vegetated bottoms with a heterogeneous substrata (presence of large substrata types, mainly pebbles and boulders). PC2 (eigenvalue=1.41, 28.2 % of variance) distinguished between deep sandy bottoms on the upper part of the diagram, to shallow muddy bottoms (Fig. 4).

Table 4 Results of SIMPER analysis with species contributions to dissimilarities between shoreline types. Avg diss: average dissimilarity; Diss/SD: ratio of AVG diss to standar deviation; Contrib (%): the percentage each species contributes to dissimilarities; Cum (%):

cumulative percent of total dissimilarity; Avg abund: average abundance by shoreline type (is based on values in the Bray-curtis similarity matrix and does not represent true abundance estimates); Unm Shor: unmodified shorelines; Mod Shor: modified shorelines

Species	Unm Shor Avg Abund	Mod Shor Avg Abund	Avg diss	Diss/SD	Contrib (%)	Cum (%)
<i>Sparus aurata</i>	1.47	0.91	5.2	1.26	11.7	11.7
<i>Liza aurata</i>	1.82	1.95	4.74	1.44	10.67	22.37
<i>Liza saliens</i>	2.29	1.58	4.65	1.33	10.47	32.84
<i>Atherina boyeri</i>	2.21	1.62	3.65	1.25	8.23	41.08
<i>Aphanius iberus</i>	1.19	0.46	3.62	1.68	8.15	49.23
<i>Syngnathus abaster</i>	1.34	0.94	3.09	1.52	6.95	56.18
<i>Salapia pavo</i>	0.91	0.69	3.02	1.16	6.81	62.98
<i>Pomatoschistus marmoratus</i>	2.37	2.86	3.01	1.38	6.79	69.77
<i>Liza ramada</i>	0.86	0.35	2.97	1.06	6.69	76.46

Fig. 3 Principal coordinates ordination plot of the sampling sites, according to their species community abundance. Vectors represent the main species affecting the observed differences, according to SIMPER analysis. Black squares: modified shoreline; grey circles: unmodified shoreline

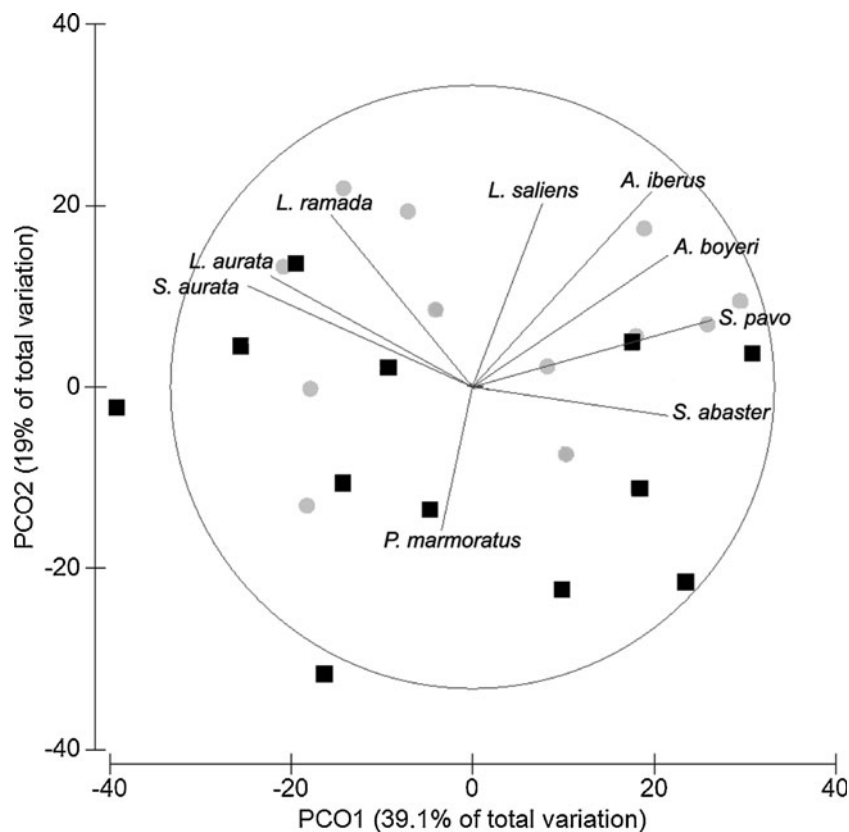
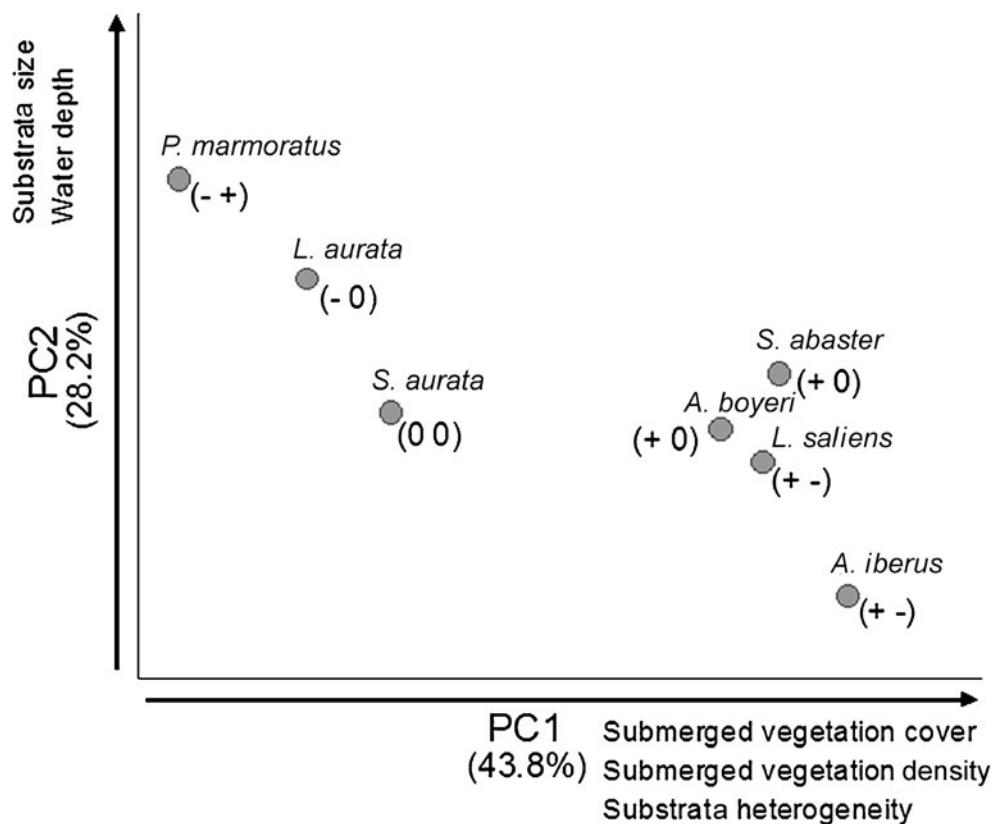


Fig. 4 Results of the principal components analysis (PCA) performed on environmental variables matrix showing the location of different fish species according to Pearson correlation coefficients and the ecological meaning of each component. The symbols 0, +, and - in the first position within brackets indicate no correlation, significant ($P < 0.05$) positive, and significant negative correlation, respectively, with respect to PC1; while the same symbols in the second position represent the correlation with respect to PC2



A. iberus and *L. saliens* abundances were positively correlated with PC1 (Pearson correlation test, $r=0.44$, $P<0.001$; Pearson correlation test, $r=0.34$, $P<0.001$, respectively) and negatively correlated with PC2 (Pearson correlation test, $r=-0.45$, $P<0.001$; Pearson correlation test, $r=-0.21$, $P<0.05$, respectively). They displayed higher abundance values in shallow, muddy bottoms with high seagrass meadow cover (Fig. 4). The abundance of *S. abaster* and *A. boyeri* was significantly correlated with PC1, with a positive relationship (Pearson correlation test, $r=0.36$, $P<0.001$, Pearson correlation test, $r=0.29$, $P<0.01$, respectively) indicating a strong preference for vegetated bottoms (Fig. 4). Conversely, *P. marmoratus* and *L. aurata* abundances were negatively correlated with PC1 (Pearson correlation test, $r=-0.35$, $P<0.001$; Pearson correlation test, $r=-0.20$, $P<0.05$, respectively) (Fig. 4). Moreover, *P. marmoratus* abundance was positively correlated with PC2 (Pearson correlation test, $r=0.30$, $P<0.01$), exhibiting a clear preference for unvegetated sandy bottoms (Fig. 4). The abundance of *S. aurata* was not significantly correlated with either of the two components (Pearson correlation test PC1, $r=-0.09$, $P=0.29$; Pearson correlation test PC2, $r=-0.12$, $P=0.21$). There was, however, a tendency towards higher abundance of this species in shallow, muddy bottoms (Fig. 4).

Discussion

In terms of abundance, the results show that the selected fish species were predominant in the shallow littoral areas of the Mar Menor. Since some of these species are important for the local fishing industry, these areas take on a special importance since they act as a nursery or feeding grounds for marine migrant species and resident species which are of commercial interest. Moreover, the littoral areas of the lagoon provide refuge and essential habitats for endangered species such as *A. iberus* and *S. abaster*.

Previous studies on the impacts of human activities on transitional waters such as estuaries, coastal lagoons and saltmarshes have shown that shoreline development negatively affects the biological communities inhabiting littoral areas (Peterson et al. 2000; Silliman and Bertness 2003; Sanger et al. 2004; Seitz et al. 2006; Bilkovic and Roggero 2008; DeLuca et al. 2008). The present study supports the finding that shoreline modification as a consequence of urbanisation and the maintenance of recreational beaches produces significant changes in habitat structure, fish community structure and the relative abundances of several fish species of the adjacent littoral zone.

These changes to fish fauna may be attributed to the reduction of habitat complexity and, probably, to reduction of secondary production and inputs of allocthanous materials due to shoreline degradation and changes in land use

(Seitz et al. 2006; Bilkovic and Roggero 2008). The littoral areas associated with recreational beaches showed an increased water depth, higher substrata grain size and scarce development of submerged vegetation. These beaches are periodically maintained and regenerated, leading to a homogeneous sandy substrata and the burying and uprooting of submerged vegetation. In contrast, substrata adjacent to saltmarshes is heterogenous composed predominantly of fine sediments (from mud to sand) with the presence of pebbles and boulders. Substrata offshore of saltmarsh also support well developed meadows of submerged vegetation (higher cover and volume) made up mainly of the phanerogams *C. nodosa* and *R. cirrhosa* and filamentous algae of the genera *Cladophora* and *Chaetomorpha*.

Habitat complexity is one of the main environmental factors influencing fish assemblages in estuaries and coastal lagoons because complex habitats possess favourable conditions that provide abundant food resources and refuge against predators for the different stages of fish species (Franco et al. 2006; Bilkovic and Roggero 2008; França et al. 2009). Consequently, natural shorelines at Mar Menor featured higher fish species richness and harboured higher abundances of species like the pipefish *S. abaster* and the endangered cyprinodontid *A. iberus*. The significant association observed between the abundance of these species and vegetated bottoms is due to the fact that they are habitat specialists that develop their life cycles in seagrass meadows (Franco et al. 2006; Oliva-Paterna et al. 2009). The former species is mainly present in the seagrass meadows of *C. nodosa*, and the latter mainly in *R. cirrhosa* meadows. The saltmarshes of Lo Poyo, El Carmolí and La Hita, together with their littoral habitats, constitute critical areas for the conservation of natural populations of *A. iberus* in the Mar Menor, and, to a certain extent, in its geographical distribution range. Although the abundance of the sand smelt *A. boyeri* did not show significant differences between shoreline types, this species was positively correlated with vegetated bottoms. This finding is partly explained by the biology of *A. boyeri*, since it reproduces in the Mar Menor during spring and early summer (Andreu-Soler et al. 2006) by attaching its eggs to submerged vegetation (Fernández-Delgado et al. 2000). Probably, this behaviour was reflected in the substantially increased numbers of individuals caught during summer in saltmarsh shorelines.

Recent studies have shown that food availability (e.g. benthic infauna or organic matter inputs) in natural shorelines was higher than in modified ones (Seitz et al. 2006). Moreover, it has been demonstrated that saltmarshes provide abundant food resources for the earlier life stages of the migrant fish (França et al. 2011). Hence, juvenile individuals of marine migrant species such as *S. aurata* and *L. saliens* may have benefitted from increased food resources at saltmarsh shorelines. Higher water turbidity and shallowness could also

provide better protection against predators resulting in a suitable nursery habitat for these commercially important fish species (Franco et al. 2006; França et al. 2009). Verdiell-Cubedo et al. (2007a) showed that juvenile individuals from the Sparidae family (*S. aurata*, *Diplodus* spp. and *Sarpa salpa*) were abundant in the seagrass meadows of the Mar Menor, which are mainly associated with unmodified shorelines.

In this study, the marbled goby *P. marmoratus* and the mullet *L. aurata* were the dominant species in altered shorelines, showing a strong association with unvegetated sandy bottoms. The former is a benthic and cryptic species which is very abundant in the sandy habitats of some Mediterranean coastal lagoons (Koutrakis et al. 2005; Franco et al. 2006; Verdiell-Cubedo et al. 2008). It is interesting to note that *L. aurata* showed an inverse pattern of habitat association to that of *L. saliens*. Although these species are omnivorous, the observed pattern could be due to the fact that *L. saliens* feeds mainly on detritus (Verdiell-Cubedo et al. 2007b). Thus, it displays higher abundances in shorelines adjacent to saltmarshes, which arguably receive important allochthonous organic matter inputs from marsh materials and seagrass meadows.

It is worth pointing out that the cyprinodontid *A. iberus* and the pipefish *S. abaster* also displayed high abundance values in modified shorelines (mainly during summer). This observation is likely due to the population dynamics of these species, since their recruitment periods occur during warmer months (May to September) (Verdiell-Cubedo 2009) and young-of-the-year individuals could colonise the small patches of submerged vegetation located in the marginal habitats of altered shorelines (e.g. areas of low hydrodynamics associated with breakwaters). These vegetated areas are mainly composed of algal mats of filamentous algae, such as *Cladophora* spp. and *Chaetomorpha* spp., and small patches of *R. cirrhosa*, which display higher growth during the warmer months. In addition, differences observed in winter for *S. abaster*, with significantly higher abundances in saltmarsh shorelines than in modified ones, were probably related to observed changes in macrophyte species composition between shoreline types and their associated seasonal cycles. The dominance and persistence of *C. nodosa* meadows in unmodified shorelines was reflected in the high cover values of submerged vegetation during winter (see Table 2), which, in turn, is reflected in the significantly increased numbers of *S. abaster* caught in these areas.

The Mar Menor lagoon system has been affected by large-scale anthropogenic disturbances, mainly related to the substantial development of intensively irrigated agriculture and an increase in population and urbanisation. The results of the present study show that shoreline modification negatively affects the habitat complexity of the adjacent littoral bottoms, a situation which causes the loss of essential

habitats for numerous fish species, including those of commercial and/or conservationist interest. Although maintenance of recreational beaches has become a tourist necessity in the study area, sustainable management requires information on the functioning of the concerned ecosystems, especially an understanding of how vulnerable particular habitats, communities and species are to different human coastal activities (Nordstrom 2005; Seitz et al. 2006; Bilkovic and Roggero 2008).

The conservation of habitat complexity and habitat heterogeneity within the littoral zone should be a primary aim in the management plans of transitional waters that are subjected to several types of shoreline human development. Therefore, the preservation of areas with natural and near-natural shorelines through protectionist policies and the application of habitat restoration measures (e.g. creation and conservation of natural areas along modified shorelines) should be a priority. It would be also necessary to develop and evaluate alternative beach management practices and technologies, and to incorporate diverse stakeholder interests into design and implementation of beach maintenance programmes, in order to minimize impacts on shallow water habitats.

Acknowledgements We are grateful to Pedro A. Miñano, Andrés Egea and Ana Ruiz for help in field sampling and laboratory processing, and to Melissa Crim and Javier Lloret for their English revision and expert commentaries, respectively. Many thanks to María Francisca Carreño for her help in Fig. 1. We also acknowledge the comments of two anonymous reviewers which have greatly improved the manuscript. Part of this research was supported by the Environmental Service of the Autonomous Government of Murcia, Spain.

References

- Andreu-Soler A, Oliva-Paterna FJ, Torralva M (2006) Seasonal variations in somatic condition, hepatic and gonad activity of sand smelt *Atherina boyeri* (Teleostei Atherinidae) in the Mar Menor coastal lagoon (SE Iberian Peninsula). *Folia Zoologica* 55:151–161
- Attrill MJ, Power M (2004) Partitioning of temperature resources amongst an estuarine fish assemblage. *Estuarine, Coastal and Shelf Science* 61:725–738
- Bain MB (1999) Substrate. In: Bain MB, Stevenson NJ (eds) Aquatic habitat assessment: common methods. American Fisheries Society, Bethesda, pp 95–100
- Baldó F, Drake P (2002) A multivariate approach to the feeding habits of small fishes in the Guadalquivir Estuary. *Journal of Fish Biology* 61:21–32
- Bilkovic DM, Roggero MM (2008) Effects of coastal development on nearshore estuarine nekton communities. *Marine Ecology Progress Series* 358:27–39
- Carreño MF, Esteve MA, Martínez J, Palazón JA, Pardo MT (2008) Habitat changes in coastal wetlands associated to hydrological changes in the watershed. *Estuarine, Coastal and Shelf Science* 77:475–483
- Clarke KR, Warwick RM (2001) Change in marine communities: an approach to statistical analysis and interpretation, 2nd edn. PRIMER-E, Plymouth

- Courrat A, Lobry J, Nicolas D, Amara R, Lepage M, Girardin M, Le Pape O (2009) Anthropogenic disturbances on nursery function of estuarine areas for marine fish species. *Estuarine, Coastal and Shelf Science* 81:179–190
- DeLuca WV, Studds CE, King RS, Marra PP (2008) Coastal urbanization and the integrity of estuarine waterbird communities: threshold responses and the importance of the scale. *Biological Conservation* 141:2669–2678
- Elliott M, Whitfield AK, Potter IC, Blaber SJM, Cyrus DP, Nordlie FG, Harrison TD (2007) The guild approach to categorize estuarine fish assemblages: a global review. *Fish and Fisheries* 8:241–268
- Fernández-Delgado C, Drake P, Arias AM, García D (2000) Peces de Doñana y su entorno. Organismo Autónomo de Parques Nacionales. Ministerio de Medio Ambiente, Madrid
- França S, Costa MJ, Cabral HN (2009) Assessing habitat specific fish assemblages in estuaries along the Portuguese coast. *Estuarine, Coastal and Shelf Science* 83:1–12
- França S, Vasconcelos RP, Tanner S, Máguas C, Costa MJ, Cabral HN (2011) Assessing food web dynamics and relative importance of organic matter sources for fish species in two Portuguese estuaries: a stable isotope approach. *Marine Environmental Research* 72:204–215
- Franco A, Franzoi P, Malavasi S, Riccato F, Torricelli P, Mainardi D (2006) Use of shallow habitats by fish assemblages in a Mediterranean coastal lagoon. *Estuarine, Coastal and Shelf Science* 66:67–83
- Franco A, Elliott M, Franzoi P, Torricelli P (2008) Life strategies of fishes in European estuaries: the functional guild approach. *Marine Ecology Progress Series* 354:219–228
- Koutrakis ET, Tsikliras AC, Sinis AI (2005) Temporal variability of the ichthyofauna in a Northern Aegean coastal lagoon (Greece). Influence of environmental factors. *Hydrobiologia* 543:245–257
- Lloret J, Marín A, Marín-Guirao L, Velasco J (2005) Changes in macrophytes distribution in a hypersaline coastal lagoon associated with the development of intensively irrigated agriculture. *Ocean & Coastal Management* 48:828–842
- Martínez J, Esteve-Selma MA, Robledano-Aymerich F, Pardo-Sáez MT, Carreño-Fructuoso MF (2005) Aquatic birds as bioindicators of trophic changes and ecosystem deterioration in the Mar Menor lagoon (SE Spain). *Hydrobiologia* 550:221–235
- Nordstrom KF (2005) Beach nourishment and coastal habitats: research needs to improve compatibility. *Restoration Ecology* 13:215–222
- Oliva-Paterna FJ, Andreu-Soler A, Miñano PA, Verdiell-Cubedo D et al (2006) YOY fish species richness in the littoral shallows of the mesosaline coastal lagoon (Mar Menor, Mediterranean coast of the Iberian Peninsula). *Journal of Applied Ichthyology* 22:235–237
- Oliva-Paterna FJ, Ruiz-Navarro A, Torralva M, Fernández-Delgado C (2009) Biology of the endangered cyprinodontid *Aphanius iberus* in a saline wetland (SE Iberian Peninsula). *Italian Journal of Zoology* 76:316–329
- Pérez-Ruzafa A, Marcos C, Gilabert J (2005) The ecology of the Mar Menor coastal lagoon: a fast changing ecosystem under human pressure. In: Gönenç IE, Wolflin JP (eds) *Coastal lagoons. Ecosystem processes and modelling for sustainable use and development*. CRC Press, Boca Raton, pp 392–422
- Pérez-Ruzafa A, García-Charton JA, Barcala E, Marcos C (2006) Changes in benthic fish assemblages as a consequence of coastal works in a coastal lagoon: the Mar Menor (Spain, Western Mediterranean). *Marine Pollution Bulletin* 53:107–120
- Peterson MS, Comyns BH, Hendon JR, Bond PJ, Duff GA (2000) Habitat use by early life-history stages of fishes and crustaceans along a changing estuarine landscape: differences between natural and altered shoreline sites. *Wetlands Ecology and Management* 8:209–219
- Pombo L, Elliot M, Rebelo JE (2005) Environmental influences on fish assemblage distribution of an estuarine coastal lagoon, Ria de Aveiro (Portugal). *Scientia Marina* 69(1):143–159
- Quinn G, Keough M (2002) *Experimental design and data analysis for biologists*. Cambridge University Press, Cambridge
- Rountree RA, Able KW (2007) Spatial and temporal habitat use patterns for salt marsh nekton: implications for ecological functions. *Aquatic Ecology* 41:25–45
- Sanger DM, Holland AF, Hernandez DL (2004) Evaluation of the impacts of dock structures and land use on tidal creek ecosystems in South Carolina estuarine environments. *Environmental Management* 33(3):385–400
- Seitz RD, Lipcius RN, Olmstead NH, Seebo MS, Lambert DM (2006) Influence of shallow-water habitats and shoreline development on abundance, biomass and diversity of benthic prey and predators in Chesapeake Bay. *Marine Ecology Progress Series* 326:11–27
- Silliman BR, Bertness MD (2003) Shoreline development drives invasion of *Phragmites australis* and the loss of plant diversity on New England salt marshes. *Conservation Biology* 18(5):1424–1434
- Underwood AJ (1997) *Experiments in Ecology. The Logical Design and Interpretation Using Analysis of Variance*. Cambridge University Press, Cambridge
- Vasconcelos RP, Resi-Santos P, Fonseca V, Maia A, Ruano M, França S, Vinagre C, Costa MJ, Cabral H (2007) Assessing anthropogenic pressures on estuarine fish nurseries along the Portuguese coast: A multi-metric index and conceptual approach. *Science of the Total Environment* 374:199–215
- Velasco J, Lloret J, Millán A, Marín A, Barahona J, Abellán P, Sánchez-Fernández D (2006) Nutrient and particulate inputs into the Mar Menor lagoon (SE Spain) from an intensive agricultural watershed. *Water, Air, and Soil Pollution* 176:37–56
- Verdiell-Cubedo D, Oliva-Paterna FJ, Andreu A, Torralva M (2007a) Characterisation of the nursery areas for YOY Sparidae fish species in a Mediterranean coastal lagoon (SE Iberian Peninsula). *Anales de Biología* 29:3–11
- Verdiell-Cubedo D, Egea-Serrano A, Oliva-Paterna FJ, Torralva M (2007b) *Biología trófica de los juveniles del género Liza (Pisces: Mugilidae) en la laguna costera del Mar Menor (SE Península Ibérica)*. *Limnetica* 26:67–74
- Verdiell-Cubedo D, Oliva-Paterna FJ, Egea-Serrano A, Torralva M (2008) Population biology and habitat associations of benthic fish species in the shallow areas of a Mediterranean coastal lagoon (SE Iberian Peninsula). *Scientia Marina* 72:319–328
- Verdiell-Cubedo D (2009) *Ictiofauna de las zonas someras litorales del Mar Menor (SE, Península Ibérica): parámetros de su biología y relaciones con el hábitat*. University of Murcia, Spain