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Effects of inter-annual freshwater inflow shifts on the community structure of estuarine decapods

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Abstract: The objective of this study was to evaluate how inter-annual changes in freshwater inputs have affected the decapod assemblages in the Guadiana estuary. Three major areas in the estuary were sampled during the summer, in 2001 (high inflow year and before the filling of the Alqueva dam), in 2002 (low inflow and after filling of the Alqueva dam), and in 2008 and 2009 (low inflow and after consolidation of the impacts of the Alqueva dam). A significant increase in total decapod densities was recorded for the entire estuary, but especially in the upper estuary, after the closure of the dam in 2002. Changes in salinity, turbidity and temperature, which were mainly due to changes in freshwater input and climatic influence (North Atlantic Oscillation index), had an important influence on the structure of the decapod crustacean assemblages. The major conclusions of the study were that, following the construction of the Alqueva dam and regularization of the freshwater inflow, the decapod crustacean community in the Guadiana estuary changed and a shift of the dominant decapod species to upper zones of the estuary happened. These changes, and the presence of the non-native *Palaemon macrodactylus* in 2008 and 2009, further enhance the importance of estuarine monitoring studies to improve ecologists' knowledge on distinguishing and understanding natural changes and anthropogenic impacts in the ecosystem.

Résumé : *Effets des variations interannuelles d'apports d'eau douce sur la structure d'une communauté estuarienne de décapodes*. L'objectif de cette étude était d'évaluer comment les variations interannuelles d'apports d'eau douce affectent l'assemblage de décapodes dans l'estuaire du Guadiana. Trois grands domaines de l'estuaire ont été échantillonnés en été : en 2001 (année d'apports importants et avant le remplissage du barrage d'Alqueva), en 2002 (faible apport d'eau douce et après le remplissage du barrage d'Alqueva), en 2008 et 2009 (après la consolidation de l'impact du barrage d'Alqueva). Une augmentation significative de la densité totale des décapodes pour tout l'estuaire a été enregistrée, mais surtout dans l'estuaire supérieur, après la fermeture du barrage en 2002. Les variations de salinité, turbidité et température, principalement dues à des changements d'apports d'eau douce et à l'influence du climat (indice d'oscillation nord-atlantique), ont eu une influence importante sur la structure des assemblages de crustacés décapodes. Les principales conclusions de l'étude sont que, à la suite de la construction du barrage d'Alqueva et de la régulation de l'apport d'eau douce, la communauté de crustacés décapodes dans l'estuaire du Guadiana a changé et les principales espèces de décapodes

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se sont déplacées vers les zones supérieures de l'estuaire. Ces changements, ainsi que la présence de l'espèce non native *Palaemon macrodactylus* en 2008 et 2009, soulignent l'importance de surveiller l'estuaire dans le futur proche afin de pouvoir mieux distinguer et comprendre les changements naturels et les impacts anthropiques sur l'écosystème.

Keywords: Alqueva dam ● Freshwater regularization ● Inter-annual shifts ● *Crangon crangon* ● *Palaemon macrodactylus* ● *Palaemon longirostris*

Introduction

Ecohydrologists are always eager to find biological indicators that can be used to identify how large-scale processes occurring at the basin scale, as river inflow changes, affect the functioning of ecosystems. Until now, this has been accomplished after studying the inter-annual fluctuations of fish eggs abundance (Chícharo et al., 2001a; Morais et al., 2009), the proportion of fish species hatching from pelagic and demersal eggs (Faria et al., 2006), and also by determining the inter-seasonal and inter-annual diet variability of a piscivorous bird (Dias et al., 2012). We speculate that macrocrustaceans also have innate characteristics, as their relatively low longevity and mobility (Nedwell & Raffaelli, 1999), that turn them good indicators of how basin-scale processes affect estuarine ecosystems.

Estuaries are among the biologically richest ecosystems in the world, with high primary and secondary productivities, mainly due to a large supply of nutrients originated in freshwater ecosystems (Levinton, 2001). Ecological zonation in estuaries is essentially controlled by the balance between freshwater input and marine water intrusion, so that the freshwater discharged into an estuary tends to be the major structuring factor in estuaries (Sklar & Browder, 1998; Morais et al., 2009). This is especially relevant in estuaries under the influence of a Mediterranean climate, as the Guadiana estuary, where significant inter-annual variations of freshwater inflow structure the physical, chemical and biological compartments of this ecosystem (Domingues et al., 2005; Faria et al., 2006; Wolanski et al., 2006; Morais et al., 2009). The regularization of river flow by dams tends to augment the natural repercussions of inter-annual river flow variation, and during periods of low inflow, as drought years, the estuarine circulation changes significantly and the salinity gradient, as well as other physical and chemical water parameters, are further extended (Nixon et al., 2004; Morais et al., 2009).

It was identified that the construction of dams in basins with Mediterranean climate have meaningful and deleterious impacts on water quality (e.g. eutrophication), sediment dynamics (e.g. coastal erosion), and fish populations (e.g. marine fishes reduce the use of estuaries as spawning/nursery habitats) (Morais, 2008). Benthic meiofauna and macrofauna communities, and not just fish (Chícharo et al., 2006a; Faria et al., 2006), also respond to river inflow regularization. In the Nueces estuary, macrofauna and meiofauna also decreased after the construction of two dams, but a recovery was visible when a diversion channel was constructed (Montagna et al., 2002). Once the freshwater inflow was restored, macrofauna abundance, biomass and diversity increased, but when hypersaline events occurred, these descriptors declined again (Montagna et al., 2002).

Macrobenthic invertebrates are a group of organisms often used in monitoring programs (e.g. Rosenberg & Resh, 1993; Van Hoey et al., 2010; Varandas & Cortes, 2010), mainly because it has been demonstrated that they respond rapidly to environmental stress (Pearson & Rosenberg, 1978; Dauer, 1993). Decapod crustaceans play a critical role in metabolizing and controlling the energy flow in estuarine ecosystems and, even though having a great economic impact on them (Cuesta et al., 2006), few comprehensive studies have evaluated the abundance, biomass and structure of decapod assemblages in temperate European estuaries under the influence of a Mediterranean climate, with the exception of Guadalquivir estuary (SW-Iberian Peninsula, Europe) (Cuesta et al., 2006). In the Odiel and Guadiana estuaries (SW-Iberian Peninsula, Europe), macrocrustaceans have already been studied (Sanchez-Moyano & Garcia-Asencio, 2010 & 2011), but not the decapod community specifically.

The Guadiana estuary is one of the most studied estuaries in the Iberian-Peninsula, mainly since 1996 (e.g. Chícharo et al., 2001b) and one of the most recurring study topics is the impact of river inflow changes, caused by the construction of the Alqueva dam in early 2002, which created the largest artificial freshwater body in Europe (Morais, 2008). Thus, considering all the background knowledge that exists concerning the functioning of the Guadiana estuary (e.g. Wolanski et al., 2006), the impact of river flow variation on several compartments of this ecosystem, either caused by natural variations or due to the construction of the Alqueva dam in 2002 (e.g. Domingues et al., 2005; Chícharo et al., 2006b; Morais et al., 2009), we aim to assess if decapods are useful indicators to detect the shifts of basin-scale processes- river flow changes, by (1) comparing the summer decapod assemblage structure, between three distinct hydrological years: 2001 (before the construction of the Alqueva dam), 2002 (after construction of the Alqueva dam), and 2008 and 2009 (after seven years of impacts from operation of the dam) and (2) evaluating the role of several environmental variables on the structure of the decapod assemblage.

Material and Methods

Study area

The Guadiana estuary is on the southeastern border between Portugal and Spain (Fig. 1), with a catchment basin of approximately 67,500 km^2. The Guadiana basin shows clear seasonal and inter-annual variations, characterized by severe droughts and heavy floods, as a result of seasonal and annual fluctuations in rainfall, as is characteristic of a Mediterranean climate; however, variations in freshwater inflow were significantly reduced after construction of the Alqueva dam (INAG, 2012).

For this study, the estuary was divided into three zones (Fig. 1): lower, middle and upper estuary, according to Chícharo et al. (2006b). The upper estuary is characterized by salinities close to zero (< 0.5). The middle section is the salinity-mixing zone, with salinity values between 0.5 and 25, and the lower estuary has salinities similar to seawater (> 25) (Chícharo et al., 2006b).

Environmental parameters

Freshwater inflow data, obtained from the Instituto Nacional da Água (www.inag.pt), was measured at the Pulo do Lobo hydrometric station (37°48'N-7°38'W), located a few kilometers above the last point of tidal influence (Mértola) and about 39 km NNW from Alcoutim, the last sampling point (Fig. 1). Average and standard deviation were calculated for the Winter/Spring period of each sampling year.

At each sampling location, salinity and water temperature were measured using a multiparameter probe (YSI Professional Plus) and turbidity with a Secchi disk. Water samples for analysis of *in situ* chlorophyll *a* were collected at the surface with a Van Dorn bottle, and analysed with a Turner 10 AU fluorometer.

As an indicator of climatic conditions of the area, the NAO (North Atlantic Oscillation) index was obtained from the National Center for Atmospheric Research (USA) database (NCAR, 2012).

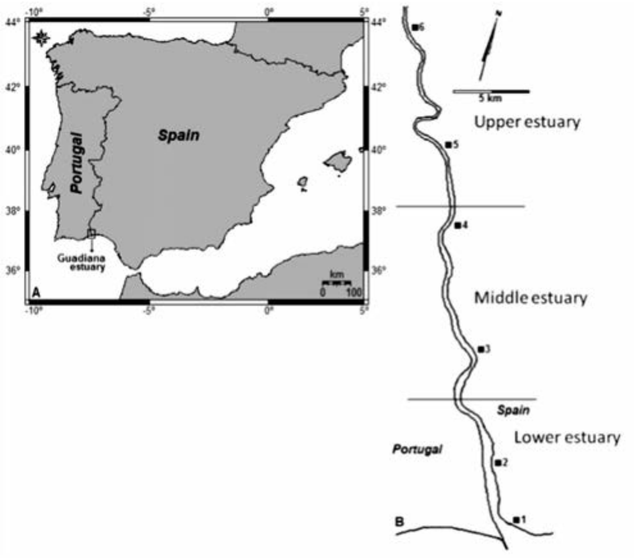

Figure 1. Location of the Guadiana estuary in the Iberian Peninsula (**A**) and the division of the estuary in lower, middle and upper estuary (**B**). Six sampling stations were sampled, two *per* estuary zone (1- Barra, 2- Ayamonte, 3- Posto Cinturão, 4- Foz de Odeleite, 5- Guerreiros do Rio, 6- Alcoutim).

Experimental design and sampling methods

Trawls were performed along transects in three estuarine zones (upper, middle and lower) in summer 2001, 2002, 2008 and 2009. At each estuary zone, two trawls were performed. Sampling was carried out in 2001, before the Alqueva dam construction, in 2002, right after the closure of the dam and in 2008 and 2009 after the regularization of the river flow.

An otter trawl, composed of a conical-shaped net with a 3 m mouth, a total length of 25 m and equipped with two otter boards each weighing 12 kg was used. The net was composed of two panes: an outer pane (30 mm stretched mesh) and an inner pane (5 mm stretched mesh). Trawling periods varied between 5 and 10 minutes at a stable speed (5 knots).

Samples were preserved in buffered formaldehyde (4%) until further laboratory analysis.

Decapod specimens were counted and identified in laboratory to species level according to Ashelby et al. (2004), Beguer et al. (2007), Cottiglia (1983), Fischer et al. (1987), González-Ortegón & Cuesta (2006), Gurrianrán & Méndez (1985), Hayward & Ryland (1990), Ingle (1996) and Smaldon et al. (1993).

Data analysis

Characterization of the decapod community was initially assessed through ecological indices (S - total individuals; N - total species; H' - Shannon's diversity; J' - Pielou's evenness). Decapod average density and standard deviation were calculated for each of the sampling years. Standard deviation was used as a measure of dispersion.

A two-way analysis of variance (ANOVA) was performed on environmental parameters, ecological indices and decapod density to detect if significant differences between years and estuary zones occurred. Differences within estuary zones and years were also assessed by one-way ANOVA. The above statistical analyses were conducted using SigmaStat 3.5 software.

The community structure was analysed by a nonmetric multidimensional scaling (MDS) analysis, based on triangular matrices of Bray-Curtis measure of similarity of $\log_{10}$ (x+1) transformed data.

In order to assess relationships between the biological and environmental data, the BIO-ENV procedure was performed on density and biomass data. This test was also based on Bray-Curtis matrices of $\log_{10}$ (x+1) transformed data, using all the environmental variables available (temperature, salinity, chlorophyll *a*, Secchi depth, river flow, NAO index). The above statistical analyses were conducted using PRIMER 6.

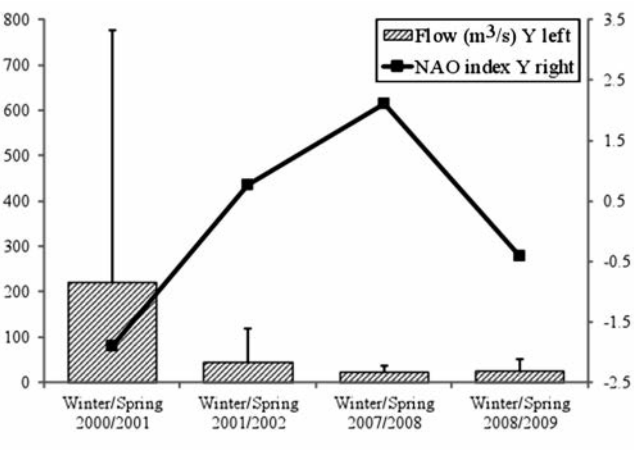

Figure 2. Average and standard deviation of river flow in winter and spring from the hydrometric station of Pulo do Lobo and the NAO index.

Results

Environmental data

The maximum Guadiana River inflow occurred in the hydrological year 2000-2001 (220.0 ± 556.3 $m^3 s^{-1}$), before construction of the Alqueva dam and was lowest in 2007-2008 (22.7 ± 13.9 $m^3 s^{-1}$). For the hydrological year immediately after construction of the dam, 2001-2002, both the mean and SD (43.8 ± 75.8 $m^3 s^{-1}$) of the flow values decreased abruptly (Fig. 2). In the last hydrological year analysed (2008-2009), the river flow mean and SD (24.1 ± 26.3 $m^3 s^{-1}$) increased, compared with the previous year. The NAO index showed the lowest value of -1.90 in 2001, increased in the two following years of this study

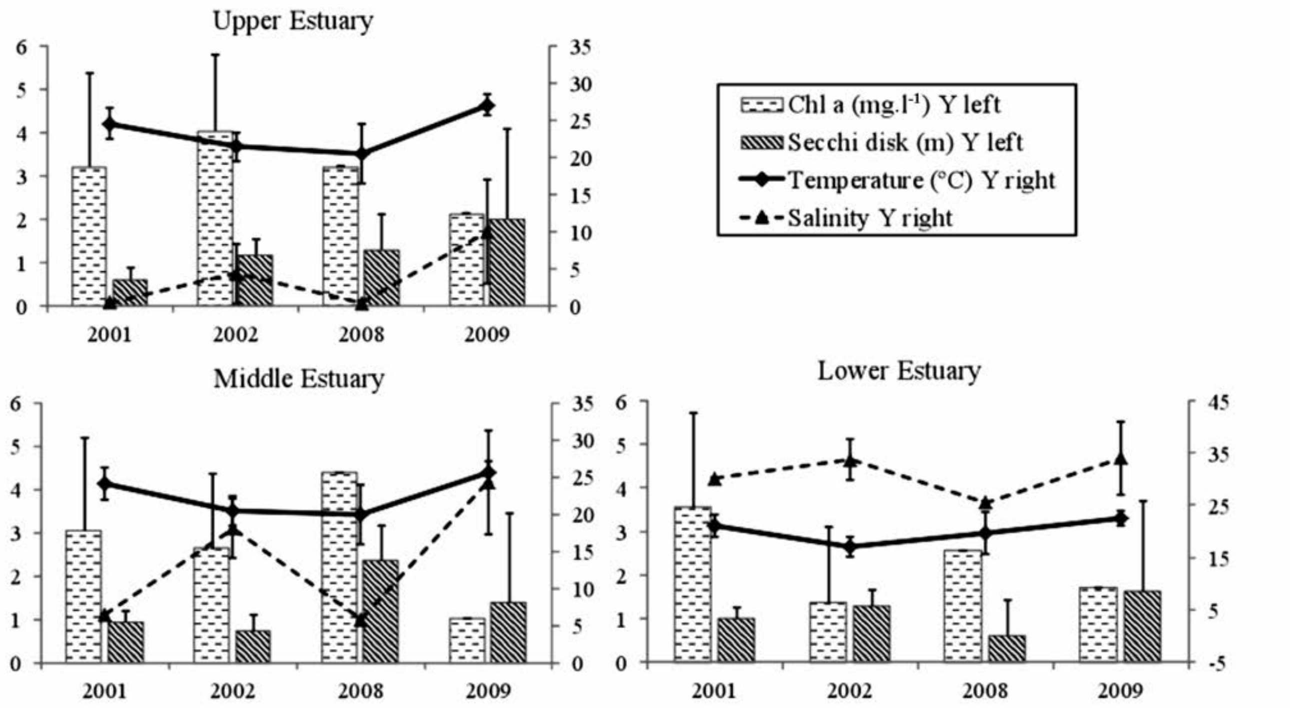

Figure 3. Average and standard deviation of water parameters for upper, middle and lower estuary in 2001, 2002, 2008 and 2009.

(maximum value of 2.10 in 2008) and then decreased to -0.41 in 2009 (Fig. 2).

Secchi disk depth ranged from 0.6 to 2.4 m and increased from 2001 to 2009 in all estuary areas, with the exception of 2008, when there was a decrease in the lower estuary (Fig. 3). Chlorophyll *a* concentrations remained lower than 5 mg.L^{-1} in the entire area, rising from the lower to the upper estuary and decreased from 2001 to 2009 (Fig. 3). Water Temperatures ranged between 17 and 27°C with values rising from the lower to the upper estuary (Fig. 3). Salinity varied from 34 in the lower estuary to values close to zero (< 5) in the upper estuary. Between sampling years, average salinity also showed a rising trend, particularly for the upper estuary (Fig. 3).

The performed two-way ANOVA (Table 1) showed that the differences between years were significant for all the environmental variables. Between estuary zones, only temperature and salinity showed significant changes.

Decapod assemblages

During the sampling periods, 9 decapod species were identified. Eight species were identified in 2001, five in 2002 and four in 2008 and 2009. For lower estuary in 2009 it was not possible to carry out the sampling, so there is no data for that area and date.

Table 1. Two-way ANOVA results (*p* values) of environmental variables, ecological indices and decapod density between years and between estuary zones.

	Variable	Source of variation	
		Year	Estuary Zone
Environmental	Temperature	**	**
	Salinity	**	**
	Chlorophyll *a*	*	0.280
	Secchi depth	*	0.582
	River flow	**	-
	NAO index	**	-
Ecological indices	Total species (S)	0.258	0.143
	Total individuals (N)	**	0.080
	Shannon's diversiy (H')	0.167	0.155
	Pielou's evenness (J')	*	0.466
Decapod density	*C. maenas*	*	0.072
	C. crangon	**	0.082
	D. pugilator	0.501	0.318
	L. holsatus	0.501	0.318
	P. longirostris	0.105	0.154
	P. macrodactylus	**	0.754
	P. kerathurus	0.050	0.125
	S. carinata	0.356	0.095
	U. tipica	0.477	0.440

* $p < 0.05$; ** $p < 0.01$

Table 2. Species with their feeding habits and ecological guilds, their average density (ind m^{-2}) and standard deviation (SD) and respective percentages of total density in the Guadiana estuary in summer 2001, 2002, 2008 and 2009.

Species	Feeding habits	Ecological guild	Summer 2001		Summer 2002		Summer 2008		Summer 2009	
			Density ± SD	%	Density ± SD	%	Density ± SD	%	Density ± SD	%
C. maenas	Carnivorous	Marine	0.0050 ± 0	9.0	0.0000	0.0	0.0180 ± 0.005	7.4	0.0014 ± 0.001	0.1
C. crangon	Omnivorous	Marine/Nursery	0.0015 ± 0.001	2.7	0.0071 ± 0.003	5.5	0.0483 ± 0.046	19.8	1.1880 ± 0.518	95.5
D. pugilator	Scanvenger/Carnivorous	Marine	0.0003 ± 0	0.5	0.0000	0.0	0.0000	0.0	0.0000	0.0
L. holsatus	Carnivorous	Marine	0.0001 ± 0	0.2	0.0000	0.0	0.0000	0.0	0.0000	0.0
P. longirostris	Carnivorous	Resident	0.0163 ± 0.015	29.4	0.0616 ± 0.100	48.0	0.1714 ± 0.162	70.3	0.0414 ± 0.020	3.3
P. macrodactylus	Carnivorous	Non-native	0.0000	0.0	0.0000	0.0	0.0060 ± 0	2.5	0.0129 ± 0.005	1.0
P. kerathurus	Carnivorous	Marine	0.0219 ± 0.032	39.5	0.0520 ± 0.054	40.5	0.0000	0.0	0.0000	0.0
S. carinata	Carnivorous	Marine	0.0099 ± 0.010	17.9	0.0016 ± 0	1.3	0.0000	0.0	0.0000	0.0
U. tipica	Suspension feeder	Marine	0.0005 ± 0	0.9	0.0060 ± 0	4.7	0.0000	0.0	0.0000	0.0
Total			**0.0555**	**100**	**0.1283**	**100**	**0.2437**	**100**	**1.2436**	**100**

Table 3. Occurrence of decapod species in the lower (LE), middle (ME) and upper (UE) Guadiana estuary.

	2001			**2002**			**2008**			**2009**	
Species	**LE**	**ME**	**UP**	**LE**	**ME**	**UP**	**LE**	**ME**	**UP**	**ME**	**UP**
C. maenas	■						■	■		■	■
C. crangon	■	■		■	■		■	■	■	■	■
D. pugilator	■										
L. holsatus	■										
P. longirostris	■	■		■	■	■	■	■	■	■	■
P. macrodactylus									■	■	■
P. kerathurus	■	■	■	■	■	■					
S. carinata	■			■							
U. tipica	■					■					

In 2001 and 2002, *Palaemon longirostris* Milne Edwards, 1837 and *Penaeus kerathurus* (Forskål, 1775) dominated the decapod community (Table 3). In 2008 *P. longirostris* still dominated (70%) and *Crangon crangon* (Linnaeus, 1758) increased in density to 0.048 ± 0.046 ind m^{-2} (20%). In the last year (2009), *C. crangon* constituted the dominant species with an average density of 1.188 ± 0.518 ind m^{-2}, which corresponded to 95.5% of the total of decapods in that year.

In ecological indices, although the number of identified species decreased from 2001 to 2009 (Table 1), these differences showed no to be significant (Table 2). ANOVA also showed that changes in Shannon's diversity index were not significant. The total number of individuals increased since the closure of the Alqueva dam, while Pielou's evenness showed a decreasing trend. These two last indices were the only ones that ANOVA showed to have significant changes between years (Table 1).

Changes in the decapod community showed to be significant between years in *Carcinus maenas*, *C. crangon* and *Palaemon macrodactylus* (Rahtbun, 1902) (Table 1), but not between estuary zones. The crab *Carcinus maenas* (Linneaus, 1758) existed in 2001 in the lower estuary and in 2002 none specimen was found in the entire estuary (Table 3). Seven years after the regularization of the river flow (2008) the crab was present in the lower and middle estuary (Table 3) and although the total density decreased in 2009, the species was also found in the upper estuary with a density of 0.0005 ind m^{-2}. In 2001 (before the construction of the dam), *C. crangon* showed its minimum value of density of 0.0003 ind m^{-2} in the middle estuary. In 2002, the distribution was the same (Table 3), but the density increased in both estuary zones. After the settlement of the impacts from the regularization of the river flow (2008), *C. crangon* was already present throughout the entire estuary (Table 3), decreasing in the lower estuary but increasing in the middle and present in the upper estuary with a density of 0.0338 ind m^{-2}. In 2009, although the lower estuary was not sampled, a substantial increase was observed in the other two zones. In the middle estuary a density of 1.6253 ind m^{-2} was recorded, being the highest density value in the entire study. The non-native *P. macrodactylus* appeared for the first time in 2008 in the upper estuary (Table 3) with a density of 0.0060 ind m^{-2}. In 2009, this value increased to 0.0090 ind m^{-2} and the species was also recorded in the middle estuary with a density of 0.0168 ind m^{-2}.

The one-way ANOVA showed that the change in total decapod density (Table 4) across years was only significant in the upper estuary, that is, a significant increase in the decapod community occurred in the upper estuary in the years after the closure of the dam (Fig. 4).

The MDS plot (Fig. 5) showed a segregation of the upper estuary from 2001 (before the Alqueva dam) and of the samples from 2008 and 2009 (after the settlement of the impacts). An aggregation of the estuary zones was also visible.

Correlations from the BIO-ENV procedure are presented in Table 5 and only values higher than 0.270 were kept in order to highlight the more important combinations of variables. The variable with the higher correlation with the biological data was the river flow alone. This variable also appeared in the following six combinations of variables. Salinity and Secchi depth were presented in five of the combinations, with salinity situated in the combinations with the second and third higher correlation values (Table 5).

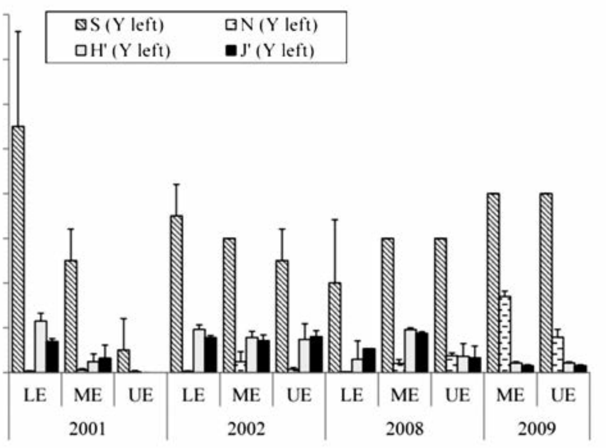

Figure 4. Average and standard deviation of total species (S), total individuals (N), Shannon's diversity index (H') and Pielou's evenness (J') of decapods in the lower (LE), middle (ME) and upper (UE) Guadiana estuary in 2001, 2002, 2008 and 2009. In 2009 the lower estuary was not sampled.

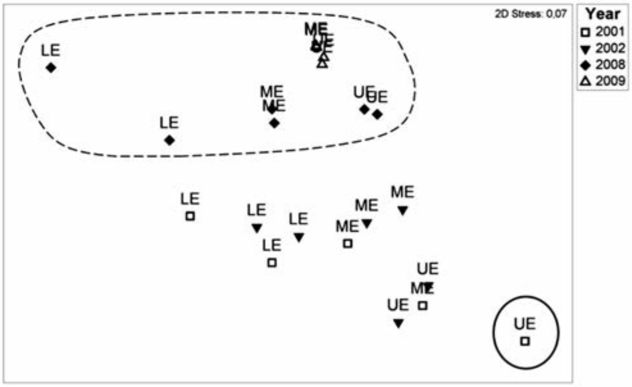

Figure 5. Non-metric multidimensional scaling (MDS) plot of decapods densities in lower (LE), middle (ME) and upper (UE) Guadiana estuary in 2001, 2002, 2008 and 2009.

Table 4. One-way ANOVA results (*p* values) of estuary zones across years and years across estuary zones.

	Variable	*p* value
Across years	Lower estuary	0.933
	Middle estuary	0.162
	Upper estuary	*
Across zones	2001	0.333
	2002	0.200
	2008	0.067
	2009	0.333

* $p < 0.05$

Discussion

The decrease in freshwater flows and nutrient loading reduces the primary productivity in downstream ecosystems and the coastal zone (Sklar & Browder, 1998). Moreover, a general decreasing trend of primary productivity has been described in the Guadiana estuary since 2002 (Barbosa et al., 2009).

Important changes in the community of crustacean decapods were detected in the Guadiana estuary among sampling years and also within estuary zones. A significant increase in total density was recorded after the construction of the Alqueva dam in 2002 and a shift of the community to upper zones of the estuary. On the other hand, the decrease in species evenness reflects the decrease in number of species identified in the two latter years.

Some of the shrimp species here represented can compete for food resources (González-Ortegón & Cuesta, 2006; González-Ortegón et al., 2007). It is reasonable to hypothesize that the shift of species abundance to the upper zones of the estuary could have also contributed to increased competition (for food/habitat) within the estuarine nursery areas and with other resident species. The non-native *P. macrodactylus* is already present in many estuarine ecosystems across Europe (Lavesque et al., 2010) and was recorded for the first time in the Guadiana in 2008 (Chícharo et al., 2009) and in 2009 its density and distribution increased along the estuary. Although no ecological impacts have been identified in European waters so far, this is a powerful invader and therefore may further threaten the diversity of decapods (Micu & Niță, 2009; González-Ortegón et al., 2010a; Lavesque et al., 2010). *P. macrodactylus* can compete for resources with *P. longirostris* as their trophic levels are the same, but the non-native species is more tolerant to environmental variables, like hypoxia, than the native caridean shrimps (González-Ortegón et al., 2010a). It is, therefore, important to monitor this species in the following years, in order to understand if native species are being affected by this non-native *Palaemon* species, as already highlighted (Chícharo et al., 2009; Lavesque et al., 2010).

Table 5. Result from the BIO-ENV procedure applied on density of decapods from the Guadiana estuary (Cut-off for correlations under 0.270).

Correlation	Best variable combinations
0.375	River flow
0.331	Salinity; Secchi; River flow
0.313	Salinity; River flow
0.307	Salinity; Secchi; NAO; River flow
0.303	Secchi; River flow
0.280	Temperature; River flow
0.273	Temperature; Salinity; Secchi; River flow
0.271	Salinity; Secchi; NAO

These sifts in the decapod community might be explained by river inflow regularization (Bunn & Arthington, 2002) and its effects on other environmental variables, but also by climatic changes linked to the NAO index (Erzini, 2005; González-Ortegón et al., 2010b). In fact, these variations were reflected by changes in salinity, turbidity and temperature with an important influence on the structure of the decapod assemblage of the Guadiana estuary. The effect of reduced freshwater inflow and consecutive increase in salinity, has already showed to impact fish assemblages, namely their abundance, biomass and distribution, and may further be amplified by drought years (Chícharo et al., 2006b). The increased salinity seemed to be one of the more important changes and resulted from the decrease in river flow. The relation was shown by negative correlations of 0.5 in middle and upper estuary. The changes in salinity were more obvious in the upper (0.4 ± 0.2 in 2001 to 9.9 ± 7.0 in 2009) and middle (6.5 ± 5.4 in 2001 to 24.3 ± 9.3 in 2009) estuary. These changes probably allowed the colonization of these two areas by the non-native marine species *P. macrodactylus*, the native resident *P. longirostris*, the native migrant *C. crangon* and the marine *C. maenas*, in an area that was usually characterized by freshwater species. For fish assemblages, the observed reduction of freshwater inflow reduced the amount of habitat available to the native freshwater species (Chícharo et al., 2006b), and the same might have occurred for decapod species.

The increase in total density in the middle and upper estuary in the latter two years of the study shows that these species have been able to colonize new habitats and compete with the resident fauna.

Conclusions

Following construction of the Alqueva dam, the decapod assemblages in the Guadiana estuary changed. The decapod assemblages shifted to upper zones of the estuary and also increasing in density. These changes were more significant in the upper estuary, where the non-native *P. macrodactylus* was firstly identified in 2008, increasing his density and distribution across the estuary in 2009. These changes were mainly due to the reduction of freshwater flow that led to an increase in salinity.

The identified modifications in the decapod assemblages, makes it important to intensively monitor the estuary to allow distinguishing, as far as possible, natural changes from anthropogenic impacts resulting from dam operation and the possible inadequacy of the river flow management solutions implemented.

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References

Ashelby C.W., Worsfold T.M. & Fransen C.H.J.M. 2004. First records of the oriental prawn *Palaemon macrodactylus* (Decapoda: Caridea), an alien species in European waters, with a revised key to British Palaemonidae. *Journal of the Marine Biological Association of the United Kingdom,* **84**: 1041-1050.

Barbosa A.B., Domingues R.B. & Galvão H.M. 2009. Environmental forcing of phytoplankton in a Mediterranean estuary (Guadiana Estuary, south-western Iberia): a decadal study of anthropogenic and climatic influences. *Estuaries and Coasts,* **33**: 324-341.

Beguer M., Girardin M. & Boët P. 2007. First record of the invasive oriental shrimp *Palaemon macrodactylus* Rathbun, 1902 in France (Gironde Estuary). *Aquatic Invasions,* **2**: 132-136.

Bunn S.E. & Arthington A.H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management,* **30**: 492-507.

Chícharo L., Chícharo M.A. & Ben-Hamadou R. 2006a. Use of a hydrotechnical infrastructure (Alqueva Dam) to regulate planktonic assemblages in the Guadiana estuary: Basis for sustainable water and ecosystem services management. *Estuarine, Coastal and Shelf Science,* **70**: 3-18.

Chícharo L., Chícharo M.A., Esteves E., Andrade J.P. & Morais P. 2001a. Effects of alterations in fresh water supply on the abundance and distribution of *Engraulis encrasicolus* in the Guadiana estuary and adjacent coastal areas of south Portugal. *Ecohydrology and Hydrobiology,* **1**: 341-345.

Chícharo M.A., Chícharo L., Galvão H., Barbosa A., Marques M.H., Andrade J.P., Esteves E., Miguel C. & Gouveia C. 2001b. Status of the Guadiana estuary (South Portugal) during 1996-1998: an ecohydrological approach. *Aquatic Ecosystem Health and Management,* **4**: 1-17.

Chícharo M.A., Chícharo L. & Morais P. 2006b. Inter-annual differences of ichthyofauna structure of the Guadiana estuary and adjacent coastal area (SE Portugal/SW Spain): Before and after Alqueva dam construction. *Estuarine, Coastal and Shelf Science,* **70**: 39-51.

Chícharo M.A., Leitão T., Range P., Gutierrez C., Morales J., Morais P. & Chícharo L. 2009. Alien species in the Guadiana Estuary (SE-Portugal/SW-Spain): *Blackfordia virginica* (Cnidaria, Hydrozoa) and *Palaemon macrodactylus* (Crustacea, Decapoda): potential impacts and mitigation measures. *Aquatic Invasions,* **4**: 501-506.

Cottiglia M. 1983. *Crostacei decapodi lagunari*. Consiglio Nazionale delle Ricerche. Genova. 147 pp.

Cuesta J.A., Gonzàlez-Ortegó E., Rodríguez A., Baldó F., Vilas C. & Drake P. 2006. The decapod crustacean community of the Guadalquivir Estuary (SW Spain): seasonal and inter-year changes in community structure. *Hydrobiologia,* **557**: 85-95.

Dauer D.M. 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. *Marine Pollution Bulletin,* **26**: 249-257.

Dias P., Morais P., Leopold M., Campos J. & Antunes C. 2012. Natural born indicators: great cormorant *Phalacrocorax carbo* (Aves: Phalacrocoracidae) as monitors of river runoff influence on estuarine ichthyofauna. *Journal of Sea Research,* **73**: 101-108.

Domingues R.B., Barbosa A. & Galvão H. 2005. Nutrients, light and phytoplankton succession in a temperate estuary (the Guadiana, south-western Iberia). *Estuarine, Coastal and Shelf Science,* **64**: 249-260.

Erzini K. 2005. Trends in NE Atlantic landings (southern Portugal): identifying the relative importance of fisheries and environmental variables. *Fisheries Oceanography,* **14**: 195-209.

Faria A., Morais P. & Chícharo M.A. 2006. Ichthyoplankton dynamics in the Guadiana estuary and adjacent coastal area, South-East Portugal. *Estuarine, Coastal and Shelf Science,* **70**: 85-97.

Fischer W., Bauchot M.L. & Schnieider M. 1987. *Fiches FAO d'identification des espèces pour les besoins de la pêche: Méditerranée et Mer Noir (zone de pêche 37). Volume 2: Vertébrés*. Publication préparée par la FAO, résultant d'un accord entre la FAO et la Commission des Communautés européennes (Projet GCP/INT/422/EEC) et financée conjointement par ces deux organisation, Rome. 1529 pp

González-Ortegón E. & Cuesta J.A. 2006. An illustrated key to species of Palaemon and Palaemonetes (Crustacea: Decapoda: Caridea) from European waters, including the alien species *Palaemon macrodactylus*. *Journal Marine Biology,* **86**: 93-102.

González-Ortegón E., Cuesta J.A., Pascual E. & Drake P. 2010a. Assessment of the interaction between the white shrimp, *Palaemon longirostris*, and the exotic oriental shrimp, *Palaemon macrodactylus*, in a European estuary (SW Spain). *Biological Invasions,* **12**: 1731-1745.

González-Ortegón E., Cuesta J.A. & Schubart C.D. 2007. First report of the oriental shrimp *Palaemon macrodactylus* Rathbun, 1902 (Decapoda, Caridea, Palaemonidae) from German waters. *Helgoland Marine Research,* **61**: 67-69.

González-Ortegón E., Subida M.D., Cuesta J.A., Arias A.M., Fernández-Delgado C. & Drake P. 2010b. The impact of extreme turbidity events on the nursery function of a temperate European estuary with regulated freshwater inflow. *Estuarine, Coastal and Shelf Science,* **87**: 311-324.

Gurriarán E.G. & Méndez G.M. 1985. *Crustáceos decápodos das Costas de Galicia. I. Brachyura. Cadernos na Área de Ciências Biolóxicas, Seminário de Estudos Galegos*. Ediciós do Castro, Vol. 2. A Coruña. 242 pp.

Hayward P.J. & Ryland J.S. 1990. *The marine fauna of the British Isles and North-West Europe. Vol. I: Introduction and Protozoans to Arthropods*. Clarendon Press: Oxford. 671 pp.

INAG (Instituto Nacional da Água) **2012.** http://www.inag.pt.

Ingle R.W. 1996. Shallow-water crabs. In: *Synopses of the British Fauna (New Series). Nº 25 (2nd ed)* (R.S.K. Barnes, & J.H. Crothers eds), pp. 243. Field Studies Council: Great Britain.

Lavesque N., Bachelet G., Béguer M., Girardin M., Lepage M., Blanchet H., Sorbe J., Modéran J., Sauriau P. & Auby I. 2010. Recent expansion of the oriental shrimp *Palaemon macrodactylus* (Crustacea: Decapoda) on the western coasts of France. *Aquatic Invasions,* **5**: S103-S108.

Levinton J.S. 2001. *Marine Biology: Function, Biodiversity, Ecology*. 2nd Ed. Oxford University Press: New York. 515 pp.

Micu D. & Niță V. 2009. First record of the Asian prawn *Palaemon macrodactylus* Rathbun, 1902 (Caridea: Palaemonoidea: Palaemonidae) from the Black Sea. *Aquatic Invasions,* **4**: 597-604.

Montagna P.A., Kalke R.D. & Ritter C. 2002. Effect of restored freshwater inflow on macrofauna and meiofauna in upper Rincon Bayou, Texas, USA. *Estuaries,* **25**: 1436-1447.

Morais P. 2008. Review on the major ecosystem impacts caused by damming and watershed development in an Iberian basin (SW-Europe): focus on the Guadiana estuary. *Annales de Limnologie - International Journal of Limnology,* **44**: 105-117.

Morais P., Chícharo M. A. & Chícharo L. 2009. Changes in a temperate estuary during the filling of the biggest European dam. *Science of The Total Environment,* **407**: 2245-2259.

NCAR (National Center for Atmospheric Research) **2012.** http://climatedataguide.ucar.edu/guidance/hurrell-north-atlantic-oscillation-nao-index-station-based.

Nedwell D.B. & Raffaelli D.G. 1999. *Advances in Ecological Research: Estuaries.* Academic Press, **29**. 306 pp.

Nixon S.W., Olsen S.B., Buckley E. & Fulweiler R. 2004. Lost to the tide. The importance of freshwater flow to estuaries. Final report submitted to the coastal resources center. *Narragansett, RI: University of Rhode Island, Graduate School of Oceanography*, **14**. 30 pp.

Pearson T. & Rosenberg R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Annual Review,* **16**: 229-311.

Rosenberg D.M. & Resh V.H. 1993. *Freshwater biomonitoring and benthic macroinvertebrates*. Chapman & Hall: New York. 488 pp.

Sanchez-Moyano E.J. & Garcia-Asencio I. 2010. Crustacean assemblages in a polluted estuary from South-Western Spain. *Marine Pollution Bulletin,* **60**: 1890-1897.

Sanchez-Moyano E.J. & Garcia-Asencio I. 2011. Crustacean assemblages along the Guadiana River estuary (south-western Iberian Peninsula). *Journal of the Marine Biological Association of the United Kingdom,* **91**: 127-138.

Sklar F. & Browder J. 1998. Coastal environmental impacts brought about by alterations to freshwater flow in the Gulf of Mexico. *Environmental Management,* **22**: 547-562.

Smaldon G., Holthuis L.B. & Fransen C.H.J.M. 1993. Coastal shrimps and prawns. In: *Synopses of the British Fauna (New Series). Nº 15 (2nd Edition)* (R.S.K. Barnes & J.H. Crothers eds), pp. 1-142. Field Studies Council: Great Britain. 142 pp.

Van Hoey G., Borja A., Birchenough S., Buhl-Mortensen L., Degraer S., Fleischer D., Kerckhof F., Magni P., Muxika I., Reiss H., Schröder A. & Zettler M. 2010. The use of benthic indicators in Europe: from the Water Framework Directive to the Marine Strategy Framework Directive. *Marine Pollution Bulletin,* **60**: 2187-2196.

Varandas S.G. & Cortes R.M. V. 2010. Evaluating macroinvertebrate biological metrics for ecological assessment of streams in northern Portugal. *Environmental Monitoring and Assessment,* **166**: 201-221.

Wolanski E., Chícharo L., Chícharo M.A. & Morais P. 2006. An ecohydrology model of the Guadiana Estuary (South Portugal). *Estuarine, Coastal and Shelf Science,* **70**: 132-143.