Ecology of megabenthic bivalve communities from sandy beaches on the south coast of Portugal

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SUMMARY: Ecological aspects of 75 megabenthic bivalve species found on the south coast of Portugal (from Vila Real to Sagres) were studied based on the information provided by seasonal bivalve surveys from 2000 to 2007 (8600 hauls, simultaneously using a razor shell dredge and a clam dredge). Of the 75 species identified, 36 occurred less than 30 times, and thus were considered rare in the area. The remaining 39 bivalves were analysed according to their occurrence, bathymetric distribution, geographic preferences, seasonal preferences, burying-depth, beach exposure and river mouth proximity. All species belonging to the Pharidae and Solenidae families (razor shells) and most Tellinidae were significantly more frequent in the razor shell dredge (indicating deeper burying in the sediment), whilst the families Cardiidae and Donacidae were significantly more frequent in the clam dredge (indicating that these species are probably closer to the sediment surface). As for the season, most bivalve species occurred similarly in both seasons (19 sp; 49%), but a large proportion were more abundant during the autumn surveys (17 sp, 44%), whereas only three species were commoner during the spring surveys. Most species belonging to the families Cardiidae and Mactridae were commoner in the autumn surveys. The spatial distribution differed between species and cluster analysis identified four communities with greater geographic affinity. Species belonging to the family Cardiidae were preferably found in the western part (WB) and the eastern part (S) of the study area, whereas the families Donacidae, Mactridae and Tellinidae occurred mainly in the central area (EB) and the eastern (S) coastal sectors. Overall, shallower species (modal depth at 3-6 m) showed greater occurrences and abundances than the deeper ones, and the depth pattern observed did not change between seasons. Donacidae and Mactridae (except Mactra glauca) were represented essentially by shallow species, whereas Cardiidae (except Acanthocardia tuberculata and Cerastoderma edule) included mostly species occurring in deeper waters. Bathymetric sequence of species distribution within some families was observed.

Keywords: bivalves, geographic distribution, bathymetric distribution, beach morphology, river proximity.

RESUMEN: ECOLOGÍA DE COMUNIDADES DE BIVALVOS MEGABENTÓNICOS EN PLAYAS DE ARENA DE LA COSTA MERIDIONAL DE PORTUGAL. – Se estudiaron algunos aspectos ecológicos de 75 especies de bivalvos megabentónicos en la costa meridional de Portugal (desde Vila Real a Sagres), basados en la información obtenida a lo largo de varios muestreos estacionales realizados entre el año 2000 y 2007 (8600 muestras). Las muestras se obtuvieron utilizando simultáneamente un rastro para capturar navajas y un rastro para capturar almejas). De los 75 taxones identificados, 36 aparecieron menos de 30 veces, considerándose raros en el área. De los 39 taxones de bivalvos restantes se analizaron sus patrones de presencia, distribución bathimétrica, preferencias geográficas y estacionalidad y se relacionaron con la profundidad de enterramiento, la exposición de las playas y la proximidad a desembocaduras de ríos. Todas las especies de las familias Pharidae, Solenidae (navajas) y la mayor parte de Tellinidae fueron más frecuentes en el rastro para capturar navajas, indicando una mayor profundidad de enterramiento en el sedimento, mientras que las familias Cardiidae y Donacidae fueron significativamente más frecuentes en el rastro para capturar almejas, indicando que estas especies se encuentran más cercanas a la superficie del sedimento. La mayoría de especies presentaron abundancias similares a lo largo de todo el año (19 especies, 49%), pero una gran proporción fueron más abundantes en los muestreos de otoño (17 especies, 44%), mientras que sólo 3 especies fueron más comunes en primavera. La mayoría de especies de las familias Cardiidae y Mactridae fueron más comunes en otoño. La distribución espacial fue distinta para cada especie y el análisis de clasificación jerárquica mostró 4 comunidades con mayor afinidad geográfica. Las especies pertenecientes a la familia Cardiidae se encontraron preferentemente en la parte occidental de la zona de estudio (WB) y en la oriental, mientras que las familias Donacidae, Mactridae y Tellinidae aparecieron principalmente en
INTRODUCTION

Faunistic studies provide essential tools for understanding the dynamics of exploited communities and accordingly other inter-specific relationships (Pearson and Mannvik, 1998; Teske and Wooldridge, 2001; Abelló et al., 2002; Laudien et al., 2007). Benthic communities have long been recognised as a good tool for monitoring either man-induced or natural long-term changes in marine ecosystems (Grémare et al., 1998). Coastal areas, which are particularly vulnerable due to the impact of tourism and associated activities, have a crucial importance to the communities and thus their conservation and management should be a priority.

Marine environmental impact/monitoring studies are usually done through macrofauna sampling, which involves expensive and laborious procedures (Thrush et al., 1994; Chicharo et al., 2002; Fugi, 2007; McBreen et al., 2008). Large bivalves are easier to sample and identify, they can be good biological indicators (Simboura and Zenetos, 2002) and many species are relatively short living (3-10 years), thus rapidly reflecting environmental changes (Guillou and Sauriau, 1985; Gaspar et al., 1999b; Zeichen et al., 2002). Additionally, bivalves constitute a large fraction of the littoral benthic communities and play essential roles in ecosystems as agents of sediment structuring (Reise, 2002), as a food item of many species (Ansell et al., 1999), and as contributors to biogenic sediment formation. Long term data series can provide valuable information on species ecology through the analysis of individual occurrences in relation to environmental variables.

The beach morphodynamics (breaking waves, tides and sediment) determine the morphology and slope of the beach as well as the circulation pattern (Harriague et al., 2006) and have a strong influence on the communities living there (McLachlan, 1990). Exposed sandy beaches support benthic fauna well-adapted to the physical rigours of these dynamic environments (McLachlan et al., 1995). These communities may be described by the auto-ecological hypothesis (Noy-Meir, 1979; McLachlan, 1990), which states that sandy beaches are physically controlled environments, where communities are structured by the independent responses of individual species to the physical environment, biological interactions being minimal (Defeo and McLachlan, 2005). Thus, by identifying the factors controlling individual species and determining their ecological response, one obtains a picture of the community (McLachlan et al., 1995). Among the main factors affecting sandy beach benthic fauna are beach morphology and river proximity (Dexter, 1992; Defeo and McLachlan, 2005; Cravo et al., 2006), which, though they do not constitute the environmental forces per se, are relatively easy to obtain and thus can be considered in most studies. Therefore the individual response of bivalve species to these aspects can be important for fisheries management and coastal areas protection.

A locally important bivalve dredge fishery takes place along the south coast of Portugal, targeting four species: Chamelea gallina, Spisula solida, Donax trunculus and Ensis siliqua. In order to manage this fishery, the Portuguese Institute for Fisheries Research (IPIMAR) has carried out bi-annual bivalve surveys since 1986, covering all sandy bottoms along the southern Portugal from the Mediterranean areas to the Atlantic ones (Gaspar, 1996; Gaspar et al., 1999a; Rufino et al., 2008). These surveys are a unique opportunity to delimit the geographic and bathymetric distribution and interrelationships of many species with a high degree of accuracy, given the duration of the surveys and the high sampling effort. Information on beach profile is available only for a small part of the surveyed area: some sites off the eastern part of the Algarve south coast (west side of the Ria Formosa: Garrão, Faro and Culatra, eastern south coast of Portugal), all showing a reflective profile with a steep upper foreshore and a more gentle low-tide terrace (Ciavola et al., 1997; Reyes et al., 1999). The predominant wave direction in the area is W/SW (90% of the year) (Costa, 1994). Wave height ranges from 0.30 m to 1.8 m, with rare exceptional heights of more than 3.7 m. Such high waves are associated with storms from the SW when waves attain an average height of 2–3 m with a pe-
period of 7–8 s (Pires, 1989; Moura et al., 2006, and ref. therein). The sampled area is characterised by sediments with a large range of grain sizes, from muddy areas on the outflow of the Guadiana river to the coarse sand found on western grounds. The most recent description of the sediments of the south coast of Portugal was made in 1986 (Moita, 1986).

The objectives of the present paper are: 1) to provide comprehensive data on species occurrence and abundance of the megabenthic bivalve soft-bottom coastal assemblages in S Portugal; and 2) to relate the geographical and bathymetric patterns described with ecological factors such as beach exposure, river proximity and burying depth.

MATERIAL AND METHODS

Study area and sampling

Bivalve surveys were carried out between 2000 and 2007 in both spring and autumn, except in 2003 (only spring was sampled) and 2004 (only autumn was sampled), with the RV Diplodus. During these surveys the sampling design was kept unchanged. The coast was subdivided into 108 transects perpendicular to the coastline, with a distance of ½ nautical mile between each other (Fig. 1). Each transect was established between 3 and 15 m depth, comprising 8 sampling stations distanced 1.8 m from each other (A: 3 m; B: 4.8 m; C: 6.6 m; D: 8.4 m; E: 10.2 m; F: 12 m; G: 13.8 m; H: 15.6 m). In each transect 2 to 4 stations were randomly chosen. During fishing operations, two dredges were used simultaneously, one adapted to razor clam fishing (dredge tooth length of 35 cm) and one designed for clam fishing (dredge tooth length of 20 cm); mesh size on both dredges was 25 mm. Further details on the dredges used can be found in Gaspar (1996; 2003). Dredges were towed for 5 min at a mean speed of 1.5 knots, sweeping an area of 144 m². Once onboard, the catch from each of the dredges was placed in a labelled plastic bag. The samples were later processed in the laboratory, where the bivalve species were identified to species level, counted, measured and weighed. In the present study data from 8600 samples were analysed. Species names followed CLEMAM nomenclature.

For the description of geographical patterns, the coast was divided into three sectors (Fig. 1): Sotavento (S) (from 7.3°W to 7.88°W longitude; transects 1-10); East Barlavento (EB) (from 7.88°W to 8.42°W longitude; transects 59-92); and Western Barlavento (WB) (from 8.42°W to 9.00°W longitude; transects 93-108) (Gaspar, 1996; Gaspar et al., 1999a; Gaspar et al., 2002b; Gaspar et al., 2003). For a finer geographic approach, these three sectors of the coast were further subdivided. Sotavento sec-
tor was subdivided into three sub-areas: 1) Guadi-
ana, around the delta of the Guadiana river (transects
1-10); 2) Tavira, from Cacela to Tavira (transects
11-26); and 3) ERia, between Tavira and Olhão
(transects 27-58). The EB sector was also subdivided
into three sub-areas: 4) WRia, West side of Ria For-
mosa (transects 59-76); 5) Quarteira, from the be-
ginning of Ria Formosa coastal lagoon to Quarteira
(transect 77-85); and 6) Vilamoura, from Vilamoura
to Olhos de Água (transect 86-92). In the WB sector,
sampling was carried out in three separate areas: off
7) Portimão (Delta of the river Arade, transects 93-
96); 8) Lagos, between Alvor and Lagos (transects
97-101); and 9) Salema, between Salema and Zavial
(transects 102-108). The location of all sectors and sub-
sectors is shown in Figure 1.

Beach exposure was calculated for the EB and S co-
astal sectors. Thus, the successive azimuths of the
3 m bathymetric line were estimated and for each
point an exposure index was calculated, in agreement
with the coast geographical direction (NE, E and SE)
(Nunes, 2007). According to the exposure index es-
timated (NE coast corresponded to a 0.47 exposure,
E to a 0.99 and SE to a 0.96 exposure), the area was
divided into high (E or SE direction, respectively
transects 1-14, 49-53 and 60-92) and low (NE direc-
tion, transects 15-48 and 54-59) beach exposure.

The river influence was determined by visually
selecting sedimentation areas surrounding the river
inlets/mouths, using both Google Earth (http://earth.
google.com/) and aerial ortho-photomaps of the
coast, for the EB and S Sectors. The sites outside/in-
side these areas were classified as having a low/high
river influence, respectively. Neither river influence
nor beach exposure was estimated for the WB area,
due to the sparseness of sampling points (this area is
not continuous sandy beach like the others, but it is
intercepted by rocky cliffs).

Data analysis

All species caught were classified according to
their global occurrence over the 7 years of sampling
into rare (species occurring less than 30 times dur-
ing all surveys, i.e. N<30 or less than 0.35% of oc-
currence) and common (N>30). For the commoner
species the percentage occurrence, median density
and significant differences across factors analysed,
.i.e. dredge type, season, beach exposure and river
influence (whether species occurred significantly
more in any factor level than in the remaining ones,
i.e. showed a preference), were estimated. The me-
dian was used (instead of the mean) due to the non-
Gaussian highly skewed nature of the data (typical
in such datasets). Percentage occurrence was calcu-
lated as the number of times the species occurred in
the respective factor level, divided by the number of
samples in the factor. Significant differences in oc-
currences were tested by applying a chi-squared test
on the number of times the species occurred in each
factor level, and using the total number of samples
within each factor level as prior probability.

Cluster analysis using the Bray-Curtis distance
matrix and the average agglomeration method was
applied to sub-areas and depth matrices of species
occurrences, in order to identify the main patterns in
species assemblages in relation to depth and geo-
graphy. Species occurrence within each of the main
clusters was calculated in relation to the environ-
mental factor. All analyses were performed using
the R-project software (R-project, 2006). Multivari-
ate methods were applied using the vegan package
(Oksanen et al., 2007).

RESULTS

During the 7 years of bivalve surveys on the
fishable grounds of the Algarve coast, 75 mega-
benthic bivalve species were identified, repre-
senting 25 families and 7 orders (Tables 1 and
2, Appendix 1). From these, 48% (36 species)
occurred less than 30 times over the 8600 hauls
(~0.3%) and were thus considered rare species
for the area/depth sampled in the study (Table 1).
Most of these occurred fewer than 10 times (26
species, 0.1% occurrence), with 12 appearing only
once. Among the 36 less common species, 11 oc-
curred only in the Sotavento area, 8 in Sotavento/
East Barlavento and 4 only in East Barlavento. No
species occurred exclusively in West Barlavento.
In relation to the dredge, 9 species were captured
only with bivalve dredge and 8 species with the
razor shell dredge (Table 1).

A more detailed analysis was performed for the
most common bivalves (52% of the species), i.e. spe-
cies occurring more than 30 times. Among these, the
commonest species were Chamelea gallina, Spisula
solida, Mactra stultorum, Acanthocardia tubercu-
lata and Donax trunculus. These bivalves occurred
more than 2000 times (i.e. in 21% of the samples).
Six species occurred 1000-2000 times and fourteen
species 100–1000 times. The remaining fourteen species, less than 100 times. The species that showed greatest density were Donax venustus followed by Chamelea gallina, Spisula solida, Acanthocardia paucicostata and Spisula subtruncata (Table 2).

### Burying depth

Two different dredges were used: one specific for razor clams, which has larger teeth and thus buries deeper into the substrate, and one for clams, equipped with shorter teeth and catching mainly species closer to the sediment surface. Thus, bivalve occurrence in each dredge may be used an indirect indicator of the maximum burying-depth of the species, by comparing the species occurrence for both dredges.

From the 39 species showing greatest occurrences, 13 species (33%) occurred similarly in both dredges, 15 species (38%) were significantly more frequent in the clam dredge (CD), i.e. closer to the sediment surface, and the other 11 species (28%) were significantly more frequent in the razor clam dredge (RD), suggesting that these species burrow deeper into the sediment (Fig. 2 and Table 2). All species belonging to the Pharidae and Solenidae families (razor shells) and most Tellinidae were significantly more frequent in the RD dredge, whilst the families Cardiidae and Donacidae were significantly more frequent in the CD dredge.

### Season

Although most bivalve species occurred similarly in both seasons (19 sp; 49%), a large proportion were more abundant in the autumn surveys (17 sp., 44%), whereas only three species were commoner during the spring surveys (Fig. 3 and Table 2). Most species belonging to the families Cardiidae and Mactridae were commoner in the autumn surveys (6 out of 7,
and 5 out of 5, respectively). All remaining bivalve families showed no seasonal trend.

**Spatial distribution, beach exposure and river influence**

All species showed significant differences in the occurrences between the areas, except *Cerastoderma edule*, *Chamelea striatula*, *Gari fervensis* and *Thracia papyracea* (Fig. 3A). All species occurred in the Sotavento sector, whereas *Pitar rudis* and *Acanthocardia paucicostata* were not found in EB, *Anomia ephippium* and *Chlamys flexuosa* were not present in WB. Species belonging to the family Cardiidae were preferably found in WB and S, whereas the families Donacidae, Mactridae and Tellinidae occurred mainly in the EB and S coastal sectors.

Cluster analysis identified four main groups of species with particular affinities according to geographic distribution (Fig. 3B). Group 1 contains 13 species that occurred mainly in the Guadiana outflow and vicinities; Group 2 contains 4 species that occurred mainly in Vilamoura and Tavira; Group 3 contains three species that occurred mainly in Selea and Lagos; and Group 4 contains 22 species distributed along the entire coast. The results of the cluster analysis are in agreement with Figure 3A.

Eleven species (28%) showed no significant statistical differences in function of beach exposure (Fig. 3 and Table 2), whereas eight (21%) were commoner in low exposed beaches and 20 (51%) species occurred significantly more in exposed areas. Species belonging to Mactridae and Veneridae were more frequent on more exposed beaches and tellinids preferred non-

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exposed coasts. Regarding river influence, 20 species (51%) were not significantly influenced by the distance to the river mouths, 11 species (28%) were more frequent outside the vicinity of river mouths and eight (21%) were significantly more common within the river sedimentation area (Fig. 2).

**Bathymetry**

Overall, shallower species with a modal depth at 3-6 m (Donax trunculus, Spisula solida, Ensis siliqua, Mactra stultorum and Chamelea gallina) showed greater occurrences and abundances than the deeper ones (Fig. 4). Bathymetric distribution was clearly unimodal in most species, although Spisula solida, Tellina tenuis, Dosinia exoleta, Thracia papyracea, Donax variegatus and Claasinella fasciata appeared to have a second peak in bathymetric distribution.

In general the depth distribution patterns observed did not change between seasons (Table 2, Fig. 4A). Nevertheless, some species (e.g. Anomia ephippium, Acanthocardia paucicostata and A. aculeata) appeared to have a bathymetric shift over the modal class, from depth E (10.2 m) in spring...
Fig. 3. – A, bivalve species occurrence (%) across the sub-areas on the south coast of Portugal (see the text for further details). The colour of the bars corresponds to species median density (N.m⁻²), which can be seen in the top right corner. B, cluster analysis of species/subareas standardised matrices and respective boxplots for the cluster composition. See Table 2 for complete species names.
Fig. 4. – A, bivalve species occurrence (log % +1) by depth interval. The bars represent overall occurrence and the lines show seasonal occurrences (continuous line for autumn surveys; dashed line for spring surveys). The plots are ordered first by species modal depth, then by maximum level of occurrence. B, cluster analysis of species/depths intervals standardised matrices and respective boxplots for the clusters composition. See Table 2 for complete species names.
to depth F (12 m) in autumn. Some species showed a similar occurrence pattern in spring and autumn surveys, whereas others appeared to undertake some kind of seasonal bathymetric migration. Both occurrence peaks of *Solen marginatus* were deeper in the autumn surveys (from 4.8/8.4 m in spring to 6.6/10.2 m in autumn). *Spisula elliptica* showed greater occurrences at 4.8/6.6 m in autumn and at 3/10.2 m in spring. *Chamelea striatula* peaks were shallower in autumn and appeared to occur deeper in spring, similarly to *Anomia ephippium*, *Pandora inaequivalvis* and *Ostrea edulis* (Table 2, Fig. 4a).

Four main groups were identified by cluster analysis applied to the bathymetric distributions (Fig. 4b). Cluster 1 contained 6 species that occurred mainly in shallow waters, between 3 and 6.6 m (A-C) water depth, Cluster 2 contained 17 species that showed a wide depth distribution from 3 to 10.2 m (A-E), Cluster 3 contained 17 bivalve species that were mostly distributed between 6.6 and 15.6 m depth (D-H) and Cluster 4 contained only two species that mainly occurred between 12 and 15.6 m (F-H) depth.

Donacidae and Mactridae (except *Mactra glauca*) were represented mostly by shallow species, whereas Cardiidae (except *Acanthocardia tuberculata* and *Cerastoderma edule*) were represented mostly by species occurring in deeper waters (Table 2, Fig. 5). Some genera showed a sequential bathymetric distribution of the modal class. For example, the genus *Acanthocardia*, with relatively large and hard shells, showed a bathymetric sequence of species maximum occurrences, from the shallower *A. tuberculata* (A-D) followed by *A. aculeata* (D-F), *A. paucicostata* (E-G, with maximum at E) and *A. echinata* (E-G, with maximum at G) towards the deepest species, *A. spinosa* (G-H). The species belonging to the genus *Donax*, were all shallow species, but also showed sequential maximum occurrences, from shallower to deeper distribution: *D. trunculus*, *D. vittatus*, *D. semistriatus* and *D. variegatus*. Within the razor clams species, *Ensis siliqua* was the shallower species (mainly A-B), followed by *Pharus legumen* (mainly B-C) and *Ensis ensis* in deeper waters (C-H), although with large differences in

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**Fig. 5.** – Bathymetric distribution of the most common species by family. See Table 2 for complete species names.
occurrences. In the family Tellinidae, the shallow *Tellina tenuis* was replaced by *T. incarnata* and *Arcopagia crassa* in deeper waters. The families Mactridae and Veneridae, the most important in number of species, formed a more heterogeneous group. *Chamelea gallina* and *C. striatula* are two closely resembling species; the former, inhabiting shallower waters (maximum occurrences at 4.8 m), is distributed mainly in the Mediterranean, whereas the latter occurs mainly in deeper waters (maximum occurrences at 10.2 m) and is commoner in the northeastern Atlantic. Among the venerids, *Callista chione* has the largest and hardest shell, and this species occurs in deeper waters, peaking both at 10.2 and at 15.6 m depth. Both *Dosinia exoleta/D. lupinus* and *Clausinella fasciata/C. bronniartii* showed very similar depth distributions, although the first genus was shallower than the second one. Within Mactridae, all *Spisula* species and *Mactra stultorum* showed a similar shallower depth distribution, followed by *Mactra glauca*, peaking at 8.4-10.2 m. However, the occurrences of these species were largely different, i.e. *Spisula solida* showed a maximum of 56% occurrences, *S. subtruncata* 23% and *S. elliptica* only 3%. Similarly, *Mactra stultorum* maximum occurrences were 56.8%.

In the remaining species belonging to other families, *Corbula gibba*, *Ostrea edulis* and *Anomia ephippium* showed similar bathymetric distributions, occurring mainly from 10.2 to 13.8 m depth. The large and thin species *Gari fervensis* (Family Psammodiidae) and *Lutraria angustior* (Family Mactridae), which have similar shapes, showed a distinct bathymetric distribution, with the former occurring in shallow waters and the latter occurring in deeper waters. The fragile *Pandora inaequivalvis* showed a shallow distribution.

**DISCUSSION**

The coastal area under study constitute a pas-sage from the Atlantic to the Mediterranean, thus representing a bio-geographic transition in which changes in species composition and abundance are of particular importance. The existence of a well-documented upwelling close to the western part of the sampling area is expected to be reflected in the abundance of most coastal species (Erzini, 2005). Most species identified (*Acanthocardia aculeata*, *Acanthocardia paucicostata*, *Acanthocardia tuberculata*, *Callista chione*, *Clausinella fasciata*, *C. striatula*, *Donax variegatus*, *Dosinia lupinus*, *Ensis silicula*, *Ensis laevicardium crassum*, *Lutraria lutraria*, *Modiolus adriaticus*, *Modiolus sp.*, *Ostrea edulis*, *Pandora inaequivalvis*, *Spisula elliptica*, *Spisula solida*, *Tellina fabula*, *Tellina incarnata* and *Tapes rhomboides*) have their northern geographic limit of distribution in Norway, Iceland or the British Isles and have their southern limit near Morocco or in the Iberian Peninsula. The remaining species (*Anomia ephippium*, *Arcopagia crassa*, *Cerastoderma edule*, *Corbula gibba*, *Donax trunculus*, *Donax vittatus*, *Dosinia exoleta*, *Gari fervensis*, *Lutraria angustior*, *Pharus legumen*, *Solen marginatus*, *Spisula subtruncata* and *Tellina tenuis*) have a wider geographic distribution, and are present from the northern hemisphere (Norway, Iceland and the UK) to central Africa. Other species (*Acanthocardia spinosa*, *Donax semistriatus*, *Donax venustus*, *Flexopecten flexuosus*, *Gouldia minima*, *Macoma melo*, *Mytilus galloprovincialis* and *Venus cassina*) are found in the Iberian Peninsula, including the Mediterranean Sea. *Chamelea gallina* is found mainly in the Mediterranean, having its limit in the Algarve (Backeljau et al., 1994; Rufino et al., 2007). Finally, *Pitar rudis* is a more tropical species, being distributed from Spain to Angola and in the Mediterranean Sea (Macedo et al., 1999).

Between 2000 and 2007, 75 megabenthic bivalve species were caught in the dredging along the Algarve coast. Of these, 48% occurred fewer than 30 times, which may be related to aspects such as the sampling techniques (e.g. small specimens are certainly under-estimated), bathymetry (e.g. some species in the current work have their bathymetric limits deeper from the 15 m surveyed) and/or depth in the sediment (deeper buriers were probably underestimated), type of substrate (e.g. *Mytilus galloprovincialis*, as well as *Ostrea edulis* and *Anomia ephippium* typically occur in rocky areas, which were not covered in the current surveys) and/or specimen fragility (e.g. the strong metal dredges can severely damage thinner/more fragile shells such as those of *Barnea candida* and *Tellina spp.*). Chicharo et al. (2002), sampling with quadrats sieved through a 1 mm mesh (for macrofauna) and corers (for meiofauna) at 7-9 m depth off Lagos and Vilamoura (western coast of the Algarve), identified 38 bivalve species, among which 7 were not collected in the current study. Within the commonest species, occurring in >21% of the samples, were the commer-
cial species *Chamelea gallina*, *Spisula solida*, *Donax trunculus* and *Ensis siliqua*. This result was expected since the surveys were designed to evaluate the stock status of these species and within the surveyed area these species are the most common bivalves.

Burying depth into the sediment has important consequences for species ecology (Zwarts, 1986). Living closer to the sediment surface may increase the susceptibility of animals to predators and to being flushed away. However, it is also advantageous: suspension feeding is more efficient for physical reasons and deposit feeding is more profitable as a longer part of the siphon can be stretched over the surface, thus increasing the feeding radius (De Goeij and Luttikhuiizen, 1998, and ref. therein). For these reasons, the depth at which a bivalve is buried appears to be a compromise between the risks of starvation and predation, but it is also affected by oxygen deficiency and sediment characteristics (Zwarts, 1986; Zwarts and Wanink, 1989; Tallqvist, 2001). Also, as burying depth is actively controlled by the animal, it may change between areas, seasons and environmental gradients (De Goeij and Luttikhuiizen, 1998).

Overall, about one third of the species were captured with both dredges; one third was caught with CD so they must be less buried; and the remaining species were caught mainly with the RD dredge so they must be buried more deeply in the sediment.

In the current study, species from the families Cardiidae and Donacidae were mostly shallow burrowers. Species belonging to the former family have a rounded/globose shell shape, with fairly small siphons and a strong muscular foot; they avoid predators by jumping and some species may even show a limited swimming capability (Savazzi, 1985). Further, Cardiidae shell sculpture may increase/facilitate anchoring in the sediment (Watters, 1994), thus avoiding the problem of being flushed away easily. Donacidae species are small and flat-shaped and have relatively elongated shells, being able to live within the swash zone (Huz et al., 2002). Donacids were found mainly in a shallower bathymetry (<10 m depth). They occupied the swash area, thus being subject to tides and desiccation, although their rapid burying allows them to avoid the problems associated with this type of habitat (McLachlan and Young, 1982). Most species from the family Tellinidae and all species from the families Pharidae and Solenidae were more frequently caught by the RD dredge. In the case of tellinids, the species observed in the catches have characteristically thin and fragile shells, so burying deeper could provide an extra protection. Species from the other two families, Pharidae and Solenidae, have elongated shells which easily dig into the sediment like a razor blade. Urban (1994) concluded that species with an elongated shape, such as *Ensis* spp., spend less energy in burrowing, being adapted to deeper burying.

Most bivalve species did not show marked seasonal differences. Seventeen species were commoner in the autumn surveys and three in the spring surveys (44% mainly in autumn, 49% in both seasons and 8% mainly in spring). Braziero and Defeo (1996) observed that beach species tended to occupy the upper levels of their distributional areas in spring-summer and the lower levels in autumn-winter. Therefore, it is possible that the greater abundance of some species in autumn is related to species occupying the lower limit of their distribution. Seasonal changes in burying depth, which have been reported for some bivalve species (Zwarts and Wanink, 1989), may also cause such differences. For example, the increase in storm events in autumn-winter can lead to both changes in burying behaviour and sediment movements that cause differences in species catchability. Neuberger Cywiak et al. (1990) concluded that the migration observed in *Donax semistratus* to the beach upper zone took place as a result of heavy storms and currents. Some species can perform seasonal bathymetric migrations while others are known to perform migrations during their life cycle, from a couple of metres to many kilometres (Hiddink et al., 2002; Hiddink and Wolff, 2002; Gibson, 2003). Recruitment could also influence seasonal differences in bivalve abundance. Still, the life cycles are studied mainly for commercial species in the current area: *Chamelea striatula* spawning occurs between April and early August and *Donax trunculus* between March and August (Gaspar and Monteiro, 1998; Gaspar et al., 1999b). Both species occurred significantly more in the spring surveys of the present study, which correspond to the spawning season.

Most of the species studied were commoner in more exposed coastal areas than in less exposed areas. Most previous studies focus on beaches whose limits are not exactly the ones of the study area, but as they are a part of it, some features could be comparable (McLachlan and Dorvlo, 2007a, b). Bivalves from reflective beaches were found to be uniformly small, medium- to fast-burrowing, wedge-shaped and of high density, whereas those from more dissipative beaches vary widely in all these characteristics (McLachlan et al., 1995). The three beaches charac-
terised in terms of morphology on the south coast of Portugal all showed a reflective profile (Garão, Faro and Culatra), with wave heights of 0.34-0.8 m and sediment grain sizes of 0.26-0.38 mm (Ciavola et al., 1997). These three beaches probably represent an intermediate profile within the study area, but no further study was found. Towards the Guadiana river, as the grain size decreases the beaches may be more dissipative. In one way, more exposed beaches might have a greater turnover of nutrients, which is favourable to suspensivorous species, but higher beach exposure results in a more hydrodynamic environment and therefore lower sediment stability of the sediment (i.e. species can be flushed away).

Twenty-eight percent of the species were significantly more frequent outside areas of river influence. The influence of river presence on the south coast of Portugal is more important in the case of the Guadiana River, which is the most important one in the study area and showed the highest bivalve diversity (Rufino et al., 2008). River flow rate is known to influence the bivalve communities nearby. Ambrogi and Ambrogi (1987) observed the highest recruitment of Spisula subtruncata in years with the greatest river flow rates, whereas Schoeman and Richardson (2002) observed that recruits of Donax serra were more abundant in areas further from the main river mouth vicinity. Due to river sedimentation any animal buried in the sediment close to a river mouth will have progressively more sediment above it, especially during rainy periods. Another factor that may interfere is the presence of a water treatment plant in the area (Rufino et al., 2008). Most effluents are discharged into rivers, which transport not only organic matter but also undesirable pollutants that could be harmful to the species living nearby (Cabaço et al., 2008).

All species except Pitar rudis and Acanthocardia paucicostata, which were not found in EB, and Anomia ephippium, Chlamys flexuosa and Macoma melo, which were not present in WB, were found all over the coastal area studied. Cluster analysis classified species according to their occurrence in different geographic sectors, distinguishing 10 species typical from Sotavento, three from WB and six from EB. Nevertheless, the geographic trends observed are related to environmental differences between areas rather than to biogeographic trends. Of the 10 species occurring mainly in S, most were found around the outflow area of the Guadiana river (these species were not commoner within the river vicinity, but were specifically found in the Guadiana). The Guadiana delta has the largest extension of muddy sediments on this part of the Portuguese coast and most of these species (Acanthocardia aculeata, A. paucicostata, Anomia ephippium, Corbula gibba, Dosinia lupinus, Pandora inaequivalvis and Pitar rudis) are probably typical inhabitants of this type of sediment. Similarly, the area between Vilamoura and Quarteira has coarser sediments, which corresponded to larger occurrences of three species typical of this sediment type (Clausinella brongniartii, Clausinella fasciata and Dosinia exoleta). Arcopagia crassa, Donax variegatus and Macrta glauca, which were found preferentially on S coastal sector and were not caught in the muddier sediments, were also found in large percentages between Vilamoura and Quarteira, where there is also a river outflow (Ribeira de Quarteira). Thus, rivers outflows are probably the primary factor contributing to the presence of these four species.

Depth is an important factor structuring the community (Abelló et al., 2002; McBreen et al., 2008). Although the majority of the species showed a clearly unimodal bathymetric distribution, some species appeared to have a bimodal distribution in depth (Spisula solida, Tellina tenuis, Dosinia exoleta, Thracia papyracea, Donax variegatus and Clausinella fasciata). The shallowest species also showed the greatest occurrences and abundances, so overall occurrence/abundance decreased with depth. The bathymetric patterns observed did not change greatly between seasons. Furthermore, some species may show a depth segregation between adults and juveniles, as is the case of Donax trunculus (Gaspar et al., 2002a). Therefore, in the case of species with a broad bathymetric distribution in which this phenomenon is observed, the survey design adopted only allows the sampling of a fraction of the population. For example, Lutraria angustior was caught in samples taken below 10.2 m depth with a mean size of 45 mm SL, although it is reported in the literature that this species reaches 118 mm SL and may occur to a maximum depth of 55 m (Macedo et al., 1999).

Thus, the area under study shows a large diversity of geographical aspects representing specific environmental characteristic that may influence bivalve species. Among those that have been proven to be important are the river influence (mainly in the Guadiana delta; (Erzini, 2005; Cravo et al., 2006)), the inlets of the Ria Formosa coastal lagoon (Vila-Concejo et al., 2002; Vila-Concejo et al., 2006)).
2003; Newton and Mudge, 2005; Vila-Concejo et al., 2006), no river/inlet influence, and more/less exposed areas (according to the dominant coastal currents). During the seven years of data presented, some of the factors considered (river/inlet proximity and wave exposure) may have changed their exact values slightly. However, the current work provides an initial approach towards the potential influence of such factors on bivalve abundance and distribution. For a more specific analysis on those relationships, further studies specifically designed for such purpose are required.

Coastal bivalves are economically important for local populations in terms of fisheries resources and tourism, among others. However, these groups are severely impacted by anthropogenic sources, so their conservation and management should be a priority for marine resource managers. The information provided in the current paper about species ecology adds further basic knowledge that can be used to improve the difficult task of preserving the coastal area of the Algarve.

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Appendix 1. – Bivalve species caught during the surveys carried out between 2000 and 2006 along the south coast of Portugal.

Subclass ANOMALODESMATA
  O. PHOLADOMYOIDA
  Fam. LYONSIIDAE
  *Lyonia norwegica* (Gmelin, 1791)
  Fam. PANDORIDAE
  *Pandora bicaudalis* (Linnaeus, 1758)
  Fam. THRACIIDAE
  *Thracia papyracea* (Poli, 1791)

Subclass HETERODONTA
  O. LIMOIDE
  Fam. LIMIDAE
  *Lima exillis* Wood, 1939
  Fam. MYOIDA
  *Barnea candida* (Linnaeus, 1758)
  Fam. CORBULIDAE
  *Corbula gibba* (Olivi, 1792)
  Fam. PHELADIDAE
  *Acanthocardia aculeata* (Linnaeus, 1758)
  *Acanthocardia deshayesi* (Payraudeau, 1826)
  *Acanthocardia echinata* (Linnaeus, 1758)
  *Acanthocardia spinosa* (Solander, 1786)
  *Acanthocardia tuberculata* (Linnaeus, 1758)
  *Cerastoderma edule* (Linnaeus, 1758)
  *Cerastoderma glaucum* (Poiret, 1789)
  *Laevicardium crassum* (Gmelin, 1791)

Subclass HETERODONTA
  O. MYOIDA
  Fam. CARIDIDAE
  *Donax semistriatus* (Poli, 1795)
  *Donax trunculus* (Linnaeus, 1758)
  *Donax variegatus* (Gmelin, 1791)
  *Donax vittatus* (da Costa, 1778)
  Fam. LUCINIDAE
  *Lucinella diversicolor* (Linnaeus, 1758)
  *Lucinula diversicolor* (Linnaeus, 1758)
  Fam. MACRIDAE
  *Lutraria angustior* (Philippi, 1844)
  *Lutraria latraria* (Linnaeus, 1758)
  *Macrostoma lawrenzii* (Linnaeus, 1758)
  *Macroscapha glauca* (Born, 1778)
  *Spisula solida* (Linnaeus, 1758)
  *Spisula subtruncata* (da Costa, 1778)
  Fam. PETRIGOLIDAE
  *Mytilus edulis* (Linnaeus, 1758)
  Fam. PHARIDAE
  *Ensio arcuatus* (Jeffreys, 1865)
  *Ensio ensis* (Linnaeus, 1758)
  *Ensio silqua* (Linnaeus, 1758)
  *Pharus legumen* (Linnaeus, 1758)
  Fam. PSAMMOPHILALIDAE
  *Gari depressa* (Penny, 1777)
  *Gari fervensia* (Gmelin, 1791)
  Fam. SEMELIDAE
  *Abrida alba* (W. Wood, 1802)
  Fam. SOLICURTIDAE
  *Solecurtus scopula* (Turton, 1822)

Subclass PALAETOXODONTA
  O. NUCULOIDA
  Fam. NUCULIDAE
  *Nuculana minuta* (O.F. Müller, 1776)

Subclass PTERIOMORPHA
  O. MYTILOIDA
  Fam. MYTILIDAE
  *Modiolus multicaulis* (Cantraine, 1835)
  *Modiolus adriaticus* (Lamarck, 1819)
  *Modiolus barbatum* (Linnaeus, 1758)
  *Mytilus edulis* (Linnaeus, 1758)
  Fam. PINNAEIDAE
  *Pinna fragilis* (Penny, 1777)
  Fam. OSTEIDAE
  *Ostrea edulis* (Linnaeus, 1758)
  Fam. PECTINIDAE
  *Americana ephippium* (Linnaeus, 1758)
  *Anomia ephippium* (Linnaeus, 1758)
  Fam. PINNIDAE
  *Pinna fragilis* (Penny, 1777)
  Fam. OSTREIDAE
  *Ostrea edulis* (Linnaeus, 1758)
  Fam. PECTINIDAE
  *Aequipecten opercularis* (Linnaeus, 1758)
  *Chlamys varia* (Linnaeus, 1758)
  *Chlamys flexuosa* (Poli, 1795)
  *Pecten maximus* (Linnaeus, 1758)