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Abstract

The Biocoenosis of Well Sorted Fine Sands (WSFS) (SFBC, Sables Fins Bien Calibrés in French) is a Mediterranean community very well delimited by bathymetry (2-25 m) and sedimentology (> 90 % of fine sand) occurring in zones with relatively strong hydrodynamics. In this study focused on sites located along the Algerian, French, Italian and Spanish coasts of the Western Basin of the Mediterranean Sea (WBMS) we aim to compare the structure, ecological status and diversity of the macrofauna of the WSFS and examine the effects of recent human pressures on the state of this shallow macrobenthic community. We assess the ecological status and functioning of these WSFS using three categories of benthic indices: a) five indices based on classification of species into ecological groups, AMBI, BO2A, BPOFA, Ind. Qual. and Ind. Poll.-Degra., b) the ITI index based on classification of species in trophic groups, and c) the Shannon H’ index, and the Biological Traits Analysis (BTA), which is an alternative method to relative taxon composition analysis and integrative indices. Cluster analyses show that each zone show a particular taxonomic richness and dominant species. The seven benthic indices reveal that the macrobenthos of the WSFS of the four coastal zones show good or high Quality Status, except for one location on the Algerian coast (the Djendjen site) in 1997. BTA highlights the presence of three groups of species: 1) typical characteristic species; 2) indicator species of enrichment of fine particles and organic matter, and 3) coarse sand species which are accessorily found on fine sand. Finally, the WSFS which are naturally subject to regular natural physical perturbations show a high resilience after human pressures and are very sensitive to changes in the input of organic matter.

Keywords	Mediterranean Sea; diversity; benthic structure; benthic indices, Biological Traits Analysis; human pressures

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Pr Jean-Claude Dauvin

Caen 12 October 2016

Dear Editor of Environmental Pollution,

I have the pleasure to propose our typescript entitled 'The well sorted fine sand community from the western Mediterranean Sea: a resistant and resilient marine habitat under diverse human pressures' for its publication in 'Environmental Pollution. I have written this paper with Spanish, Italian, Algerian and French Mediterranean colleagues.
In this paper we have studied the structure and the ecological status of the Well Sorted Fine Sands (WSFS) (SFBC, Sables Fins Bien Calibrés in French) is four zones of the Mediterranean Sea. We assess the ecological status and functioning of these WSFS using three categories of benthic indices. The seven benthic indices reveal that the macrobenthos of the WSFS of the four coastal zones show good or high Quality Status, except for one location on the Algerian coast. In a second step, the Biological Traits Analysis highlights the presence of three groups of species. Our main results underline that the WSFS which are naturally subject to regular natural physical perturbations show a high resilience after human pressures and are very sensitive to changes in the input of organic matter.

We hope that this typescript will be published in the scope of your journal 'Environmental Pollution'.

Sincerely yours

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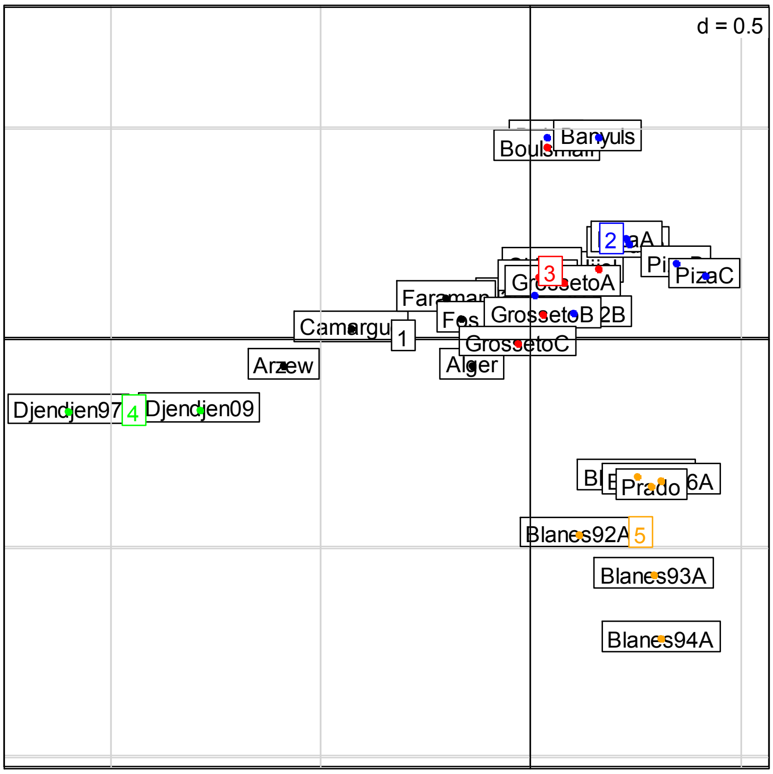

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The well sorted fine sand community from the western Mediterranean Sea: a resistant and resilient marine habitat under diverse human pressures

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ABSTRACT

The Biocoenosis of Well Sorted Fine Sands (WSFS) (SFBC, Sables Fins Bien Calibrés in French) is a Mediterranean community very well delimited by bathymetry (2-25 m) and sedimentology (> 90 % of fine sand) occurring in zones with relatively strong hydrodynamics. In this study focused on sites located along the Algerian, French, Italian and Spanish coasts of the Western Basin of the Mediterranean Sea (WBMS) we aim to compare the structure, ecological status and diversity of the macrofauna of the WSFS and examine the effects of recent human pressures on the state of this shallow macrobenthic community. We assess the ecological status and functioning of these WSFS using three categories of benthic indices: a) five indices based on classification of species into ecological groups, AMBI, BO2A, BPOFA, Ind. Qual. and Ind. Poll.-Degra., b) the ITI index based on classification of species in trophic groups, and c) the Shannon H' index, and the Biological Traits Analysis (BTA), which is an alternative method to relative taxon composition analysis and integrative indices. Cluster analyses show

that each zone show a particular taxonomic richness and dominant species. The seven benthic indices reveal that the macrobenthos of the WSFS of the four coastal zones show good or high Quality Status, except for one location on the Algerian coast (the Djendjen site) in 1997. BTA highlights the presence of three groups of species: 1) typical characteristic species; 2) indicator species of enrichment of fine particles and organic matter, and 3) coarse sand species which are accessorily found on fine sand. Finally, the WSFS which are naturally subject to regular natural physical perturbations show a high resilience after human pressures and are very sensitive to changes in the input of organic matter.

Key words: Mediterranean Sea; diversity; benthic structure; benthic indices, Biological Traits Analysis; human pressures

1. Introduction

The Biocenosis of Well Sorted Fine Sands (WSFS) (SFBC, Sables Fins Bien Calibrés in French, Pérès and Picard, 1964) is a Mediterranean community very well delimited by bathymetry (2-25 m) and sedimentology (very low proportion of fine particles < 63 µm; Organic Matter < 2%; and proportion of fine sand > 90 %) occurring in zones with a relatively strong hydrodynamic regime. Its typology is well recognized at the scale of the western basin of the Mediterranean Sea and has been studied at numerous locations mainly along the French coast (Massé, 1970, 1971a,b,c, 1972, 1996, 1998, 2000; Guille, 1970, 1971; Grémare et al., 1998a,b, 2003; Labrune et al., 2007a, b, 2008; Sardá et al., 2014), Spanish (De-la-Ossa-Carretero et al., 2008, 2010; Sardá et al., 1999, 2000, 2001; Sanchez-Moyana et al., 2004), and Italian (Fresi et al., 1983; Somaschini, 1993; Somaschini et al., 1998; Diviacco and Somaschini, 1994; De Biasi and Aliani, 2001; Simonini et al., 2005), but also along the Algerian coast (Bakalem, 1979, 2008; Bakalem et al., 2009, Grimes, 2010; Grimes et al., 2010). Based on polychaete assemblages near the French-Spanish border, Labrune et al. (2007a) proposed a new terminology for the WSFS: Littoral Fine Sands; however, this proposal has not yet been adopted. Therefore, we conserve here the classic WSFS terminology as currently used in the European EUNIS classification ('Mediterranean communities of well sorted fine sands': http://eunis.eea.europa.eu/habitats/2197). Studies on this benthic habitat concern mainly the description of community structures, i.e. the species living in the WSFS community and their abundances, as well as the estimation of species or taxonomic richness in terms of diversity index, particularly the Shannon H' diversity index, and, in some cases, biomass and more rarely production (Massé, 1972). Some authors have also assessed ecological status using benthic indicators (Tataranni and Lardicci, 2010; Sardá et al., 2014). This community is well recognized and characterized by a relatively low number of dominant species at the scale of the western basin of the Mediterranean Sea. Moreover, over the last few decades, WSFS communities located in shallow waters have been subject to a multitude of human pressures: outfalls of treated and untreated urban waste, new constructions of dykes, dredging and recharging of beaches with sand collected in the WSFS at shallow depths (<10 m), as well as embankment of terrestrial territories for urban development, industries, harbours, airport extensions, etc.. Fish trawling continues to have an impact, in spite of its prohibition at a distance of less than three nautical miles from the coastline due to the importance of this habitat for flatfishes which depend on the WSFS community for feeding. In addition, the WSFS is also changing in response to the global increase in sea temperatures leading to the warming of shallow waters in the Mediterranean Sea, which is mainly observed in summer (Nykjaer, 2009; Shaltout and Omstedt, 2014). Since the WSFS is located above the thermocline, it can be directly damaged by a greater increase of Sea Surface Temperature and the overall rise in temperature of the water masses of the Mediterranean Sea, probably in relation to global climate change.

There has been a notable increase in the number of benthic indices due to the implementation of the European Water Framework Directive (WFD) and the Marine Strategy Framework (for example, see Borja et al., 2000, 2010; Blanchet et al., 2008; Rice et al., 2012; Dauvin et al., 2016). Nevertheless, most of these benthic indices are based on the assumption that the response of macrobenthic species is linked to the increase of organic matter (OM) in the sediment, in view of 1) the increase in the abundance of tolerant and opportunistic species with increased OM and 2) on the contrary, the disappearance of sensitive species. According to this paradigm, the species are classified into five Ecological Groups (EG) and their relative abundances serve to calculate benthic indices (Borja et al., 2010). Subsequently, these indices, such as AMBI and BOPA (as well as its associated modifications), were tested to detect other human pressures unconnected with the OM content (i.e. long-term changes of benthic communities under natural stressors) in areas affected by harbour construction, zones of granulate extraction, metal contamination, etc. (Borja et al., 2011, 2015; Tararanni and Lardicci, 2010; Dauvin et al., 2016). Along the same lines i.e. the classification of macrobenthic species in terms of ecological groups corresponding to the response to pollution is mostly related to organic matter input from urban waste water outfalls, Bellan (2007) proposed an environment quality index and a Pollution-Degradation index based on the percentage of six groups of sentinel, indicative or characteristic species. However, the generalization of these OM benthic indicators to other human pressures has hindered the search for specialized indicators based on the impact of pressures acting alone, i.e. a single type of pressure leading to a particular impact.

As an alternative to analysing relative taxon composition or using integrative indices (Bremner et al., 2003, 2006), Biological Traits Analysis (BTA) takes into account the biological characteristics of the benthic species (life-history, morphological, behavioural aspects) to study the functioning of benthic communities (Verissimo et al., 2012). In this way, BTA offers a motivating approach that is complementary to benthic indicators for detecting changes in the functioning of benthic communities in response to human pressures.

This study is focused on some selected sites in the northern, south-western and eastern parts of the Western Basin of the Mediterranean Sea (WBMS) along the Algerian, French, Italian and Spanish coasts, with the aim of comparing the structure, ecological status and diversity of the macrofauna and examining the effects of recent human pressures on the ecological status of this shallow macrobenthic community established on well-sorted fine sands.

2. Materials and methods

2.1. Study sites and available data

The selected data comes from studies carried out in four areas in the western Basin of the Mediterranean Sea, from sites located on the Spanish, French and Italian coasts in the north and on the Algerian coast in the south (Fig. 1).

For the French coasts, two main kinds of data are selected (Table 1). Firstly, the classic data collected in the 1970s in the area around Marseilles by Massé (1970, 1971a,b,c, 1972, 1996, 1998, 2000) in five small bays (Bandol, Faraman, Fos, Prado and Verdon) can be considered as representing the 'pristine state' of the WSFS community before the increase of human activities in shallow waters along the French coast (Massé, 1996, 1998 and 2000). In the case of the Bay of Banyuls-sur-Mer, near the Spanish border, station 43 sampled in 1994 by Grémare et al. (1998a) is considered as an outlying site of the Marseilles area. Secondly, a recent survey of shallow stations along 55 km of the coast of the Camargue (from Lat. 4°13,474' E to 4°54,473' E) provides information on the state of the community under fishing pressure in the western part of the zone, in spite of being subject to regulatory prohibitions (Bellan et al., 2013) and the effects of contamination in the east coming from the Rhône River. This survey was undertaken in the framework of Natura 2000 (Labadie et al., 2011).

The data for Spain come from the Bay of Blanes (NW Mediterranean). Samples were taken at two stations located at a depth of 15 m (stations A and B; Sardá et al., 1999, 2000). The first station (A), located near the town and around 300 m off Blanes harbour, was sampled for five years (from 1992 to 1996). The second station (B) was only sampled for two years (1992 and 1993), and was located near the mouth of the Tordera River (Table 1). The organisms retained by a 0.5 mm mesh sieve were counted and classified to the lowest possible taxonomic level for polychaetes, bivalves and echinoderms. The rest of the taxa were classified only according to major groups.

For the Algerian coast (Southwestern Mediterranean Sea), the data come from the PhD work of Bakalem (2008) and Grimes (2010) (see also Bakalem et al., 2009 and Grimes et al., 2010) for historic data collected between 1979 and 1990 in the bays of Algiers, Arzew, Bejaia, Bou Ismail, Jijel and Skikda, and in 1997 and 2009 for the Djendjen area (Table 1).

For Italy (eastern part of the North-Western Mediterranean Sea), the data cover two maritime areas on the coast of Tuscany (Pisa and Grosseto) which are about 120 km apart. The area near Pisa is located on a stretch of the coast that is more intensively affected by urbanization and industrialization, although there are no major urban or industrial centres. This area is characterized by a prevailing northward longshore drift associated with the estuary of the Arno River, giving rise to freshwater, organic and nutrient inputs which can influence the coastal macrobenthic communities. Site A is located to the north, while site C is father south and site B is near the river mouth; the sites are separated by distances of thousands of metres. The Grosseto coastal area is located father south, and is characterized by weak anthropogenic pressure compared to other western Italian sandy coasts. Only a few small tourist centres and marinas are situated along this part of the coast, while there is also an extensive terrestrial natural park. All the samples from the Pisa and Grosseto coastal areas were collected in September 2005 and in May 2006 (Table 1; Tataranni and Lardicci, 2010).

Overall, the database is made up of 306 samples, with a great disparity of information as regards number of replicates as well as seasonal sampling between the different sites, i.e. ranging from only one sample for the Bay of Banyuls to 56 sampling dates at station A in the Bay of Blanes. The database contains more than 800 taxon names, but after updating with WORMS (http://www.marinespecies.org; accessed on 15 December 2015), removing doubtful species and pooling the disparities due to different persons carrying out identification of the species to the genus level, the number of taxa is reduced to 521.

The abundances are normalized to the number of individuals per m^2.

2.2. Data analysis

Assemblages of species are determined with multivariate analyses using the PRIMER 6 software (Clarke and Gorley, 2006). Hierarchical cluster analysis (HCA) with group average and multidimensional scaling (MDS) are based on Sørensen's coefficient for Presence/Absence data (concerning species richness) or the Bray Curtis coefficient with $\log_{10}x$ transformation (concerning abundances). First at all, clustering is carried out on the total matrix, i.e. 306 samples and 521 taxa. Four samples (one from Camargue, and three from Djendjen) are excluded because they contain too few taxa (between four and seven), and can be statistically separated in the first analyses, especially in the cluster. In a second step, clustering (302 samples and 520 taxa, one taxa being present only in one of the four excluded samples) reveals the influence of sampling between the various locations, i.e. the separation of samples according to sites. Finally, the data are averaged per site and per year in the case of the Spanish and Italian stations used for temporal monitoring, amounting to a total of 28 situations.

In a second step, only the ten most abundant taxa of each situation are selected and a new matrix is constructed including a total of 108 taxa for the 28 situations (considering the densities per m^2 of the 108 taxa). HCA and MDS are performed in order to describe and characterize these 28 situations.

2.3. Benthic indices

In this study, we select three categories of indices (see Table 2 for the thresholds of the different indices, taken from Dauvin et al., 2012 and 2016).

The five indices used here are based on species classification in ecological groups. The AZTI Marine Biotic Index (AMBI), as developed by Borja et al. (2000), is used to analyse the proportions of five ecological groups in terms of the gradient of organic matter enrichment, and is calculated according to the guidelines of Borja and Muxika (2005). The Benthic Opportunistic Annelida Amphipods index (BO2A) and the Benthic Polychaete Opportunistic Families Amphipods index (BPOFA) are also calculated; these indices are based on the principle of taxonomic sufficiency and use the abundance frequencies of two well-known zoological groups as indicator taxa: the opportunist annelids and the sensitive amphipods (Dauvin et al., 2016). The indices of environmental quality (Ind. Qual.) and Pollution-Degradation (Ind. Poll.-Degra.) used here are based on the relative percentages of six groups of sentinel, indicative or characteristic species (Bellan, 2007; Table 3). These groups of species show the sensitivity or resistance of species to pollution. The term *sentinel species* was established by Bellan (1967 and 2007) for a species that, by virtue of its presence or relative abundance, 'warns' an observer about the possible impact of pressures in the nearby environment (see also Bellan et al., 1999).

One index based on trophic groups, the Infaunal Trophic Index (ITI) proposed by Mearns and Word (1982), is built on the assumption that the ecological quality of the community increases with the dominance of suspension feeders and decreases with the dominance of subsurface deposit feeders.

The index based on diversity is denoted by H' (the Shannon Index with $\log_2$; Shannon, 1948).

We also make use of the five ECOlogical Quality Status (EcoQS) classes recommended by the WFD: *high* for unpolluted sites, *good* for slightly polluted sites, *moderate* for moderately polluted sites, *poor* for heavily polluted sites, and *bad* for extremely polluted or azoic sites.

2.4. Biological Traits of Life

A total of ten Biological Traits (BT) were selected covering different aspects of the life history, morphology and behaviour of each taxon: position on the substratum, habit, feeding mode, adult mobility, bioturbation, size, life span, developmental mechanisms, substratum affinity and ecological groups (Table 4). The choice of BTs is based on seven studies (Garcia, 2010; Paganelli et al., 2012; De Juan and Demestre, 2012; Verisissimo et al., 2012; Bolam and Eggleton, 2014; Rigolet et al., 2014 and La Rivière et al., 2016), in accord with their supposed importance in community functioning and their potential ability to detect the main impacts of human activities on the WSFS habitats. Each trait is divided into modalities (42 over the 10 studied traits) (Table 4). The significance of the selected BTs in terms of benthic functioning is given in Garcia (2010), Verisissimo et al. (2012) and Bolam and Eggleton (2014).

According to Verisissimo et al. (2012), three different types of data matrices are required: 1) 'taxa by station' (taxa abundance for each sampling station); 2) 'taxa by traits' (biological traits for each taxon) and (3) 'traits by station' (biological traits at each sampling station). Information for assigning taxa to functional traits is obtained from different sources including the PhD thesis of Garcia (2010), the WORMS site (http://www.marinespecies.org; accessed on 15 December 2015), the UK Marlin site (http://www.marlin.ac.uk/biotic/; accessed on 15 December 2015), scientific journals and the scientific expertise of the authors. When reliable information is missing, data are considered from the phylogenetic nearest neighbour taxa. The resulting 'traits by station' data matrix is then subjected to multivariate analysis.

The Biological Traits Analysis is performed according to the Rigolet et al. (2014) approach. The fuzzy coded 'species by trait' matrix is computed using a Fuzzy coded multiple analysis (FCA). The FCA output (coordinates of taxa on the first axes) is used to plot a dendrogram applying Ward's linkage method based on Euclidean distances (Ward, 1963). Clusters of species exhibiting similar traits are then defined by selecting a given partitioning level. Finally, a biological profile is created for each cluster, showing for each trait the proportion of modalities exhibited by the cluster (Usseglio-Polatera et al., 2000).

The « species x trait » matrix is then multiplied by the abundance of the species at each station to obtain a « station x trait » matrix. This new matrix is ordinated by an FCA. A cluster analysis is then performed on the results by applying Ward's linkage method using Euclidean distances. This analysis groups stations with similar biological trait patterns. A PERMANOVA is used to test the statistical validity of the groups of stations obtained by cluster analysis.

3. Results

3.1. Assemblage patterns

Four HCA and four MDS are performed taking into account the abundances and species richness according to the 28 selected situations, considering all the 521 species found at the different sites, and then the 108 top ten species found at each site. The results show very high levels of resemblance between the assemblages identified by the different analyses. As an example, Figs. 2 and 3 show the HCA and MDS for the matrix of abundances after a Log(x+1) transformation of the 108 top ten species and 28 situations. The first group (A) is represented by the Banyuls site, which is isolated from the other clusters. Group B includes the seven Spanish situations, while the third group (C) brings together the two Djendjen situations plus the Arzew sites (Algeria). Group D is made up of 12 situations and can be sub-divided into three sub-groups: D1 with the five historic situations in the Marseilles area, D2 with the six Italian situations and D3 with the Bay of Algiers. Group E comprises four Algerian situations plus the Camargue site, corresponding to a low faunal density at these sites coupled with low percentages of fine particles.

Table 5 summarizes the results of the four cluster analyses. For each analysis, the Banyuls and Blanes sites always contain the same assemblages, while Marseilles forms a single group which includes Skikda when using the P/A analyses and the 108 ten top species. Similarly, Italy forms a single group which includes Algiers when based on the P/A analysis and the 108 ten top species. Algiers is separated with the abundance analyses, and can be regrouped with other assemblages by using the P/A analyses. Camargue is always clustered with the Algeria situations (all seven or only four). The two Djendjen situations are grouped together with Arzew, and Djendjen97 forms a cluster alone with Arzew (analyses on the 108 ten top species). The Djendjen sites correspond to semi-enclosed areas with sedimentation of fine particles, while the shallow Bay of Arzew receives a regular input of fine particles coming from the main Algerian ‘oueds’. In both areas, the fauna is enriched by muddy species.

3.2. Biotic indices

Table 7 gives the values of the seven indices along with the corresponding colours of the WFD. Most of the values indicate that the macrobenthos shows good or high Quality Status, e.g. all the values of AMBI, Ind. Qual. and Ind. Pollu. Degra., and all the values of BO2A and BPOFA values except for Djendjen97 (presence of high abundance of the opportunistic polychaete *Heteromastus filiformis*, which was also present in 2009 but at lower abundance than in 1997). ITI also gives a degraded status for the Djendjen97 situation. ITI highlights the dominance of suspension feeders when the status is normal, and deposit-feeders when the status is perturbed; thus, most of the Spanish, Algerian and Grosseto situations are classified as perturbed, in a similar way to Bandol and Faraman for the Marseilles area, while the others are classified as normal. The Shannon diversity index H’ is very sensitive to the dominance of a single or a few species as observed at Banyuls (*Ditrupa arietina*), Pisa B and C (*Spisula subtruncata*), Blanes 93A, 94A and 96A (*Owenia fusiformis* and *Spisula subtruncata*), Prado (*Phoronis psammophila)* and Faraman (*Magelona mirabilis*). Nevertheless, all these dominant species are characteristic of the WSFS and are not opportunistic; the high recorded abundances correspond to a very successful recruitment of few dominant species at these locations.

3.3. Biological Traits Analysis

Stations

Cluster analysis (FCA) separates five groups of stations (Fig. 4; Table 8). Group D (two Djendjen situations) is discriminated on axis 1, being characterized by species with a long lifespan and relatively low mobility (crawlers) as well as traits associated with opportunistic species (large non-specific deposit feeders; EG-IV with an affinity for mud and muddy sand). Axis 2 discriminates group E (Blanes and Prado), which is made up of a small number of species and a high proportion of EG-II species, as well as dominant species such as *Owenia fusiformis* and *Spisula subtruncata*. Groups B and C are opposed on axis 3 (not shown in Fig. 4), with group B being characterized by free-living species, whereas group C contains a higher proportion of very small sessile epifauna. Group A exhibits no specific set of traits, representing a mix of communities typical of other groups.

Functional groups (FG)

Cluster analysis (not shown here) separates seven groups of species which correspond to functional groups (FG) (Table 9). Axis 1 separates group 2, which is characterized by interstitial fauna (free-living species that move by walking or crawling, associated with weak bioturbation) having an affinity for coarse sand (Table 9). Axis 3 distinguishes group 7 from groups 3 and 6. Group 7 is composed of large walking species with upward conveyor bioturbation. Groups 3 (all amphipods) and 6 (15 crustaceans, including 12 amphipods) are characterized by very small species with high mobility (burrower/swimmer and walker/swimmer), pooling together species of the main community (WSFS). On axis 4, group 6 is distinguished from group 3 by its bioturbation mode (diffusive mixing species). Axis 3 opposes groups 4 and 1. Group 4 contains high proportions of opportunists associated with bioturbation (upward and downward conveyors) (EG-V), whereas group 1 is composed of long-lived sessile suspension feeders (i.e. molluscs). Both groups 4 and 1 are characterized by an affinity for muddy substratum. Group 5 is not separated from the others on any of the axes because these species do not exhibit conventional set of traits (their traits are not correlated with each other according to a specific pattern).

Group A has no dominant FG (Fig. 5; Tables 8 and 9). In addition, there is a large proportion of FG-5. It seems that these stations contain a mixture of assemblages from other stations. Groups B and E are largely dominated by FG-1 (over 80% of the abundance), which is one of the groups of the main community (WSFS). However, group E contains a higher proportion of FG-4, indicating organic enrichment and the presence of FG-2 (coarse sand species). Group C combines stations dominated by WSFS species (molluscs and the amphipods *Urothoe* spp., GF-1 and FG-6). Group D is dominated by FG-4 (opportunistic group), suggesting that these stations have undergone organic enrichment. In addition, they also contain a high proportion of FG-7 (carnivorous Polychaeta), which could be explained by the larger proportion of their prey item (FG-4 species).

4. Discussion

4.1. Species composition and assemblages of the WSFS

As stressed previously by numerous authors, the soft-bottom communities of the Mediterranean Sea are characterized by their high species richness (Bakalem, 2008; Grimes, 2010 and references therein). In this study, the diversity of chosen sites and the long-term monitoring of certain sites increased the probability of sampling a large collection of species; in this way, the species composition of our sites reaches a total of 521 species. This value is high for a single shallow community that is known to show moderate species richness (see the publications of Massé in the 1970s). Nevertheless, our overall list contains several categories of species:

- Species characteristic of the WSFS, which can be found in the 'pristine state' i.e. the lists of Massé's stations sampled in the late 1960s.
- Species which are characteristic of one site (locality) showing some differences with fauna from surrounding regions, such as the polychaetes *Aricidea* (*Acmira*) *catherinae*, *Spiophanes reyesi*, and the bivalve *Loripinus fragilis* along the Italian coast, the amphipod *Ampelisca sarsi* and the ophiurid *Amphiura chijei* along the Algerian coast, the polychaetes *Aricidea* (*Strelzonia*) *suecica* et *Paraexogone hebes* and the bivalve *Ensis* along the Spanish coast and the polychaete *Euclymene oerstedi* along the French coast.
- Species which respond to an increase in fine particles and organic matter in the sediment (tolerant and opportunistic species belonging to EG3, EG4 and EG5 which are not found on WSFS under normal conditions). This increase of fine particles on the WSFS is well documented (see Bakalem, 2008; Grimes, 2010; and also Bayed and Bazairi, 2008); it corresponds to natural river discharges in some areas such as the Bay of Algiers or recent human modifications that increase the sedimentation of fine particles on the sea bottom as in the Djendjen area.
- Species which are numerically dominant at one or several locations (see Table 6), including the polychaetes: *Owenia fusiformis*, *Prionospio caspersi*, and *Ditrupa arietina*; the bivalves: *Spisula subtruncata, Lucinella divaricata, Thracia phaseolina, Tellina fabula,* and *Chamelea gallina*; the amphipods *Ampelisca tenuicornis* and *A. brevicornis* (which were also described

as dominant in Bayed and Bazairi, 2008), and the tanaid *Apseudopsis latreillii* for the Italian sites. This latter species also shows high abundances along the Mediterranean Spanish coast (Valencia) (de-la-Ossa-Carretero et al., 2010), but its response to increased organic matter remains a matter of debate. Dense populations of the polychaete *Ditrupa arietina* have recently been observed on the French and Spanish Catalan coast, with high abundances recorded at Banyuls-sur-Mer and in the Blanes area, as well as at Bejaia and Arzew along the Algerian coast. For example, the species was rare or absent during the late 1960s (Guille, 1970 and 1971). Following a peak of abundance in the 1990s and up until the middle of the years 2000 (Grémare et al., 1998b; Labrune et al., 2007a,b; Sarda et al., 1999, 2001), the populations decreased dramatically (Labrune et al., 2012; Romero-Rodriguez, 2016). In his review of the occurrence and ecology of dense populations of *Ditrupa arietina*, Hartley (2014) pointed out that dense populations are found in areas where the sea bed is periodically disturbed by internal wave action. The WSFS are known to be located in shallow waters under high-energy hydrodynamic conditions, so any rapid increase in the population of *D. arietina*, which is an annual species, could be linked to an episode of higher energy.

Therefore, our results show that each zone has a particular taxonomic richness and specific dominant species (Table 6). Taking into account the mean total density of the macrobenthos per m^2 at the 28 situations, three categories of sites can be recognized: nine locations with very low densities < 1,000 ind.m^2 (including Fos, Camargue and all the Algerian locations except Algiers); nine other locations with densities between 1,000 and 5,000 ind.m^2 (including Algiers, Blanes A in 1995 and 1996, Bandol, Faraman and Verdon, as well as Grasseto during three years of sampling, and Banyuls); nine locations with very high density > 5,000 ind. m^2, and three locations with > 20,000 ind.m^2 (Blanes A in 1993, Pisa B and Pisa C); the other locations are Blanes, Prado and Pisa A.

Banyuls is the only site characterized by a high density of the Polychaete *Ditrupa arietina* in 1994, as well as two other dominant species: the polychaete *Owenia fusiformis* and the bivalve *Spisula subtruncata*.

The Spanish site is characterized by the *Owenia fusiformis* - *Spisula subtruncata* assemblage, as well as *D. arietina* and the bivalve *Lucinella divaricata*, while the polychaetes *Spio decoratus*, *Paradoneis armata* and *Mediomastus* sp. are among the main species.

The Marseilles sites are characterized by very low density except at Prado, along with the presence of the phoronid *Phoronis psammophila* and various different dominant species recorded at the four other historic locations such as the polychaetes *Owenia fusiformis*, *Spio* *decoratus*, *Scoletoma impatiens* and *Magelona mirabilis*, the amphipod *Ampelisca brevicornis*, and the bivalves *S. subtruncata*, *Chamelea gallina* and *Fabulina fabula*.

The Italian sites are characterized by very high abundance of the dominant species *S. subtruncata* at the three Pisa sites and the bivalve *Loripinus fragilis* at the three other Grosseto sites. The tanaid *Apseudopsis latreillii* is also abundant and dominant in the six Italian situations; the small polychaetes *Prionospio caspersi* and *Paradoneis armata* are also abundant at these stations.

The Algiers site is characterized by the dominance of *Scoletoma impatiens*, *S. subtruncata, Chamelea gallina, O. fusiformis* and *P. psammophila,* while the seven other Algerian sites show very low density associated with different dominant species that are not among the 20 top species of the other locations (Table 6), such as the opportunistic polychaete *Heteromastus filiformis* at Djendjen97, where *Mediomastus* sp. is also one of the main species; *D. arietina* is the dominant species at Bejaia; the bivalve *Fabulina fabula* and the amphipod *Ampelisca brevicornis* are the dominant species at Skikda. The polychaete *Aponuphis bilineata* is predominant at Arzew along with the opportunistic polychaete *Chaetozone* sp.

Finally, the Camargue site is characterized by very low density, as observed at most of the Algerian sites, and the dominant species are the polychaetes *Lumbrineris latreilli* and *Glycera unicornis* and the amphipod *Urothoe pulchella*.

4.2. Quality Status of the WSFS in the western part of the Mediterranean Sea

Apart from Djendjen, all the situations show a high or good Ecological Status. WSFS occur under high-energy hydrodynamic conditions and are relatively resistant to human pressures, while anthropogenic fine particles and OM are probably prevented from accumulating because of the hydrodynamic regime. However, some tolerant and opportunistic species could be present due to temporary inputs of nutrients from rivers, oueds or urban discharges. All the indices yield the same patterns; moreover, H' is sensitive to dominant species and shows lower values in the case of high abundances due to one or two strongly dominant species such as at Banyuls, site A at Blanes in 1994, the Massé Prado station and Pisa C. The benthic indices appear unable to discriminate between locations or between historic and present-day compositions of the macrofauna in such shallow habitats.

Furthermore, abundance values and their response to environmental change appear to be better indicators of human pressures on such shallow macrobenthic habitats. As shown in our data, there are extreme difference of abundances between sites with very high abundances of *S. subtruncata* at both Spanish and Italian sites. At 'pristine sites', Bou Ismail Bay and other Algerian sites, Prado or Camargue, the abundances are < 1000 ind.m²; there is probably little input of nutrients and low Primary Production at these localities. The main characteristic of the WSFS is their low population density, with values ranging from 200-300 to 1000 ind.m². In a long-term comparison (1967-1968; 1996) of the benthic composition of two stations in Prado Bay, Massé (1996, 1998) showed that the improvement in water quality of the bay had a positive effect on the species richness of the WSFS, but the drastic reduction of freshwater and organic matter inputs had a negative effect on abundances and biomass of the macrobenthos. Massé (2000) compared the general patterns of the macrofauna of the WSFS between 1966 and 1996 at five sites, respectively Faraman, Fos, Verdon, Prado and Bandol. He showed that the abundance of the macrobenthos was mainly sensitive to the effect of well identified human actions, such as the deviation of the river in Prado Bay and the increase of nutrient inputs from the Rhône at the nearby Faraman site. He also highlighted a decline of abundance of crustaceans at the studied sites, especially amphipods, and considerable fluctuations and alternations in the relative abundance of molluscs and echinoderms.

Thus, the high abundances are mainly due to two phenomenon: 1) high settlement of a very limited number of species such as the bivalve *Spisula subtruncata*, the polychaetes *Owenia fusiformis* and *Ditrupa arietina*, and the phoronid *Phoronis psammophila*; 2) stability and/or changes in freshwater inputs due to natural hydrological variations controlled by climatic factors, or human actions such as improvements in water quality or the diversion of rivers. For example, the abundances of WSFS in the Bay of Algiers are higher than those observed along other parts of the Algerian coast, owing to the freshwater inputs of the main oueds and urban discharges into the Bay of Algiers.

4.3. Biological Traits of Life

An approach allowing us to classify the situations in a different way, in terms of Traits of Life, shows a clear separation of the Djendjen data points from the other sites. This is highlighted by the abundances of species which reflect the presence of tolerant and opportunistic species having specific Traits of Life. The Italian and Spanish stations with high abundances of *Owenia fusiformis* and *Spisula subtruncata* can also be distinguished by analyses of the biological traits of life (Fig. 4).

The subdivision of the species into seven functional groups is of great interest in this context (Table 9).

The first group distinguishes species that are characteristic of the WSFS, including numerous bivalves such as *Callista chione*, *Chamelea gallina*, *Spisula subtruncata* and *Tellina fabula*, as well as the polychaete families Oweniidae and Spionidae; most of these dominant and characteristic taxa are suspension feeders that underline the fact that the fauna in such benthic hydrodynamic environments depend on the quality of the water column. Pristine WSFS occur mainly in oligotrophic zones with low macrofauna abundances (Massé, 1966, 1998 and 2000). As a response to the eutrophication of the coastal zone, mainly due to the increase of nutrients supplied by freshwater inputs, there is an enrichment of the fauna with the introduction of indicative sentinel species and an increase in the abundance of macrofauna (Bellan, 1967; Bakalem et al., 2009; Bayed and Bazairi, 2008; Massé, 2000).

Groups 2 and 7 are characterized by coarse sand species mainly comprised of polychaetes of small size (G2) or large size (G7). Groups 3 and 6 are made up of crustaceans (especially the amphipods *Ampelisca* spp. *Bathyporeia* spp. and *Urothoe* spp.) which are characteristic of WSFS, with high mobility and able to swim in the water column at night (diurnal vertical migration). These species are also sensitive to pollution (Dauvin et al., 2012, 2016). Group 4 is characterized by opportunistic species found in sediments enriched in organic matter, probably indicating a temporary or permanent organic pollution. It is clear that these species are absent at stations with low macrofauna abundances, but are well represented at the Djendjen site. Finally, group 6 is comprised of 14 polychaetes found mainly in muddy fine sand and which occur in areas enriched by fine particles. In this way, the analyses based on Biological Traits of Live highlight the presence of three groups of species: i) typical characteristic species of WSFS such as groups 1, 3 and 7; ii) indicator species reflecting enrichment of fine particles and organic matter (groups 4 and 5), and iii) coarse sand species which are accessorily found on fine sand (groups 2 and 7).

4.4. Concluding remarks

Our study is focused on the shallow Biocoenosis of Well Sorted Fine Sands (WSFS) in zones with relatively high-energy hydrodynamic conditions along the Algerian, French, Italian and Spanish coasts of the western Basin of the Mediterranean Sea. We compare the structure, ecological status and diversity of the macrofauna of the WSFS, with a view to examining the effects of human pressures on the state of this shallow macrobenthic community. In spite of several types of pressure in the four studied areas (Table 1), such as river inputs, pollution by urbanization, heavy metals and hydrocarbons, only one site at Djendjen along the Algerian coast shows a low-quality status. All the other situations show a good or a high quality status according to the seven benthic indices employed in thus study. These indices appear unable to discriminate the response of WSFS communities arising from human pressures; by contrast, the total abundances of the macrofauna could serve as an indicator of dysfunction, since an increase of abundances could be due to the influence of river inputs. The change from oligotrophic (normal situation) to eutrophic conditions (with enhanced nutrient and organic matter inputs) is followed by an increase of abundances and the presence of sentinel or indicative species reflecting organic pollution. Moreover, this situation can be reversible as shown by Massé (1996 and 1998) in the case of Prado Bay in the Gulf of Marseilles, with a decrease in the total abundance of macrofauna after the cessation of continual freshwater inputs or in the case of the Besos River off Barcelona associated with the reduction of organic inputs (Cardell et al., 1999). This indicates that the WSFS communities have a high resilience. This ecological property has been highlighted in the context of sand extraction in shallow subtidal zones of Algeciras Bay (southern Mediterranean Sea, Spain) (Sanchez-Moyano et al., 2004), in the northern Adriatic Sea (Simonini et al., 2005) and along the Catalan coast (Sarda et al., 2000). In Algeciras Bay, surveys conducted over five years following dredging operations showed that the macrofauna was beginning to be re-established only one month after the cessation of dredging. After two years, there was a confusing biological impoverishment, while after four years, the population was largely re-established (Sanchez-Moyano et al., 2004). For the Northern Adriatic Sea (Simonini et al., 2005), one year after the extraction, the recolonization of the macrofauna at the impacted stations was at an advanced stage, while on the Catalan coast, two years after the cessation of dredging activities, the abundances recovered but biomasses were still high (Sarda et al., 2000). Similarly, in a study of the effect of sediment discharge (100,000 m^3 over a period of one week) on benthic communities in the Tyrrhenian coastal zone, including the shallow WSFS habitat, no changes were observed after the dumping operations, even though it took place only about 5 nautical miles from the shallow biocoenosis (De Biasi and Aliani, 2001). As discussed above, this habitat is located in shallow waters associated with high-energy environments that are continually subjected to natural physical perturbations. This ensures the selection of species adapted to living in clean sand intensely reworked by a combination of strong wave action and swell, implying that the community is able to recolonize this environment rapidly after the cessation of anthropogenic pressures. This high resilience maximizes the capacity of the characteristic species of this biocoenosis to recover rapidly after undergoing pressures. The high capacity of recovery of Mediterranean WSFS contrasts with the low resilience of typical Mediterranean communities under the combined effects of anthropogenic and climatic factors, such as observed in the case of *Posidonia oceanica* meadows (Bourcier, 1996) and coralligenous reefs (Gatti et al., 2015). In agreement with Gatti et al. (2015), who criticized the use of coralligenous reef state as an indicator of water quality, because it responds primarily to physical pressures (sedimentation, temperature, mechanical damage, etc.), our study on the WSFS not only shows similar evidence but also a high resilience after the cessation of anthropogenic pressures.

However, our analyses only take into account of the abundance of the species, and are mainly concerned with the dominant species. It is well known that shallow, non-vegetated, soft-bottom habitats of the western Mediterranean are general poor in biomass and show a low productivity (1-3 g dry weight m^{-2}) (Ben-Tuvia, 1983), except near large rivers (e.g., the Rhone or the Ebro) or major cities (e.g. Marseilles or Barcelona), where values of up to 18.4 g dry weight m^{-2} have been recorded (Massé, 1972 for the Gulf of Fos, France), or in enclosed areas or coastal lagoons [157.2 g dry weight m^{-2} for the Camargue area (Massé, 1972), and 66.0 g dry weight m^{-2} in Alfacs bay of the Ebro Delta (Martin et al., 2000)] where biomass and productivity tend to increase. Previous studies have systematically documented the dominance of annelid polychaetes, as well as bivalve species, both in terms of abundance and biomass of species. More recent studies [Albertelli et al., 1993 in the Ligurian Sea (Italy); Grémare et al. 1998a, 1998b, in the bay of Banyuls (France); Sardá et al. (1998) in the Cove of Portbou (Spain)] propose that most of the macroinfauna remains dominated by increasing numbers of small polychaetes which disappear a few months after their settlement. However, the biomass of large bivalves is lower, and there is a clear tendency for a decrease in the mean individual macroinfaunal biomass. This shift probably reflects a habitat that is being continuously stressed by anthropic disturbances (see Sardá & Fluvià, 1999 for a review of the Costa Brava). The evidence from the bay of Blanes suggests that the absence of large organisms could be associated with the continuous disturbance and stress caused by bivalve fisheries in this area. This selective pressure on larger invertebrates means that the populations of the affected assemblages are mainly structured by annual species, which may explain the recurrent pattern found in their seasonal dynamics (Sardá et al., 1999). We consider that, at present, this could be a general pattern in shallow soft-bottom habitats of the north western Mediterranean coastal zones, which could be analysed in the future using the biomass data available for this part of the Mediterranean.

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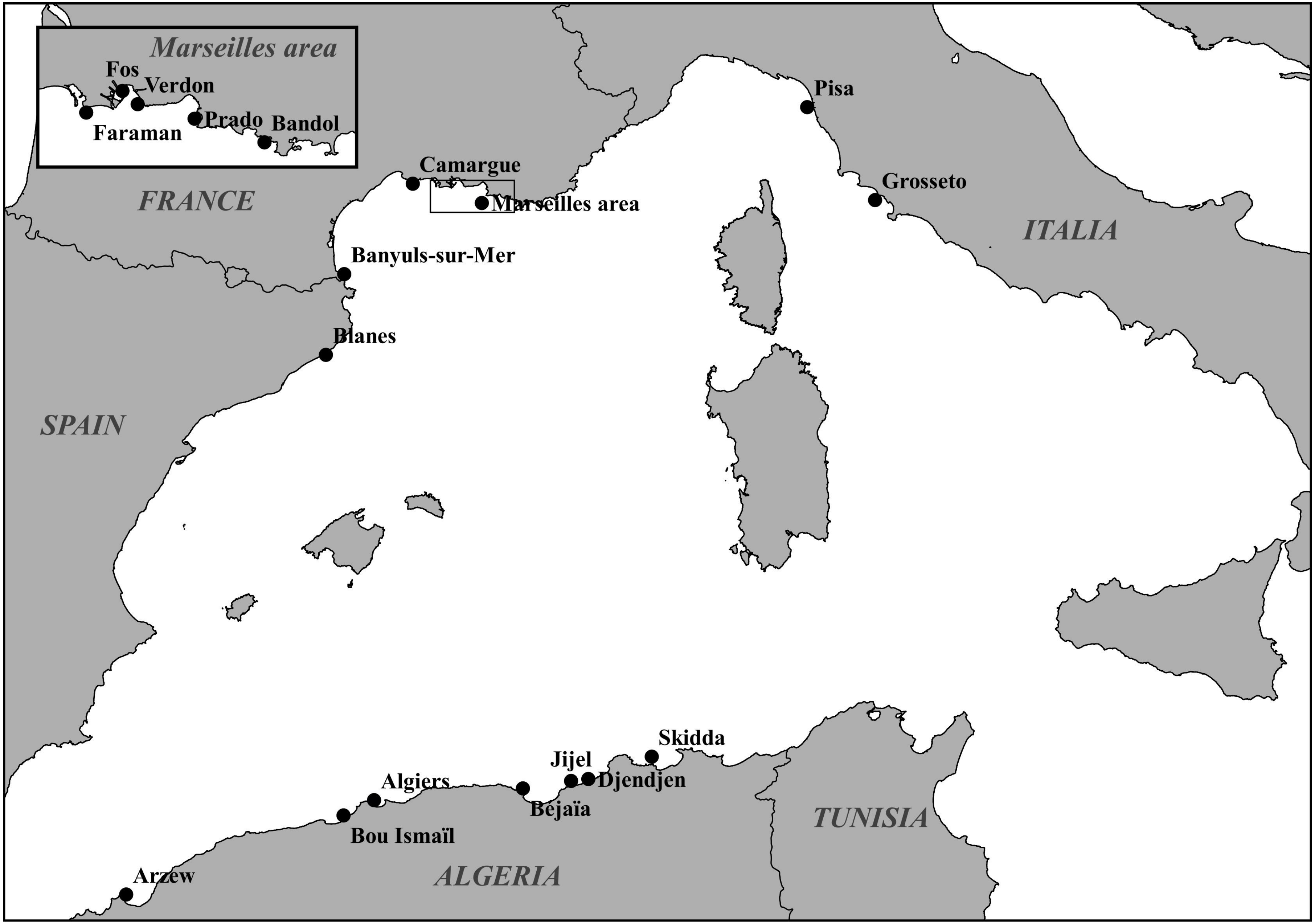
Fig. 1. Locations of the studied sites in the western basin of the Mediterranean Sea

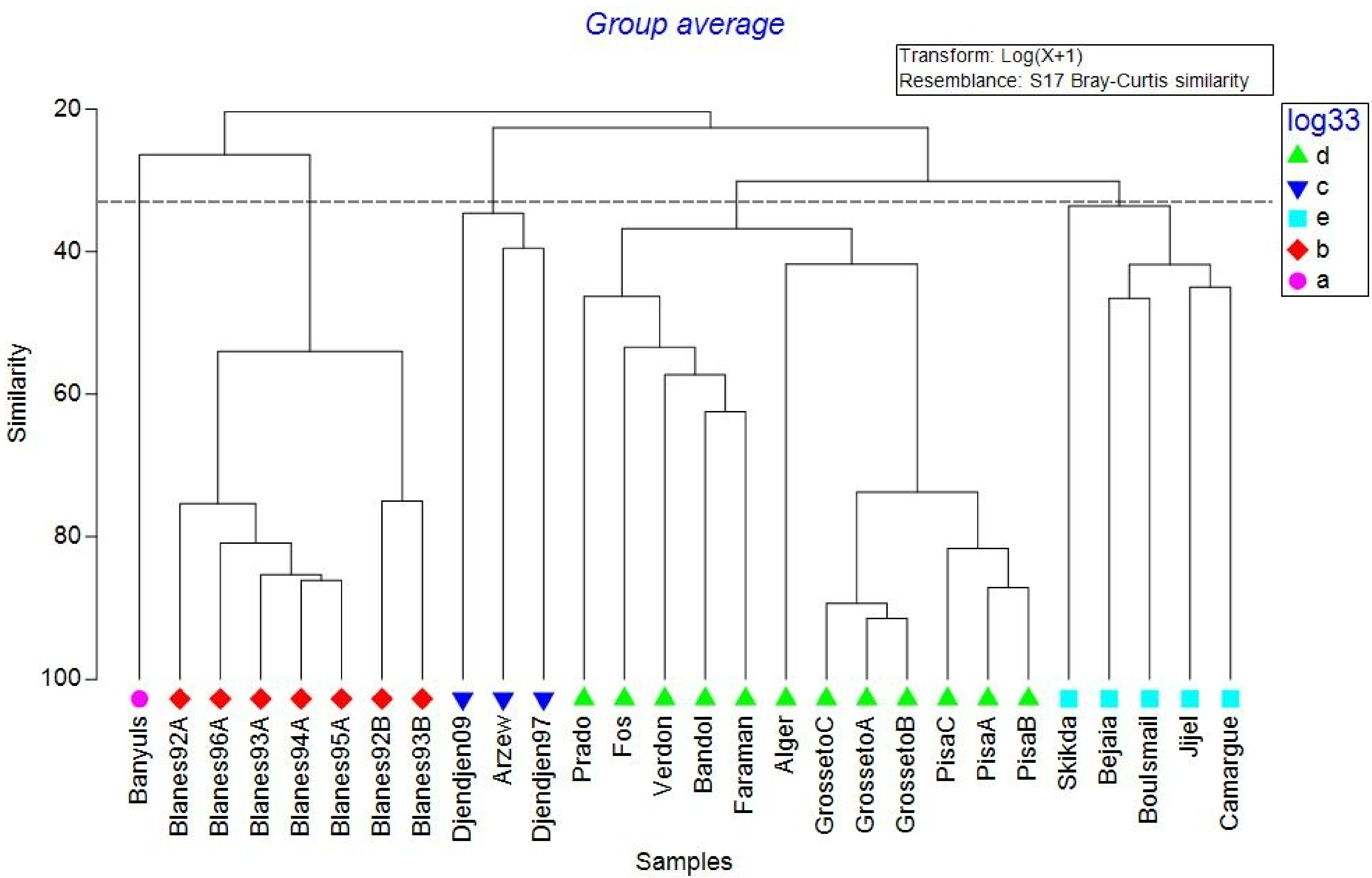
Fig. 2. Dendrogram using group average method for clustering, showing the Bray–Curtis similarity index based on abundance [with log (x + 1) transformation] using the 108 top ten species and the 28 situations matrix.

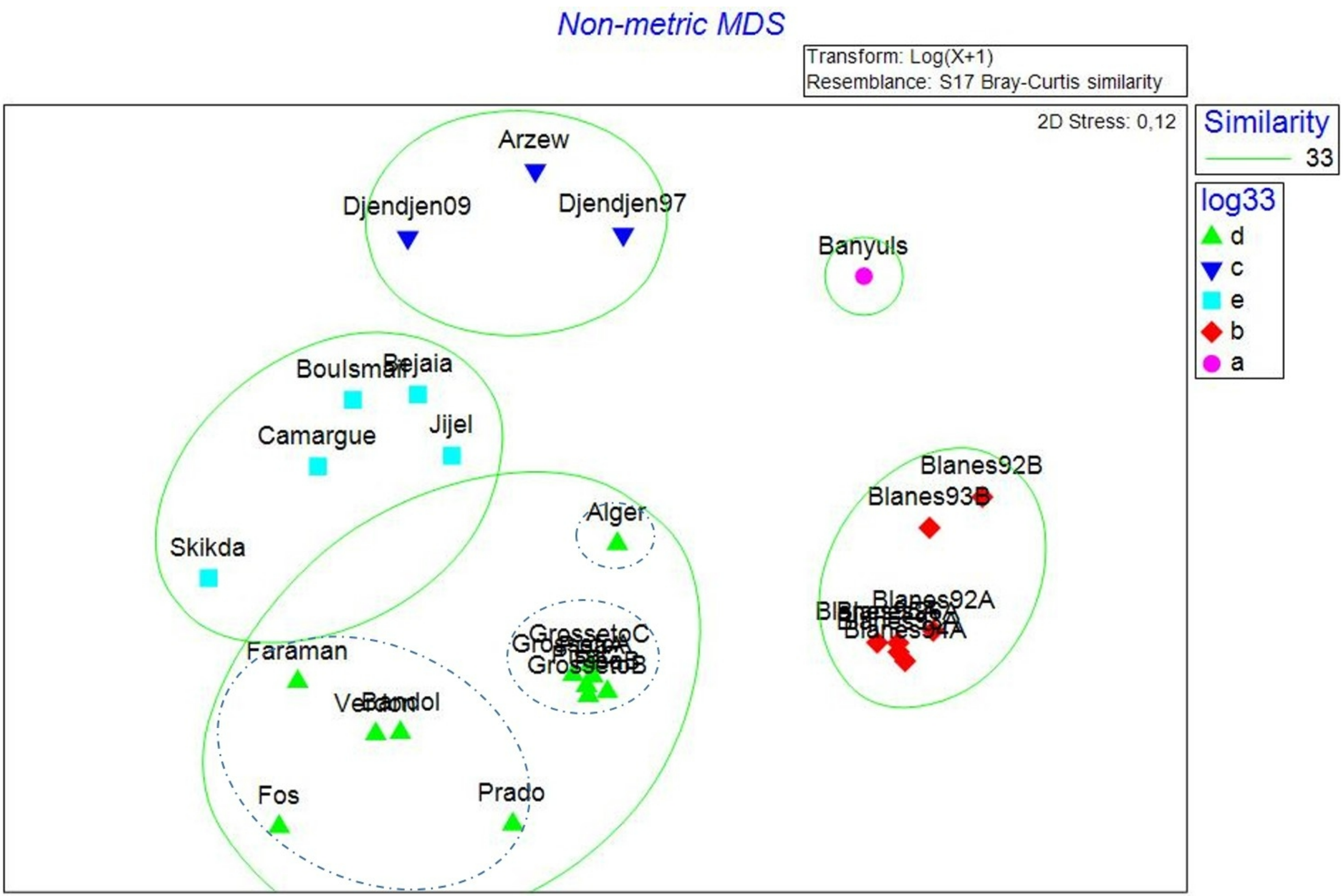
Fig. 3. MDS ordination plot of Bray–Curtis similarities based on abundance data [with log (x + 1) transformation] using the 108 top ten species and the 28 situations matrix; solid lines show groups identified at 33% similarity levels in the cluster analysis (Fig. 2).

Fig. 4. Ordination plot of the 28 situations by factorial correspondence analysis (FCA) based on abundance-weighted biological traits for axes 1 and 2 (upper part). Factorial maps of the five main biological traits contributing to station variability (lower part). For abbreviations, see Table 4.

Fig. 5. Proportion of the seven functional groups (see Table 9) for each station group (see Table 8).


Marseilles area
Fos
Verdon
Faraman
Prado
Bandol
FRANCE
Camargue
Marseilles area
Banyuls-sur-Mer
Blanes
SPAIN
Pisa
Grosseto
ITALIA
Skidda
Jijel
Djendjen
Algiers
Béjaïa
Bou Ismaïl
Arzew
ALGERIA
TUNISIA


Group average
Transform: Log(X+1)
Resemblance: S17 Bray-Curtis similarity
log33
d
c
e
b
a
Similarity
20
40
60
80
100
Banyuls
Blanes92A
Blanes96A
Blanes93A
Blanes94A
Blanes95A
Blanes92B
Blanes93B
Djendjen09
Arzew
Djendjen97
Prado
Fos
Verdon
Bandol
Faraman
Alger
GrossetoC
GrossetoA
GrossetoB
PisaC
PisaA
PisaB
Skikda
Bejaia
Boulsmail
Jijel
Camargue
Samples


Non-metric MDS
Transform: Log(X+1)
Resemblance: S17 Bray-Curtis similarity
2D Stress: 0,12
Similarity
33
log33
d
c
e
b
a
Arzew
Djendjen09
Djendjen97
Banyuls
Boulsmail
Bejaia
Camargue
Jijel
Skikda
Alger
Blanes92B
Blanes93B
Blanes92A
Blanes94A
GrossetoC
GrossetoB
Faraman
Bandol
Fos
Prado

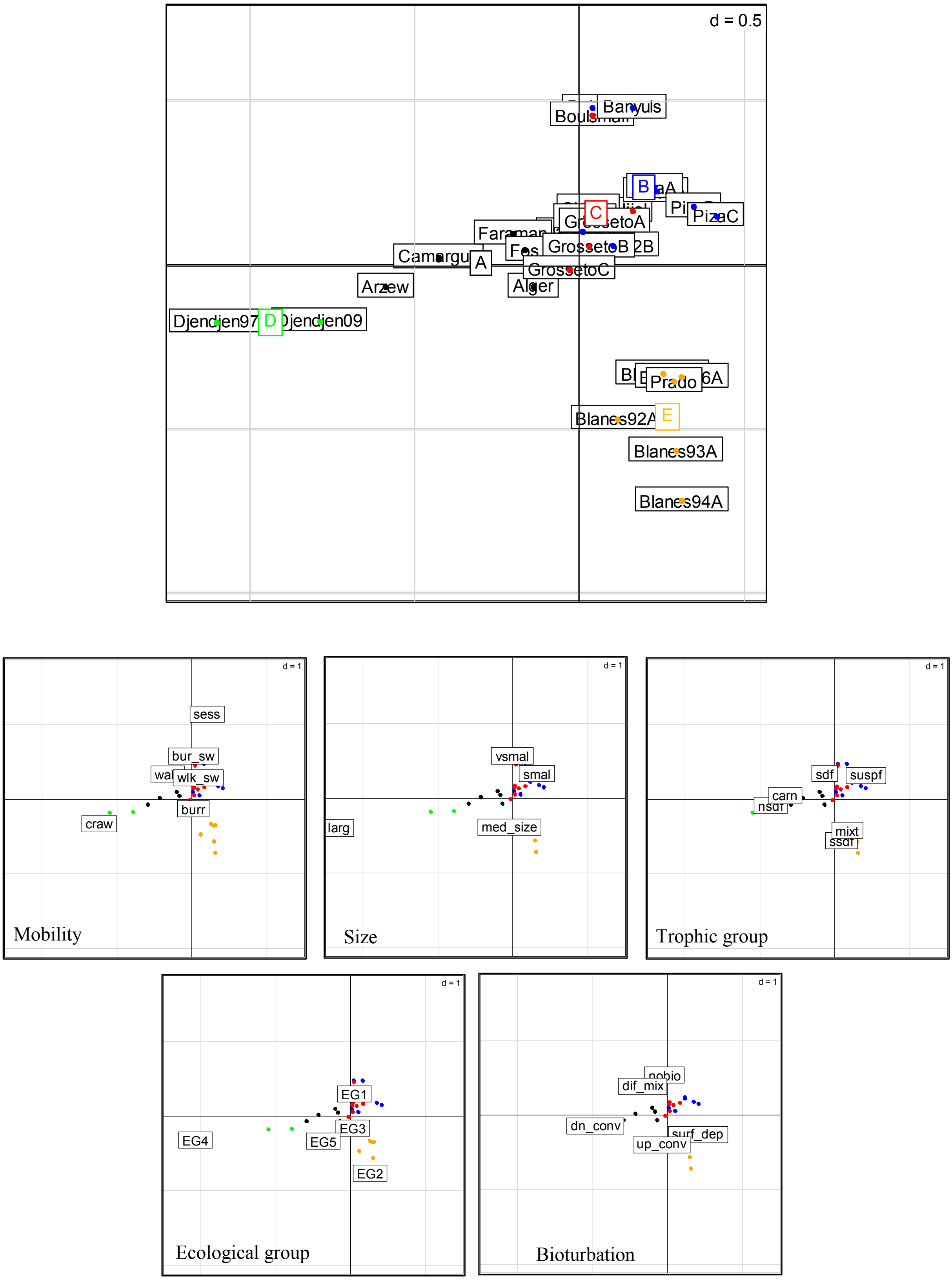

d = 0.5
Banyuls
B
C
GrossetoB
GrossetoC
Alger
Arzew
A
PizaC
Djendjen97
D
Djendjen09
Prado
Blanes92A
E
Blanes93A
Blanes94A
d = 1
sess
bur_sw
wlk_sw
burr
craw
Mobility
vsmal
smal
larg
med_size
Size
sdf
suspf
carn
mixt
Trophic group
EG1
EG3
EG4
EG5
EG2
Ecological group
dif_mix
dn_conv
up_conv
surf_dep
Bioturbation

Figure 4

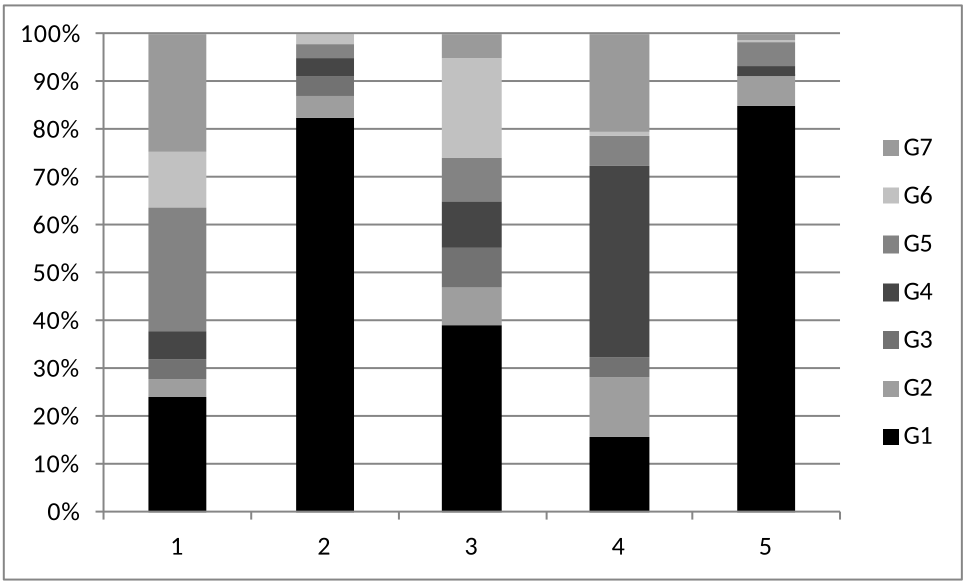


Fig. 5.

Table 1

Main characteristics of the benthic communities and human pressures at the sampling sites. Information on the sampling design is also indicated for each sampling station.

Location of the sites	Date	Sampling's season	Stations	Number of stations or temporal observations	Depth (m)	Sampling	Origin of changes and Human pressure
Marseilles area, France	1967-1968	Spring (April to June)	Bandol Faraman Fos Prado Verdon	3 3 1 2 2	5-11	Brett's hydraulic pump	Reference state from Masse (1970, 1971a,b,c,d)
Camargue area, France	2011	March-April	Camargue	19	2.5-13	0.1 m² Day grab	Two main human pressures, at the east the input of the Rhône River, and in the west forbidden trawling's near the coast in shallow waters
Banyuls-sur-mer, France	1994	May	53	1	10	0.1 m² Van Veen grab	Sediment instability with a reduction of silt between reference situation in 1968 and 1994, and occurrence of high temperature (Grémare et al., 1998)
Blanes (Girona, Spain)	1992-1996	All year	2	Biweekly to monthly	15	0.17 m² Van Veen grab	Station A. Urbanization (Balnes town) Station B. Riverine inputs (Tordera river)
Tuscany, Italy	2005 2005 2006 2006	September September May May	Pisa Grosseto Pisa Grosseto	18 18 18 18	5-10	0.1 m² Van Veen grab	Anthropogenic pressure due to organic and nutrients input of Arno river (Pisa) and natural heavy metals since the presence of the most important mineral deposits of the whole Tuscany (Grosseto) (ARPAT 2007).
Algerian coast	1984-85 1985	One year January	Algiers Arzew	4 8	8-10 10-20	0.1 m^{-2} Van Veen grab (for Algiers and	Sewage, urbanization (Fetzara, Jijel, Bou Ismail) Hydrocarbons, sewage, heavy metal, urbanization

	1983 1988 1986 1990	December August July February	Bejaia Bou Ismail Jijel Skikda	6 9 19 8	9-25 10-25 10-21 13-25	Jijel) and 0.1 m^{-2} Smith McIntyre grab in other sites	(Arzew, Bejaia, Algiers Bay)
Algerian coast	1997 2009	July December	Djendjen Djendjen	38 21	5-19 8-22	0.1 m^{-2} Van Veen grab 0.1 m^{-2} Van Veen grab	New harbour in a zone without industrialization and pollution

Table 2

Threshold values between the several ecological statuses considered for the selected benthic indicators: AMBI, BO2A, BPOFA, H', Ind.Qual., Ind.Pollu.Degra. and ITI (see Dauvin et al., 2012 and 2016; Bellan, 2007, 2008).

	AMBI	BO2A	BPOFA	H'	IQ	PD	ITI classes	ITI values
High	0-1.2	0.000-0.025	0.000-0.030	+∞-4.00	>5	1.00-2.00		
Good	1.2-3.3	0.025-0.129	0.031-0.125	4.00-3.00	4.00-5.00	2.00-3.00	Normal	60-100
Moderate	3.3-4.3	0.130-0.198	0.126-0.186	3.00-2.00	3.00-4.00	3.00-4.00	Perturbed	30-60
Poor	4.3-5.5	0.199-0.254	0.187-0.236	2.00-1.00	2.00-3.00	4.00-5.00	Degraded	0-30
Bad	5.5-7.0	0.255-0.301	0.237-0.301	1.00-0.00	1.00-2.00	>5		

Table 3

Groups of species used for measuring the Environmental Quality Index (Ind.Qual.) and the Pollution-Degradation Index (Ind.Poll.Degra.) (From Bellan, 2007).

Categories of species	Ind. Qual.	Ind. Pollu-Degra
IP1: Pollution indicative rank 1 (internal polluted sub zone) species	1	6
IP2: Pollution indicative rank 2 (external polluted sub zone) species	2	5
Opp. 1. Opportunistic rank 1, ‘sentinel’ of the subnormal zone species	3	4
Opp. 1. Opportunistic rank 2, large ecological distribution species	4	3
Sed. Quality of sediment indicative species	5	2
Bioc. Characteristics of biocenose species	6	1

Ind. Qual.= (1 x %IP1 + 2 x %IP2 + 3 x %Opp1 + 4 x Opp2 = 5 x %Sed. + 6 x %Bioc.)

Poll.-Degr.= (6 x %IP1 + 5 x %IP2 = 4 x %Opp1 + 3x Opp2+ 2 x %Sed. + 1 x %Bioc)

Table 4

Biological traits and modalities of species selected for the biological traits analysis. Abbreviations in brackets are the same used in Figure 4.

Biological trait	N°	Modality	Definition
Larval development	1	Planctotrophic	Planktonic larvae feeding on plankton
	2	Lecithotrophic	Planktonic larvae feeding on yolk
	3	Direct development	No planktonic larvae
Life span	1	Short	< 2 years
	2	Medium	2-5 years
	3	Long	> 5 years
Mobility	1	Swimmer	Adults actively swim in water column
	2	Walker	Adults capable of extensive movement at sediment surface
	3	Crawler	Adults with limited movements at sediment surface
	4	Burrower	Endofauna that moves in the sediment
	5	Sessile	Non mobile adults (attached, limited to a tube or a burrow)
	6	Burrower & Swimmer	Diel migrations
	7	Walker & Swimmer	Diel migrations
Living position	1	Epifauna	Live at the surface of the sediment
	2	Endofauna	Live in the sediment
Habit	1	Tube-dweller	Adults builds tube
	2	Burrow-dweller	Adults lives in burrows (temporary or permanent)
	3	Free-living	Adults not limited by a structure
Bioturbation	1	No bioturbation	Do not induce sediment displacement
	2	Surface deposition	Surface displacement
	3	Upward conveyor	Displacement of particles from depth to surface
	4	Downward conveyor	Displacement of particles from surface to depth
	5	Diffusive mixing	Small-scale displacement
Trophic groups	1	Non-specific deposit feeder	Feeds on particles at sediment surface and within the sediment
	2	Surface deposit feeder	Feeds on particles at sediment's surface
	3	Sub-surface deposit feeder	Feeds on particles within the sediment
	4	Suspension feeder	Feeds on particles within the water column
	5	Carnivorous	Feeds on live prey
	6	Omnivorous	Generalist feeder
	7	Mixtes	Feeds on particles in the water column and at sediments' surface
Ecological groups (AMBI)	1	Sensitives	Only present in unpolluted areas
	2	Indifferent	Always present at low densities
	3	Tolerant	More abundant in slightly enriched areas
	4	Second-order opportunists	Present in unbalanced conditions
	5	First-order opportunists	Proliferate in reduced sediment
Substratum affinity	1	Mud	Particles <63µm are present or dominant
	2	Sandy mud	50% to < 90% sand, mud remainder
	3	Muddy sand	10% to < 50% sand; mud remainder

	4	Fine clean sand	> 90% sand, median 0.125 to < 0.25 mm
	5	Coarse clean sand	> 90% sand, median 0.500 to < 1.00 mm
Maximal size	1	Very small	< 10 mm
	2	Small	10 to 20 mm
	3	Medium	21 to 100 mm
	4	Large	> 100 mm

Table 5

Summary of the results of the four cluster analyses obtained for 520 species and the 108 top ten species based on Log(x+1) transformed abundances (Bray-Curtis similarity) and Presence / Absence of the species (Sørensen index).

Transformation	Log(x+1 abundance)	Log(x+1 abundance)	Presence/Absence	Presence/Absence
Matrix (species x situations)	520 x 28	108 x 28	520 x 28	108 x 28
Group I	Banyuls	Banyuls	Banyuls	Banyuls
Group II	Blanes (7)	Blanes (7)	Blanes (7)	Blanes (7)
Group III A	Marseilles (5)	Marseilles (5)	Marseilles (5)	Marseilles (5) + Skikda (Algeria)
Group III B	Italy (6)	Italy (6)	Italy (6)	Italy (6) + Alger (Algeria)
Group III C	Alger (Algeria)	Alger (Algeria)	-	-
Group IV	Algeria (7) + Camargue (France)	Algeria (4) + Camargue (France)	Algeria (8) + Camargue (France)	Algeria (4) + Camargue (France)
Group V	-	Djendjen (2) + Arzew (Algeria)		Djendjen97 + Arzew (Algeria)

Table 6. Total number of individuals for the 20 top species, with their numerical rank in the 28 situations, with mean total density of the macrobenthos per m² in the 28 situations. > 20 indicates that the species in not among the 20 top species and 0 indicates the absence of the species at the site. (Ban: Banyuls-sur-Mer; Bl92A, Bl92B, Bl93A, Bl93B, Bl94A, Bl95A, Bl96A: Blanes, years 1992 to 1996, sites A & B; Fara: Faraman; Verd: Verdon; GrA, GrB, GrC: Grosseto, sites A, B & C; Dj97, Dj09: Djendjen, years 1997 & 2009; Ismai: Bou Ismail; Cama: Camargue).

	Total	**Ban**	**Bl92A**	**Bl92B**	**Bl93A**	**Bl93B**	**Bl94A**	**Bl95A**	**Bl96A**	**Bandol**	**Fara**	**Fos**	**Prado**	**Verd**	**GrA**	**GrB**	**GrC**	**PisaA**	**PisaB**	**PisaC**	**Alger**	**Arzew**	**Dj97**	**Dj09**	**Bejaia**	**Ismail**	**Jijel**	**Skikda**	**Cama**
Spisula subtruncata	59230	**3**	**2**	**1**	**2**	**1**	**2**	**3**	**2**	33	20	0	12	**1**	**4**	**5**	**9**	**1**	**1**	**1**	**2**	28	0	>20	>20	0	**2**	>20	>20
Owenia fusiformis	37690	**2**	**1**	**3**	**1**	>20	**1**	**1**	**1**	16	13	13	**5**	>20	>20	18	>20	18	**3**	13	**6**	17	>20	**5**	17	18	20	0	**5**
Phoronis psammophila	12992	0	0	0	0	0	0	0	0	**8**	26	30	**1**	>20	0	0	0	12	**9**	**10**	**5**	0	0	0	>20	>20	0	0	0
Spiophanes reyssi	5570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	>20	>20	0	**2**	0	0	0	0	0	0	0	0	0
Lucinella divaricata	5015	>20	**3**	>20	**3**	17	**3**	**2**	**3**	>20	>20	11	>20	15	0	0	0	0	0	0	>20	>20	0	0	0	0	>20	>20	0
Ditrupa arietina	4837	**1**	>20	**2**	19	**6**	**5**	**7**	20	0	0	0	0	0	0	0	0	0	0	0	0	**3**	0	0	**1**	>20	0	0	0
Apseudopsis latreillii	4564	>20	0	0	0	0	0	0	0	0	0	0	0	0	**2**	**2**	**3**	**2**	**2**	>20	0	15	0	0	18	**3**	>20	16	0
Spio decoratus	3382	**10**	**9**	>20	**6**	**2**	**9**	**4**	15	>20	0	0	**2**	0	>20	>20	>20	>20	>20	>20	18	>20	0	>20	0	>20	>20	0	>20
Paradoneis armata	3054	>20	**5**	16	**4**	13	**4**	**5**	**7**	0	0	0	18	0	**10**	**9**	**6**	15	**10**	**5**	0	0	0	0	0	0	0	0	0
Mediomastus sp.	2991	0	**8**	11	**5**	**10**	**7**	**8**	**8**	0	0	0	0	0	**7**	**3**	**2**	11	13	**8**	**10**	0	**9**	0	0	0	0	0	0
Loripinus fragilis	2745	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	**1**	**1**	>20	>20	>20	0	0	0	0	0	0	0	0	0
Prionospio caspersi	2689	>20	12	>20	15	0	19	**6**	**4**	12	0	0	>20	>20	**6**	**7**	**4**	**5**	**7**	**7**	**7**	0	0	>20	19	0	0	0	0
Thracia phaseolina	2604	>20	16	>20	11	11	**6**	15	**6**	15	0	17	>20	12	15	11	11	**6**	**6**	**3**	>20	0	0	0	0	0	>20	>20	>20
Ampelisca brevicornis	2056	0	0	0	0	0	0	0	0	**2**	11	12	15	**6**	>20	>20	>20	**4**	**4**	14	0	>20	15	17	**8**	**8**	**1**	**6**	11
Magelona mirabilis	1366	0	0	0	0	0	0	0	0	**10**	**1**	**6**	**6**	**3**	>20	>20	>20	>20	18	15	>20	0	0	0	>20	0	0	0	**9**
Pseudocuma longicorne	1356	0	0	0	0	0	0	0	0	14	>20	0	**4**	**10**	>20	>20	>20	20	**5**	>20	15	0	0	0	0	0	0	>20	0
Tellina fabula	1326	0	0	0	0	0	0	0	0	**5**	15	**9**	20	**7**	**5**	**4**	**5**	>20	19	16	0	0	0	18	0	0	0	**3**	0
Ampelisca tenuicornis	1280	0	0	0	0	0	0	0	0	0	0	0	0	0	>20	>20	>20	**3**	**8**	>20	0	0	0	0	>20	>20	>20	0	0
Scoletoma impatiens	1178	0	0	0	0	0	0	0	0	**4**	**3**	**3**	16	**9**	18	15	**8**	>20	>20	>20	**1**	16	**8**	**3**	**9**	29	15	24	0
Chamelea gallina	1097	**8**	>20	>20	>20	>20	>20	>20	>20	19	17	**1**	11	**2**	>20	>20	>20	19	15	12	**3**	29	0	0	14	0	**3**	12	>20
Mean density per m²		3290	9110	2737	23367	7485	13140	4080	1764	1329	1286	744	16429	2105	4818	4660	3661	11300	24594	32901	1336	400	754	320	588	590	457	268	282

Table 7

Values of indices measuring the Quality status (based on 28 situations and 108 top 10 species) according to the European Water Framework Directive. High in Blue, Good in green, Moderate in yellow, Poor in orange and Bad in black. For ITI, only three statuses are assessed represented by three colours: Normal in blue, Perturbed in yellow and Degraded in red.

Situations	H'(log2)	AMBI	BO2A	BPOFA	ITI	IQ	PD
Banyuls	0.788	0.092	0.000	0.001	95.445	4.175	2.825
Blanes92A	3.165	1.479	0.017	0.047	35.059	5.489	1.511
Blanes92B	3.334	0.983	0.008	0.053	66.855	5.198	1.802
Blanes93A	2.084	1.271	0.002	0.027	46.579	5.807	1.193
Blanes93B	3.539	1.286	0.025	0.115	62.249	5.205	1.795
Blanes94A	1.599	1.277	0.000	0.010	41.921	5.891	1.109
Blanes95A	3.020	1.190	0.005	0.044	43.173	5.611	1.389
Blanes96A	2.426	0.968	0.002	0.023	56.382	5.825	1.175
Bandol	3.996	1.033	0.000	0.009	53.871	5.675	1.325
Faraman	2.817	0.258	0.001	0.001	41.652	5.715	1.197
Fos	3.095	0.625	0.000	0.000	62.403	5.395	1.406
Prado	1.626	1.624	0.001	0.055	78.298	5.982	1.018
Verdon	3.117	0.220	0.001	0.001	71.098	5.910	1.090
GrossetoA	3.999	1.238	0.003	0.040	39.649	5.520	1.480
GrossetoB	4.173	1.388	0.005	0.061	38.723	5.249	1.751
GrossetoC	4.289	1.680	0.019	0.091	34.256	4.941	2.059
PizaA	3.249	0.828	0.010	0.029	66.783	5.670	1.330
PizaB	2.405	0.545	0.000	0.015	78.155	5.840	1.160
PizaC	1.628	0.132	0.000	0.070	82.171	5.946	1.059
Alger	3.497	1.869	0.023	0.061	58.911	4.920	2.080
Arzew	3.710	1.603	0.087	0.100	33.556	4.487	2.513
Djendjen97	3.642	2.909	0.134	0.148	29.954	4.154	2.846
Djendjen09	3.618	2.372	0.088	0.125	31.738	4.801	2.476
Bejaia	3.215	0.470	0.001	0.007	62.145	4.890	2.110
BouIsmail	4.173	1.229	0.004	0.007	58.430	5.523	1.477
Jijel	4.041	0.435	0.007	0.011	56.316	5.455	1.545
Skikda	4.038	0.890	0.012	0.022	36.502	5.367	1.633
Camargue	4.243	0.960	0.003	0.022	47.229	5.344	1.656

Table 8

Species (among 108 top ten species) contributing to 80% of the abundance of the five groups of stations, showing stations forming the five groups.

	Species contributing to 80% (Decreasing order)		Stations
A	*Magelona mirabilis* *Scoletoma impatiens* *Chamelea gallina* *Urothoe grimaldii* *Spisula subtruncata* *Owenia fusiformis* *Sigalion mathildae* *Pariambus typicus* *Phoronis psammophila*	*Chaetozone* sp. *Aponuphis bilineata* *Prionospio caspersi* *Urothoe pulchella* *Nephtys hombergii* *Bathyporeia guilliamsoniana* *Paradoneis harpagonea* *Euclymene oerstedi* *Lumbrineris latreilli*	Alger Arzew Camargue Faraman Fos
B	*Spisula subtruncata* *Spiophanes reyssi* *Ditrupa arietina* *Apseudopsis latreillii*	*Owenia fusiformis* *Thracia phaseolina* *Ampelisca brevicornis*	Bejaia Blanes92B Blanes93B Banyuls Verdon PisaA PisaB PisaC
C	*Loripinus fragilis* *Apseudopsis latreillii* *Tellina fabula* *Mediomastus* sp. *Autonoe spiniventris* *Spisula subtruncata* *Prionospio caspersi* *Paradoneis armata* *Scoletoma impatiens*	*Bathyporeia guilliamsoniana* *Paradialychone filicaudata* *Ampelisca brevicornis* *Sigalion mathildae* *Cylichna cylindracea* *Thracia phaseolina* *Perioculodes longimanus* *Tellina tenuis*	Bou Ismail Jijel Skikda Bandol GrossetoA GrossetoB GrossetoC
D	*Heteromastus filiformis* *Lumbrineris coccinea* *Amphiura chiajei* *Trichobranchus glacialis* *Corbula gibba* *Scoletoma impatiens* *Abra alba*	*Monocorophium acherusicum* *Lumbrineris latreilli* *Owenia fusiformis* *Mediomastus* sp. *Scolelepis (Parascolelepis) tridentata* *Orbinia latreillii* *Aricidea (Strelzovia) suecica*	Djendjen97 Djendjen09
E	*Owenia fusiformis* *Phoronis psammophila*	*Spisula subtruncata* *Lucinella divaricata*	Blanes92A Blanes93A Blanes94A Blanes95A Blanes96A Prado

Table 9

Biological trait profiles of species belonging to the seven functional groups on Figure 5 (BT: Biological Traits of the 108 top ten species).

	Dominant BT of the species	Species		Comments
G1	Long lifespan Sessile Suspension feeders Mud substrate	*Abra alba* *Callista chione* *Chamelea gallina* *Digitaria digitaria* *Ditrupa arietina* *Echinocardium cordatum* *Echinocardium mediterraneum* *Ensis ensis* *Galathowenia oculata* *Loripinus fragilis* *Lucinella divaricata* *Mactra stultorum* *Myriochele heeri* *Owenia fusiformis* *Pharus legumen* *Phoronis psammophila*	*Scolaricia typica* *Scolelepis (Parascolelepis) tridentata* *Solen marginatus* *Spio martinensis* *Spiochaetopterus costarum* *Spiophanes bombyx* *Spiophanes reyssi* *Spisula subtruncata* *Tellina fabula* *Tellina pulchella* *Tellina tenuis* *Terebella lapidaria* *Thracia phaseolina* *Trichobranchus glacialis*	Group dominated by mollusc assemblage and with species characteristic of the WSFS
G2	Walker Crawler Free living No bioturbation Coarse sand substrate	Actiniidae *Amphiura chiajei* *Branchiostoma lanceolatum* *Chone duneri* *Chone infundibuliformis* *Cylichna cylindracea* *Diogenes pugilator* *Euclymene oerstedi* *Euclymene santandarensis*	*Exogone verugera* *Myrianida prolifera* *Paradialychone filicaudata* *Parexogone hebes* *Protodorvillea kefersteini* *Sphaerosyllis taylori* *Spio decoratus* *Syllis* sp.	Mainly species of coarse sediment (small polychaetes)
G3	Very small Burrower-Swimmer Walker-Swimmer	*Ampelisca brevicornis* *Ampelisca sarsi* *Ampelisca spinipes* *Ampelisca tenuicornis* *Autonoe spiniventris*	*Lembos websteri* *Monocorophium acherusicum* *Pariambus typicus* *Photis longicaudata*	All species amphipods
G4	Conveyers (up/down) EG 5 Mud and sandy mud substrates	*Anobothrus gracilis* *Aphelochaeta marioni* *Axinulus eumyarius* *Capitella capitata* *Capitella minima* *Caulleriella bioculata* *Chaetozone* sp.	*Corbula gibba* *Heteromastus filiformis* *Mastobranchus trinchesii* *Mediomastus* sp. *Notomastus (Clistomastus) lineatus* *Pseudopolydora antennata*	Opportunistic species (found in sediment enriched in organic matter)
G5	Mud substrate Up conveyers Sub-surface deposit feeders	*Aponuphis bilineata* *Aricidea (Acmira) catherinae* *Aricidea (Strelzovia) suecica* *Aponuphis brementi* *Laonice cirrata* *Magelona minuta* *Magelona mirabilis*	*Orbinia latreillii* *Paradoneis armata* *Paradoneis harpagonea* *Prionospio caspersi* *Prionospio cirrifera* *Prionospio malmgreni* *Scoloplos (Scoloplos) armiger*	Non-conventional BT assemblage dominated by small polychaetes mainly from Paraonidae and Spionidae families
G6	Very small Burrower-Swimmer Walker-Swimmer Diffusive mixing	*Apseudopsis latreillii* *Atylus* sp. *Bathyporeia guilliamsoniana* *Bathyporeia pilosa* *Paramysis (Longidentia) helleri* *Perioculodes longimanus* *Pseudocuma longicorne* *Siphonoecetes (Centraloecetes) dellavallei*	*Siphonoecetes (Siphonoecetes) sabatieri* *Urothoe brevicornis* *Urothoe elegans* *Urothoe grimaldii* *Urothoe intermedia* *Urothoe poseidonis* *Urothoe pulchella*	All crustacean species including 12 amphipods characteristic of the WSFS
G7	Walker Large size Walker-swimmer Up convoyer Sub-surface deposit feeders	*Glycera capitata* *Glycera tridactyla* *Glycera unicornis* *Hilbigneris gracilis* *Lumbrineris coccinea*	*Lumbrineris latreilli* *Nephtys hombergii* *Scoletoma impatiens* *Sigalion mathildae* *Sigambra tentaculata*	Large carnivorous polychaetes with coarse sand affinity

Highlights

Biocoenosis of Well Sorted Fine Sands was study on four Mediterranean sites.

Structure, ecological status and diversity of the macrofauna were analysed using three categories of benthic indices.

Biological Traits Analysis (BTA) highlighted the presence of three groups of species.

Cluster analyses showed a particular taxonomic richness and dominant species for each site.

Good or high Quality Status, except for one location on the Algerian coast were found.

WSFS showed a high resilience in spite of numerous human pressures.