



**HAL**  
open science

## Variability in the structure of epiphytic assemblages of in relation to human interferences in the Gulf of Gabes, Tunisia

Mounir Ben Brahim, Asma Hamza, Imen Hannachi, Ahmed-Riadh Rebai,  
Othman Jarboui, Abderrahmen Bouain, Lotfi Aleya

► **To cite this version:**

Mounir Ben Brahim, Asma Hamza, Imen Hannachi, Ahmed-Riadh Rebai, Othman Jarboui, et al.. Variability in the structure of epiphytic assemblages of in relation to human interferences in the Gulf of Gabes, Tunisia. *Marine Environmental Research*, 2010, 70 (5), pp.411. 10.1016/j.marenvres.2010.08.005 . hal-00631670

**HAL Id: hal-00631670**

**<https://hal.science/hal-00631670v1>**

Submitted on 13 Oct 2011

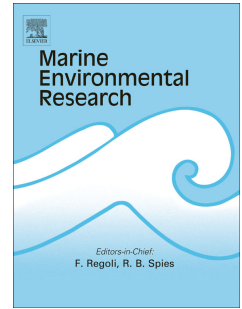
**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Accepted Manuscript

Title: Variability in the structure of epiphytic assemblages of *Posidonia oceanica* in relation to human interferences in the Gulf of Gabes, Tunisia

Authors: Mounir Ben Brahim, Asma Hamza, Imen Hannachi, Ahmed Rebai, Othman Jarboui, Abderrahmen Bouain, Lotfi Aleya



PII: S0141-1136(10)00120-0

DOI: [10.1016/j.marenvres.2010.08.005](https://doi.org/10.1016/j.marenvres.2010.08.005)

Reference: MERE 3471

To appear in: *Marine Environmental Research*

Received Date: 25 March 2010

Revised Date: 31 July 2010

Accepted Date: 16 August 2010

Please cite this article as: Ben Brahim, M., Hamza, A., Hannachi, I., Rebai, A., Jarboui, O., Bouain, A., Aleya, L. Variability in the structure of epiphytic assemblages of *Posidonia oceanica* in relation to human interferences in the Gulf of Gabes, Tunisia, *Marine Environmental Research* (2010), doi: 10.1016/j.marenvres.2010.08.005

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

1 **Variability in the structure of epiphytic assemblages of *Posidonia oceanica* in relation to**  
2 **human interferences in the Gulf of Gabes, Tunisia**

3

4

5

6 Mounir Ben Brahim<sup>1,2</sup>, Asma Hamza<sup>2</sup>, Imen Hannachi<sup>1,2</sup>, Ahmed Rebai<sup>3</sup>, Othman Jarboui<sup>2</sup>,  
7 Abderrahmen Bouain<sup>1</sup> and Lotfi Aleya\*<sup>4</sup>

8

9

10 <sup>1</sup> Université de Sfax, Faculté des Sciences Sfax. Route Soukra Km 3.5, BP: 802, 3018 Sfax.  
11 Tunisia

12 <sup>2</sup> Institut National des Sciences et Technologies de la Mer, Centre de Sfax, Rue Madagascar,  
13 BP 1035, Sfax, CP 3018, Tunisie.

14 <sup>3</sup> Centre de Biotechnologie de Sfax, Route Sidi Mansour Km 6, Sfax, Tunisie

15 <sup>4</sup> Université de Franche-Comté, Laboratoire de Chrono-Environnement, UMR CNRS 6249 1,  
16 Place Leclerc, F-25030 Besançon cedex, France.

17

18 \*Corresponding author: [lotfi.aleya@univ-fcomte.fr](mailto:lotfi.aleya@univ-fcomte.fr)

19 Phone: 03 81 66 57 64

20 Fax: 03 81 66 57 97

21

22

23

24

25

**1 Abstract**

2 In this study we evaluate whether the pattern of spatial variability of the macro-epiphytes  
3 assemblages of leaves of *Posidonia oceanica* differed in relation to anthropogenic  
4 interference in the Gulf of Gabes (southern coast of Tunisia). A hierarchical sampling design  
5 was used to compare epiphytic assemblages at 5m depth in terms of abundance and spatial  
6 variability at disturbed and control locations. The results indicate that the biomass and mean  
7 percentage cover decreased at locations near the point of sewage outlet in comparison to  
8 control locations. These losses were related to the distance from the source of disturbance.  
9 This study revealed that the diversity is reduced in disturbed locations by the loss of biomass  
10 and the mean percentage cover, explained by means of a multiple-stressor model which plays  
11 an important role in the macro-epiphytes setting. It is urgent to propose the best management  
12 plans to save the remaining *P. oceanica* meadow in the Gulf of Gabes and its associated  
13 epiphytes.

14

15

16 **Keywords:** Macro-epiphytes ; *Posidonia oceanica* ; disturbance ; spatial variability ; Gabès  
17 Gulf.

18

19

20

21

22

23

24

25

26

## 1 **1. Introduction**

2 Over the past 20 years, the Gulf of Gabes, on the southeast coast of Tunisia, has produced  
3 more than 65% of the annual fish yield in Tunisia (Ben Mustapha, 1995; C.G.P., 1996), being  
4 favoured by widespread seagrass beds widely recognized as key ecosystems in temperate and  
5 tropical infra littoral habitats (Hemminga and Duarte, 2000; Boudouresque et al., 2009).  
6 However, fish production is gradually decreasing parallel to the decline of littoral beds of the  
7 endemic Mediterranean seagrass *Posidonia oceanica* (L.) Delile species as the coastal area of  
8 the Gulf is now a threatened biotope mainly due to the pressure of anthropogenic expansion  
9 and dumping of large quantities of phosphogypsum and other chemical products which  
10 severely impacted benthic habitats ((Hamza-Chaffai et al., 1999, Bejaoui et al., 2004). The  
11 loss of the native vegetable cover in the Gulf of Gabes is estimated at 90% with the *P.*  
12 *oceanica* beds being replaced by the opportunistic and caulerpenyne-producing green algae  
13 *Caulerpa prolifera* (Forsskål) Lamouroux in deeper zones (Hamza et al., 1995; Ramos-Espla  
14 et al., 2000). The remaining *Posidonia* meadows cover the littoral fringes at depths ranging  
15 between -3 and -4 m (Hattour et al., 1998). On the other hand, most biological studies of the  
16 Gulf of Gabes have dealt with the distribution of phytoplankton (Drira et al., 2008; Bel  
17 Hassen et al., 2009) zooplankton (Drira et al., 2009) ciliates (Kchaou et al., 2009; Hannachi et  
18 al., 2009), demosponges (Ben Mustapha et al., 2003) while seagrass species and their  
19 epiphytes which are known to be highly sensitive to environmental changes (Balata et al.,  
20 2007; Prado et al., 2008; Montefalcone, 2009) have been given limited attention. Epiphytes of  
21 seagrass not only contribute significantly to the primary production of the meadow (Buia et  
22 al., 1992; Nelson and Waaland, 1997; Duarte et al., 2004), but are also more sensitive to  
23 environmental changes than the plant host (Delgado et al., 1999; Nesti et al., 2008;  
24 Giovannetti et al., 2010). For example, various studies reported increases in epiphyte biomass  
25 parallel with nutrient enrichment (Armitage et al., 2006; Neckles et al., 1993), eutrophication

1 (Balata et al., 2008; Frankovich et al., 2009) and water quality (Merić et al., 2005).  
2 Differences in the spatial heterogeneity of epiphytes (Piazzini et al., 2004; Martínez-Crego et  
3 al., 2010) and shifts in species composition (Nesti et al., 2008; Fourqurean et al., 2010) have  
4 also been observed. It is widely known that the distribution of epiphytic assemblages of *P.*  
5 *oceanica* both on leaves (Van der Ben., 1971; Mazzella et al., 1989) and rhizomes (Piazzini et  
6 al., 2002; Balata et al., 2008) can change, but these changes have not yet been explored on a  
7 horizontal scale in the Gulf of Gabes. Differences in the spatial heterogeneity of epiphytes  
8 (Piazzini et al., 2004) and shifts in species composition (Nesti et al., 2008; Fourqurean et al.,  
9 2010; Martínez-Crego et al., 2010) have also been observed. Several findings have provided  
10 evidence that epiphytes are patchy at 1 to 10 cm (Kendrick and Burt, 1997; Jernakoff and  
11 Nielsen, 1998) and > kilometer scales, (Vanderklift and Lavery 2000, Lavery and Vanderklift  
12 2002), other studies have indicated that epiphytes may be uniform at relatively small spatial  
13 scales (e.g., 0.1 m Vanderklift and Lavery 2000; <10 m, Saunders et al., 2003, Piazzini et al.,  
14 2004). Moore et al. (2006) reported that epiphytes biomass is uniform at the scale < 100 m  
15 transect. Variability in leaves epiphytic biomass at the scale of meters may be related to  
16 differences in shoot density (Gambi et al., 1989), and to impacts of water movements on both  
17 settlement and recruitment of propagules (Trautman and Borowitzka, 1999; Vanderklift and  
18 Lavery, 2000). It is, therefore, of importance to undertake a study of the effects of urban  
19 pressure on *P. oceanica* dynamics under the impact of human activities versus control  
20 conditions. To our knowledge, only the flowering and fructification of *P. oceanica* along the  
21 coastline of the Gulf of Gabes has been the subject of studies in recent years (Hattour et al.,  
22 1998). As part of a comprehensive study intended to understand the dramatic decline of the  
23 endemic Mediterranean seagrass *P. oceanica* in the Gulf of Gabes, we analyzed, for the first  
24 time in this ecosystem, the structure and patterns of spatial variability of leaf macro-epiphytic  
25 assemblages and tested their relationships with anthropogenic disturbance. We attempted to

1 answer the questions 1) how vulnerable are the leaf macro-epiphytic assemblages to these  
2 environmental pressures? 2) Does epiphyte biomass increase parallel with organic and  
3 nutrient enrichment and which members of the epiphytic community should be considered as  
4 most sensitive species? And 3) Does anthropogenic disturbance modify the spatial scales at  
5 which variability of the epiphytic communities is highest/lowest or also influences the  
6 partition of total variability among spatial scales? We, thus, compared epiphytic assemblages  
7 between locations exposed to urban and industrial effluents and control locations, and  
8 examined their variability at spatial scales ranging from cm to km, using a hierarchical  
9 sampling design (Underwood, 1994; Chapman et al., 1995).

10

## 11 **2. Material and methods**

### 12 *2.1. Study area*

13 The Gulf of Gabes is located between 35° N and 33° N and extends from “Ras kapoudia” at  
14 the 35° N parallel level to the Tunisian-Libyan border (Fig. 1). It shelters various islands  
15 (Kerkennah and Djerba) and lagoons (Bougrara and El Bibane). The climate is dry (average  
16 precipitation: 210 mm year<sup>-1</sup>) and sunny with strong easterly winds. The tide is semidiurnal,  
17 with a maximum range of about 2 m.

### 18 *2.2. Sampling*

19 Because the *P. oceanica* epiphytic community reaches its optimum seasonal development in  
20 summer (Romero, 1988) fieldwork was conducted in July-August 2006. Four locations distant  
21 30 km from each other were chosen for the samplings. The depth of all stations was 5 m and  
22 temperature and salinity ranges were 27°C-30°C and 38-40 P.S.U., respectively. Two  
23 locations were disturbed by a sewage discharge: Ghannouch (34° 30' 523" N 10° 54' 743" E)  
24 and Zarrat (33° 43'417" N 10° 20' 486" E) labeled herein respectively, D1 and D2. The other

1 two: Hassar (34° 44' 290" N 11° 08' 590" E) and Ajim (33° 45' 112" N 10° 42' 992" E) were  
2 control locations, located north and south of the disturbed area and labeled respectively, C1  
3 and C2. Within each location (D1, D2, C1, C2), three sites were randomly selected, 500-600  
4 m apart, and within each site two sub-sites were also randomly selected. Each sub-site was  
5 randomly divided into three plots, each plot then being divided into three quadrats 20 cm  
6 apart. We examined variability at tens of centimeter-scale by collecting samples from the  
7 same quadrat. This quadrat was 20 cm × 20 cm and divided into a grid of 10 cm × 10 cm sub-  
8 quadrats.

### 9 *2.3. Data collection*

10 The density of *P. oceanica* shoots was estimated from 216 replicates present within 100 cm<sup>2</sup>  
11 sub-quadrats inside each meadow. Five shoots were randomly collected from each sub-  
12 quadrat during SCUBA diving and preserved in seawater-formalin (5%) solution for species  
13 identification in the laboratory. Leaf length corresponds in fact to the average evaluated from  
14 each meadow. The samples were examined for leaf surface per shoot and the coverage  
15 (expressed as a percentage of leaf surface) of each morphological group which was estimated  
16 with a binocular lens, then carefully scraped with a razor blade (Libes, 1986). Epiphytes and  
17 scraped leaves were oven-dried at 60 °C for 48 h before weighing (Alcoverro et al., 1997;  
18 Lepoint et al., 1999).

### 19 *2.4. Data analysis*

20 Multivariate analysis (MPMANOVA) was used to test the hypothesis that the structure of  
21 epiphytic assemblages differed between disturbed and control locations and to evaluate  
22 variability at different spatial scales (Anderson, 2001). The analysis consisted of a 6-way  
23 model with sites (three levels) being nested within locations (two levels), subsites (two levels)  
24 being nested within sites, plots (three levels) being nested within subsites, quadrats being  
25 nested within plots and sub-quadrats (four levels) being nested within quadrats. Sites,



1 subsites, plots and quadrats were random whereas the contrast of disturbed versus control and  
2 the disturbed were fixed. All data were transformed to  $\ln(x + 1)$  to remove heterogeneity of  
3 variances (after Cochran's *C*-test). SIMPER analysis (Clarke, 1993) was used to identify the  
4 percentage contribution of each species to the Bray-Curtis dissimilarity between the average  
5 of the disturbed and the control locations. A two-dimensional nMDS (non-metric  
6 multidimensional scaling), based on the centroids of the sites of the four locations, was used  
7 for a graphical representation of the data for leaf epiphytic assemblages.

8 Variance components of all assemblages were calculated for each location and for all spatial  
9 scales. A discriminant analysis was used for classifying the different meadows into one  
10 among possible *K* classes. These classes were identified by linear combinations of the  
11 variables maximizing the homogeneity of each class. The test Wilks' lambda was employed to  
12 test whether there are differences between the means of identified groups of subjects among a  
13 combination of dependent variables.

14 Epiphyte biomass was standardized by shoot biomass to be able to compare epiphyte load  
15 among locations. This is necessary because a significant positive correlation was found  
16 between epiphyte biomass and leaf biomass (Fig. 2), allowing us to express epiphyte biomass  
17 as  $g_{dw} \text{ epiphytes} / g_{dw} \text{ of leaves}$ . Differences in epiphytic biomass and the percentage cover of  
18 the main phyla or morphological groups were analyzed through 6-way ANOVA with the  
19 same factors and levels used in the multivariate analysis. Student-Newman-Keuls (SNK) test  
20 was employed for a posteriori multiple comparisons of means.

### 21 **3. Results**

22 A total of 49 taxa were identified in the epiphyte assemblages of control locations: 20  
23 Macroalgae (11 Rhodophyta, 6 Cyanobacteria, 2 Chlorophyta, 1 Heterokontophyta), 11  
24 Bryozoa, 9 Cnidaria (Hydrozoans), 3 Annelida, 2 Tunicata and 3 Porifera. A total of 32 taxa  
25 were identified in the epiphyte assemblages of disturbed locations: 13 Macroalgae (7

1 Rhodophyta, 4 Cyanobacteria, 1 Chlorophyta, 1 Heterokontophyta), 9 Bryozoa, 8 Cnidaria  
2 (Hydrozoans), 1 Annelida and 1 Tunicata (Appendix 1). In control locations, leaf assemblages  
3 were dominated by filamentous algae belonging to the genera *Polysiphonia*, *Ceramium* and  
4 *Antithamnion*; common algal species were also present such as *Dasycladus vermicularis*,  
5 *Cladophora* sp., *Griffithsia opuntoides*, *Neomonospora* sp. and *Laurencia obtusa*. Among  
6 animals, the Bryozoans *Alcyonidium* and *Electra Posidoniae* dominated the community. The  
7 Tunicata *Botryllus schlosseri* and *Clavelina lepadiformis* were numerically dominant. Among  
8 the Cnidaria the most abundant species were *Dynamina cavolinii*, *Monotheca* sp. and  
9 *Aglaophenia* sp. For encrusting Annelida the genus *Spirorbis* was the dominant genus, and for  
10 the Porifera the genus *Ircinia* dominated the Porifera assemblage. In disturbed locations, leaf  
11 assemblages were dominated by filamentous algae belonging to genera *Antithamnion* and  
12 *Polysiphonia*; other common algal species were also present such as *Laurencia obtusa*,  
13 *dictyota dichotoma* and *Ceramium gracillimum*. Among Bryozoa the genera *Alcyonidium*,  
14 *Scrupocellaria* and *Bowerbankia* were the most abundant. The Cnidaria *Dynamena* and  
15 *Obelia* were the most abundant genera. For the encrusting Annelida, the genus *Spirorbis*  
16 dominated the assemblage.

17 There was a difference between the two disturbed locations; the location Ghannouch was  
18 more affected than the location Zarrat, the number of species and the mean percentage cover  
19 were reduced for the majority of taxa. We noted the absence of *Aetea truncata*, *Micropora*  
20 *complanata*. Filamentous algae, namely *Ceramium tenuissimum*, *Neomonospora* sp. and  
21 *Dasya* sp. were absent in the location of Ghannouch.

22 The high mean value of shoot density ( $1022 \pm 54.23$  shoot  $m^{-2}$ ) was recorded in the site 1 of  
23 Hassar location (C1), whereas the lowest mean value ( $119.5 \pm 17.67$  shoot  $m^{-2}$ ) has been  
24 detected in site 1 of Ghannouch location (D1) (Fig. 3). The lowest mean value of the leaf  
25 surface area ( $205.28 \pm 5.56$   $cm^2$  shoot $^{-1}$ ) was recorded in the site 1 of the location Ghannouch

1 (D1), whereas the highest mean value ( $467.28 \pm 5.82 \text{ cm}^2 \text{ shoot}^{-1}$ ) was detected in the site 2  
2 of the location Ghannouch (D1) (Fig. 4).

3 The highest mean value of leaf length ( $59.68 \pm 7.87 \text{ cm}$ ) was recorded in the site b of the  
4 control location Hassar (C1), whereas the lowest mean value ( $29.2 \pm 4.87 \text{ cm}$ ) was observed in  
5 the site a of the disturbed location Ghannouch (D1) (Fig. 5).

6 ANOVA analysis showed that for density, leaf surface area and leaf length there was a  
7 significant difference between (i) locations and (ii) between the contrast 'disturbed vs.  
8 control' locations. For leaf surface area and leaf length, no significant difference could be  
9 detected in the disturbed and the control locations separately. The difference was not  
10 significant for shoot density among the control locations (Table 1). The disturbed location D1  
11 has a lower mean epiphyte biomass ( $\text{g}_{\text{dw}} \text{ epiphytes} / \text{g}_{\text{dw}} \text{ of leaves}$ ) than the location D2; this  
12 value ranging between  $0.02 \pm 0.07$  and  $0.1 \pm 0.08 \text{ g}_{\text{dw}} \text{ epiphytes} / \text{g}_{\text{dw}} \text{ of leaves}$  at D1, and  
13 between  $0.25 \pm 0.07$  and  $0.38 \pm 0.09 \text{ g}_{\text{dw}} \text{ epiphytes} / \text{g}_{\text{dw}} \text{ of leaves}$  in the location D2. In the  
14 control location C1, the mean epiphyte biomass varied between  $0.46 \pm 0.01$  and  $0.63 \pm 0.03$   
15  $\text{g}_{\text{dw}} \text{ epiphytes} / \text{g}_{\text{dw}} \text{ of leaves}$  and between  $0.33 \pm 0.17$  and  $0.38 \pm 0.19 \text{ g}_{\text{dw}} \text{ epiphytes} / \text{g}_{\text{dw}} \text{ of}$   
16 leaves in the location C2 (Fig. 6).

17 Epiphyte biomass vs. leaf biomass displayed a fairly similar relationship in all locations,  
18 suggesting that the leaf biomass pattern and hence the leaf surface availability was an  
19 important factor governing the epiphytic biomass pattern as also reported by Borowitzka et al.  
20 (2006) (Fig. 2). The two control locations C1 and C2 had the upper slope whereas the  
21 disturbed locations present the lower what strongly suggests that anthropogenic disturbance  
22 affects epiphyte load (Test of homogeneity of slope between control and disturbed locations;  
23  $F_{(n=3)} = 430.07$ ;  $p = 0.00002$ ). Analyses of variance indicate a wide variability in the epiphytic  
24 biomass among locations, sites, subsites and quadrats, whereas variation at the scale plot was  
25 insignificant (Table 2). Variation between the two disturbed locations was important for both

1 the largest and the smallest scales (quadrat), whereas significant difference was detected only  
2 at the subsite and quadrat scale for the control locations. The structure of epiphytic  
3 assemblage of leaves differed between the contrast of disturbed vs. control locations (Table  
4 3), while no significant difference was observed among disturbed and control location  
5 separately. Significant difference was observed in particular at the smallest scales plots and  
6 quadrats. Epiphytes were generally abundant on leaves of *P. oceanica* (Fig. 7). Algae,  
7 bryozoans and encrusting Annelida were common and abundant at all locations. Also  
8 hydrozoans were widespread, but their percentage cover was generally low. The two  
9 disturbed meadows were different from each other with an extra variability in percentage  
10 covered in hydrozoans. Four morphological groups of organisms were sufficiently abundant  
11 to be included in univariate analyses. For example, and concerning the percentage cover of  
12 filamentous algae and hydrozoans, we recorded a significant difference between (i) locations  
13 when considered separately and between (ii) the contrast 'disturbed vs. control locations'. For  
14 encrusting Annelida a significant difference was detected only for the scale locations when  
15 considered separately, whereas, no significant difference was found for the contrast 'disturbed  
16 vs. control locations'. For bryozoans, there was no significant difference between these two  
17 scales (Table 4). On a scale site, a significant variability was detected for encrusting Annelida.  
18 At the scale subsite, a significant variability was detected for algae, whereas at the scale plot,  
19 variability was detected for all parameters. For the scale quadrat, a difference was significant  
20 for all variables but no difference was found between the percentage covers of disturbed and  
21 control locations.

22 nMDS ordination of leaf assemblages at the four locations showed a clear separation between  
23 the centroids based on sites of each control and disturbed locations (Fig. 8). The species  
24 responsible for the difference between disturbed and control locations changed. For example,  
25 the cover percentages of the algae *Antithamnion* sp., *Polysiphonia elongata*, *Ceramium*

1 *tenuissimum* and *Ceramium codii*, the bryozoans such as *Micropora complanata* and the  
2 hydrozoan *Dynamena cavolinii* increased on leaves in the control locations, though some  
3 species showed similar trends in these locations (Table 5).

4 Biomass, epiphytic leaf assemblages and the four abundant morphological groups of epiphyte  
5 displayed different responses to the spatial variability among different scales at the disturbed  
6 and the control locations (Table 6). Variance components indicated that most of the variability  
7 occurred not only at the plot scale but also between locations and quadrats, with the exception  
8 of biomass that displayed larger variation at the quadrat scale in disturbed locations.

9 Discriminate analysis, for both disturbed and control locations showed that there was a  
10 strongly significant variation including all the factors of the *P. oceanica* meadows. Wilks'  
11 lambda showed a high variability between locations for biomass, hydrozoans and density, and  
12 high variability within locations especially for bryozoans (Table 7).

13 The projection on the first factorial design crossing the first two factorial discriminant axes  
14 corresponding to the first two discriminating linear functions as in table 8, allows a  
15 description and a classification of the characterized variables (Fig. 9). The first axis shows  
16 discrimination between the two control and the two disturbed locations. The second axis  
17 divides locations in three groups: the control location C1, the crossing of the two disturbed  
18 locations, and the control location C2.

#### 19 **4. Discussion**

20 The multivariate analysis illustrates a decrease in seagrass vitality (i.e. shoot density, leaf  
21 surface area and leaf length) in disturbed versus control locations, thus indicating the inability  
22 of disturbed meadows to withstand increasing urban interferences. Cancemi et al. (2003) and  
23 Balestri et al. (2004) reported that the decline of the phenologic parameters used to assess the  
24 seagrass bed vitality among the disturbed locations they sampled is function of the distance  
25 from the disturbance source as compared to control locations. In fact, the mean biomass in the

1 inner Ghannouch location (D1) was lower than that recorded close to sewage outlet at Zarrat  
2 location (D2). Similar results were reported by others (Short and Wyllie-Echeverria, 1996;  
3 Leriche et al., 2006). We suspect the water column stability and the quality of sewage as  
4 probably being the most important factor affecting the growth of *P. oceanica* in the coastal  
5 disturbed area of the Gulf of Gabes. This is supported by at least two observations. First, the  
6 disturbed locations D1 and D2, which have a muddy bottom, were mechanically turbulent  
7 from the constant input of sewage outlet, conveying uniformity throughout the shallow water  
8 column (Soussi and Mammoun, 1992; Zaouali, 1993), and therefore probably reducing leaf  
9 photosynthetic activity (Mascaro et al., 2009). Decreases in shoot density and leaf length  
10 related to decreases in light environment have already been reported from inner disturbed  
11 locations (Ruiz and Romero, 2003). In contrast, Giovannetti et al. (2006) found no difference  
12 in the shoot density, the Conservation Index and the epiphyte coverage between the control  
13 (marine protected area) and the disturbed (urbanized area) locations examined in their study.  
14 Only a shift in the epiphyte species composition was observed in the urban meadows  
15 subjected to the increase of the sewage outfalls during summer, which showed a considerable  
16 development of the brown algae. Indeed, Terrados et al. (2008) found no difference in shoot  
17 density between the control and the disturbed locations that they sampled. However, these  
18 authors studied locations that received inputs of nutrients and organic matter from only the  
19 resident population (Giovannetti et al., 2006) and park visitors (Terrados et al., 2008),  
20 whereas the Gulf of Gabes is exposed to a plethora of toxic inputs. For example, studies here  
21 have reported high phosphogypsum concentration ( $10 \text{ g l}^{-1}$ ) at the sewage outlet, which spread  
22 over more than  $60 \text{ km}^2$  (Bejaoui et al., 2004). Dissolution of phosphogypsum was carried out  
23 by releasing cadmium and fluorine in sea water (Bejaoui et al., 2004), and cadmium has also  
24 been shown to be toxic to clams in the Gulf of Gabes (Hamza-Chaffai et al., 1999; Smaoui-  
25 Damak et al., 2003, 2006). In the control locations Hassar and Ajim, *P. oceanica* beds seemed

1 healthy and no death was observed (Hattour et al., 1998; Ramos-Espla et al., 2000; Ben  
2 Brahim et al., 2007). Also, since *P. oceanica* is very sensitive to low salinity in Tunisian  
3 coastal regions such as the Gulf of Tunis (Northern Tunisia) (Ben Alaya, 1972), fresh waters  
4 from sewage may also have lowered water salinity, thus affecting meadow growth too, but to  
5 a lesser extent.

6 In terms of epiphytic leaf biomass, we also found the lowest mean biomass at the inner  
7 disturbed Ghannouch location (D1). As previously mentioned for the meadow biomass,  
8 increases in water turbidity in disturbed locations are also detrimental to leaf epiphytic  
9 biomass since light is restricted (Cebrian et al., 1999). A similar general loss of epiphyte  
10 biomass and the regression of *P. oceanica* meadow according to disturbance level has also  
11 been reported (Cambrige and McComb, 1984; Guidetti, 2001; Piazzini et al., 2004). In addition,  
12 macrograzers are known to feed preferentially on leaf tips where maximum epiphyte biomass  
13 is reached (Alcoverro et al., 1997; Ruiz and Romero, 2003; Peterson et al., 2007). This may  
14 have accounted, at least partially, for the natural loss of the epiphyte biomass both in  
15 disturbed and control locations in the Gulf of Gabes. This decrease in epiphyte biomass was  
16 also associated with a reduction of species sharing the epiphyte total biomass (49 species in  
17 disturbed location vs 32 species in control locations, see Appendix). Our findings are also  
18 supported by those of Mannino et al. (2010) who found a well-structured algal assemblage  
19 close to the sea (with low anthropogenic pressure) compared to the locations subjected to  
20 human disturbance. We, therefore, propose that in the Gulf of Gabes the spectrum of existing  
21 conditions was narrow and thus unfavorable for the coexistence of a high number of species.  
22 This is most likely due to toxicity from several compounds such as Cd (10-15 ppm, Soussi et  
23 al., 1992) and, as previously mentioned, phosphogypsum with a sedimentary section reaching  
24 50 cm in Ghannouch location. In addition, concentrations in hydrocarbon were relatively high  
25 (between 882  $\mu\text{g g}^{-1}$  and 4087  $\mu\text{g g}^{-1}$ ) compared to those recorded from other coastal

1 Mediterranean sediments (Zaghden et al., 2005). The spatial distribution of these polluting  
2 elements is favored by dominant winds (west-east in summer and north-east and south-west in  
3 winter) which permanently induced not only the mixing of sediment but also the  
4 remobilization of the surface deposits (Soussi et al 1992). Others have also reported a  
5 decrease in the vitality of the *Posidonia* meadow due to trace metal pollution (Pergent-Martini  
6 et Pergent, 2000; Ben Chikha, 2009). Furthermore, animals on leaves exhibited different  
7 responses to disturbance. For example, encrusting Annelida and Bryozoa displayed a reduced  
8 amount of variation in mean cover percentage at large spatial scales; in fact, the increase of  
9 the relative dominance in mean cover near the sewage outlet indicates a functional change in  
10 the assemblage related with the increase of the trophic component of micropredators  
11 (Fraschetti et al., 2006). On the other hand, the sewage causes a significant decrease in terms  
12 of mean cover of Hydrozoans as previously reported by Cifuentes et al. (2007). The  
13 hydrozoan *Gonothyrea gracilis* and the two bryozoans *Amathia lendigera* and *Beania*  
14 *hirtissima* (Bryozoa) were presumably the most sensitive species to environmental stress as  
15 they were absent in the disturbed locations. We infer that this decrease is probably related to  
16 the water turbulence close to the discharge which affected the availability of potential preys  
17 such as zooplankton and particulate matter (Wahl, 1989; McKinney and Jackson, 1989; Ben  
18 Brahim et al., unpublished). In addition, bryozoans and hydrozoans showed different  
19 behavioral patterns related to the degree of disturbance, with bryozoans seeming more  
20 adapted than hydrozoans to increased disturbance (McKinney and Jackson, 1989). Obviously,  
21 further studies are needed, for example by comparing the response of different epiphytes taxa,  
22 in order to elucidate the resilience of each group of epiphytes against disturbance levels and  
23 their strategy facing disturbed conditions. The present study showed that the variation in both  
24 the spatial pattern and abundance of macroalgal species, rather than their presence/absence,  
25 are indicative of disturbance. For example, the assemblage of epiphytic algae dominated by



1 the Rhodophyta (order Ceramiales) tends to decrease in the two disturbed locations D1 and  
2 D2. In this context, filamentous algae, especially the Ceramiales, may be considered the most  
3 sensitive to disturbance. In other Mediterranean regions, Dictyotales were the dominant  
4 species and grew abundantly in the disturbed sampled areas (Balata et al., 2007). On the other  
5 hand, our results showed that the decrease of Ceramiales algae was paralleled with the  
6 decrease of the green algae *Dasycladus vermicularis*, the cyanobacteria *Lyngbia* sp., *Rivularia*  
7 sp., *Gloeotrichia* sp., *Phormidium* sp. and the red algae *Dasya* sp., *Griffithsia* sp. and  
8 *Pleonosporium* sp., a decrease also paralleled with increases of anthropogenic disturbance.  
9 Brown algae such as *Myrionema orbiculare* and *Giraudia sphacelarioides* are considered  
10 characteristic of epiphyte community of *P. oceanica* leaves and have been already reported  
11 along the northern Tunisian coast (Ribera et al., 1992). In many Mediterranean regions, *M.*  
12 *orbiculare* was abundant (Giovannetti et al., 2006; Pardi et al., 2006; Sliskovic et al., 2010).  
13 However, along the Tunisian coast this taxon was detected only in Bechateur which is located  
14 in northern Tunisia (Menez and Mathieson, 1981). In the present study (southern Tunisia)  
15 brown algae such as *M. orbiculare*, *G. sphacelarioides* were absent and only the species  
16 *Dictyota dichotoma* was recorded. We infer that this absence might be related to the high  
17 level of disturbance in the Gulf of Gabes. Our suggestion may be supported by the study of  
18 Giovannetti et al. (2006) at Prelo cove in the Ligurian Sea (NW Mediterranean Sea) showing  
19 that some brown algae such as *Myrionema orbiculare*, *Giraudia sphacelarioides* and  
20 *Fenestrulina johannae* did not play a significant role in the epiphytic community structure,  
21 whereas some Rhodophyta such as *Hydrolithon-Pneophyllum* spp. were the main epiphytes  
22 that were present throughout the year at all stations. In control locations, leaf epiphytes  
23 biomass of *P. oceanica* were most variable at the small scales investigated (among plots),  
24 whereas variation at the intermediate scale (among sites, subsites) was negligible. In this  
25 study, hierarchical sampling designs enabled an identification of homogeneity of epiphyte

1 assemblage distribution for the majority of functional groups and biomass among the scale  
2 site (500-600 m), while heterogeneity is displayed at large scales among regions and at small  
3 scales among plots. Our study supports the results of Pardi et al. (2006), and Piazzini et al.  
4 (2004), in terms of variability of epiphyte load on *Posidonia oceanica* which was greatest at  
5 the extremes of the spatial extents they investigated, with patchiness greatest at the among-  
6 shoot level (i.e. within quadrats), and at sites separated by a few hundred meters. Moore and  
7 Fairweather (2006) and Balata et al. (2007) also considered that the epiphytes biomass within  
8 the 100 m long transect sampled was homogenous, and more generally, Jernakoff and Nielsen  
9 (1997) and Balestri et al. (2004) indicated that patchiness in epiphytes as well as in seagrass  
10 morphology is significant over a range of scales (typically cm to km).

## 11 **5. Conclusion**

12 Our study illustrated a spatial variability related to anthropogenic disturbance for (i) the  
13 phenologic parameters of the plant host *P. oceanica*, such as shoot density, leaf length and  
14 leaf surface area in the disturbed locations, for (ii) the mean percentage cover of targeted  
15 organisms and for (iii) the epiphytic biomass on leaves of *P. oceanica*.

16 The hierarchical sampling designs used in this study similarly to other investigations dealing  
17 with the spatial structuring of epiphytes-seagrass relations, pointed out a homogeneity in the  
18 distribution of epiphyte assemblages for the majority of functional groups and biomass among  
19 the scale site (500-600 m transect) while a heterogeneity was displayed at large scales among  
20 regions and at small scales among plots. Seagrass beds separated by few hundred of meters in  
21 both disturbed and control locations will apparently be subjected to unique environmental  
22 conditions resulting in equally epiphytic leaves biomass and assemblages. *P. oceanica*  
23 meadow and its associated epiphytes appear to be strongly affected by human pressure in the  
24 Gulf of Gabes through sewage outlet (this study), in addition to other disturbances such as  
25 trawling, mooring, fish farming and coastal pollution. The regression trend will significantly

1 increase unless there is efficient implementation of legal protection along with a reduction in  
2 human interference. While restrictions on trawling have been introduced in Tunisia, this  
3 practice being responsible for the loss of about 80% of the surface area of seagrass meadows  
4 in the Gulf of Gabes (Zaouali, 1992), the legislation is not respected. In a recent review, many  
5 authors regretted the lack of data in some Mediterranean regions, particularly indicating the  
6 urgent need for studies on *P. oceanica* in North Africa (Ruiz et al., 2009). We, thus, believe  
7 that our data may be, on a North African scale, not only worthwhile but also useful in  
8 initiating other investigations. For example, the construction of “matte” by *P. oceanica*, a  
9 feature unique among Mediterranean seagrasses and which may be useful for assessing the  
10 regression of *P. oceanica* (Leriche et al., 2004; Boudouresque et al., 2009), should be further  
11 addressed. Finally, it is urgent to propose the best management plans to save the remaining  
12 20% of *P. oceanica* in the Gulf of Gabes and its associated epiphytes which have been  
13 reported to be among the most productive marine and terrestrial ecosystems (Duarte and  
14 Chiscano, 1999).

## 15 **6. Acknowledgements**

16 This study was conducted by Mounir Ben Brahim in the framework of his PhD and supported  
17 by grants from by JICA (Japan International Cooperation Agency) and ESREB project (Étude  
18 des Stocks et des Ressources Exploitable des Bivalves). It was conducted as part of a  
19 collaborative project between the INSTM (Institut National des Sciences et Techniques de la  
20 Pêche), the Faculty of Sciences of Sfax (Tunisia) and the University of Franche-Comté  
21 (Chrono-Environnement, UMR CNRS 4269). The authors wish to thank the two reviewers for  
22 helpful suggestions which improved our contribution.

1 **List of figures:**

2

3 **Figure 1.** Geographical map focussing on sampling locations in the Gulf of Gabes.

4 **Figure 2.** Leaf biomass vs. epiphyte biomass ( $g_{dw} \text{ leaf}^{-1}$ ) for disturbed (D) and control (C)  
5 locations.





6 **Figure 3.** Average  $\pm$  SD values of the shoot density at the control (C1, C2) and disturbed D1,  
7 D2) locations with the three nested sites a, b and c.

8 **Figure 4.** Average  $\pm$  SD values of the leaf surface area at the control (C) and disturbed (D)  
9 locations with the three nested sites a, b and c.

10 **Figure 5.** Average  $\pm$  SD values of leaf length at the control (C) and disturbed (D) locations  
11 with the three nested sites a, b and c.

12 **Figure 6.** Average  $\pm$  SD values of the mean biomass of leaf epiphytes of *P. oceanica* at the  
13 control (C) and disturbed (D) locations with the three nested sites a, b and c.

14 **Figure 7.** Mean percentage cover of the main epiphyte groups at the control and disturbed  
15 locations with the three nested sites a, b and c. (C1: Hassar; D1: Ghannouch; D2: Zarrat and  
16 C1: Ajim).

17 **Figure 8.** nMDS showing the dissimilarity among centroids of sites of epiphytic assemblages  
18 on leaves. Ghannouch: D1 , Zarrat: D2 , Hassar: C1,  Ajim: C2. 

19 **Figure 9.** Global projection on the first factorial design discriminating of variables and group  
20 centroids.

21

22

23

24

25

26

1 **References**

- 2 Alcoverro, T., Duarte, C.M., Romero, J., 1997. The influence of herbivores on *Posidonia*  
3 *oceanica* epiphytes. *Aquatic Botany* 56, 93-104.
- 4 Anderson, M.J., 2001. A new method for non-parametric multivariate analysis of variance.  
5 *Austral Ecology* 26, 32–46.
- 6 Armitage, A. R., Frankovich, T. A., Fourqurean, J. W., 2006. Variable responses within  
7 epiphytic and benthic microalgal communities to nutrient enrichment. *Hydrobiologia* 569,  
8 423-35.
- 9 Balata, D., Nesti, U., Piazzini, L., Cinelli, F., 2007. Patterns of spatial variability of seagrass  
10 epiphytes in the north-west Mediterranean Sea. *Marine Biology* 151, 2025-2035.
- 11 Balata, D., Bertocci, I., Piazzini, L., Nesti, U., 2008. Comparison between epiphyte  
12 assemblages of leaves and rhizomes of the seagrass *Posidonia oceanica* subjected to different  
13 levels of anthropogenic eutrophication. *Estuarine, Coastal and Shelf Science* 79, 533-540.
- 14 Balestri, E., Benedetti-Cecchi, L., Lardicci, C., 2004. Variability in patterns of growth and  
15 morphology of *Posidonia oceanica* exposed to urban and industrial wastes: contrasts with two  
16 reference locations. *Journal of Experimental Marine Biology and Ecology* 308, 1-21.
- 17 Bejaoui, B., Raïs, S., Koutitonsky, V., 2004. Modélisation de la dispersion du phosphogypse  
18 dans le Golfe de Gabès. *Bulletins de l'Institut Océanographique et de Pêche de Salammbô*.  
19 31, 103-109.
- 20 Bel Hassen, M., Drira, Z., Hamza, A., Ayadi, H., Akrouf, F., Messaoudi, S., Issaoui, H.,  
21 Aleya, L., Bouaïn, A., 2009. Phytoplankton dynamics related to water mass properties in the  
22 Gulf of Gabes: Ecological implications. *Journal of Marine Systems* 75, 216-226.
- 23 Ben Alaya, H., 1972. Répartition et conditions d'installation de *Posidonia oceanica* Delile et  
24 *Cymodocea nodosa* Ascherson dans le Golfe de Tunis. *Bulletins de l'Institut*  
25 *Océanographique et de Pêche de Salammbô* 2, 331-416.

- 1 Ben Brahim, M., Hiroaki, T., Hamza, A., 2007. Proceedings of the third Mediterranean  
2 symposium on marine vegetation, Marseille, 300 pp.
- 3 Ben Chikha, M., 2009. Evaluation de la réaction de la Magnoliophyte marine *Posidonia*  
4 *oceanica* (L.) Delile, vis-à-vis de la contamination mercurielle dans les côtes nord de la ville  
5 de Sfax. Master, Université de Sfax, Tunisie, 80 pp.
- 6 Ben Mustapha, K., 1995. The Gulf of Gabes: A case study in the Mediterranean decline in  
7 Fishing out the Mediterranean. 21<sup>st</sup> session of the G.F.C.M, Spain, Greenpeace International  
8 (Eds), Netherlands, 8-9.
- 9 Ben Mustapha, K., Zarrouk, S., Souissi, A., El Abed, A., 2003. Diversity of Tunisian  
10 demosponges. Bulletins de l'Institut Océanographique et de Pêche de Salammbô 30, 55-78.
- 11 Boudouresque, C.F., Bernad, G., Pergent, G., Shili A., Verlaque M., 2009. Regression of  
12 Mediterranean seagrasses caused by natural processes and anthropogenic disturbances and  
13 stress: a critical review. *Botanica Marina* 52, 395-418.
- 14 Buia, M.C., Zupo, V., Mazzella L., 1992. Primary production and growth in *Posidonia*  
15 *oceanica*. P.S.Z.N. Marine Ecology 13, 2-16.
- 16 Cambrige, M.L., McComb, A.J., 1984. The loss of seagrasses in Cockburn Sound. Western  
17 Australia. I. the time course and magnitude of seagrass decline in relation to industrial  
18 development. *Aquatic Botany* 20, 229-243.
- 19 Cancemi, G., De Falco, G., Pergent, G., 2003. Effects of organic matter input from a fish  
20 farming facility on a *Posidonia oceanica* meadow. *Estuarine, Coastal and Shelf Science* 56,  
21 961-968.
- 22 Cebrian, J., Enriquez, S., Fortes, M., Agawin, N., Vermaat, J.E., Duarte, C.M., 1999.  
23 Epiphyte accrual on *Posidonia oceanica* (L.) Delile leaves: implications for light absorption.  
24 *Botanica Marina* 42, 123-128.

- 1 C.G.P. 1996. Annuaire des statistiques des pêches en Tunisie. Ministère de l'agriculture,  
2 Tunisie.
- 3 Chapman, M.G., Underwood, A.J., Skilleter, G.A., 1995. Variability at different spatial scales  
4 between a subtidal assemblage exposed to the discharge of sewage and two control  
5 assemblages. *Journal of Experimental Marine Biology and Ecology* 189, 103-122.
- 6 Cifuentes, M., Kamlah, C., Thiel, M., Lenz, M., Wahl, M., 2007. Effects of temporal  
7 variability of disturbance on the succession in marine fouling communities in northern-central  
8 Chile. *Journal of Experimental Marine Biology and Ecology* 352, 280-294.
- 9 Clarke, K.R., 1993. Non-parametric multivariate analyses of changes in community structure.  
10 *Australian Journal of Ecology* 18, 117-143.
- 11 Delgado, O., Ruiz, J., Pérez, M., Ballesteros, E., 1999. Effects of fish farming on seagrass  
12 (*Posidonia oceanica*) in a Mediterranean bay: seagrass decline after organic loading  
13 cessation. *Oceanologica Acta* 22, 109-117.
- 14 Drira, Z., Hamza, A., Bel Hassen, M., Ayadi, H., Bouaïn, A., Aleya, L., 2008. Dynamics of  
15 dinoflagellates and environmental factors during the summer in the Gulf of Gabes (Tunisia,  
16 Eastern Mediterranean Sea). *Scientia Marina* 72, 59-71.
- 17 Drira, Z., Bel Hassen, M., Hamza, A., Rebai, A., Bouaïn, A., Ayadi, H., Aleya, L., 2009.  
18 Coupling of phytoplankton community structure to nutrients, ciliates and copepods in the  
19 Gulf of Gabes (South Ionian Sea, Tunisia). *Journal of the Marine Biological Association, UK*.  
20 1-11, doi: 10.1017/S002531540900023.
- 21 Duarte, C. M., Borum, J., Short, F. T., Walker, D. I., 2004. Seagrass ecosystems: their global  
22 status and prospects. In *Aquatic Ecosystems: Trends and Global Prospects*, pp. 281–294.  
23 Edited by N. V. C. Polunin. Cambridge: Cambridge University Press.
- 24 Duarte, C. M and C. L., Chiscano, 1999. Seagrass biomass and production: a reassessment.  
25 *Aquatic Botany* 1334, 1-16.

- 1 Fourqurean, J. W., Muth M. F. A., Boyer, J. N., 2010. Epiphyte loads on seagrasses and  
2 microphytobenthos abundance are not reliable indicators of nutrient availability in  
3 oligotrophic coastal ecosystems. *Marine Pollution Bulletin* 60, 971–983
- 4 Frankovich, T. A., Armitage, A. R., Wachnicka, A. H., Gaiser, E. E and Fourqurean J. W.  
5 2009. Nutrient effects on seagrass epiphyte community structure in Florida Bay. *Journal of*  
6 *Phycology* 45, 1010–1020.
- 7 Frascchetti, S., Gambi, C., Giangrande, A., Musco, L., Terlizzi, A., Danovaro, R., 2006.  
8 Structural and functional response of meiofauna rocky assemblages to sewage pollution.  
9 *Marine Pollution Bulletin* 52, 540-548.
- 10 Gambi, M.C., Giangrande, A., Chessa, L.A., Manconi, R., Scardi M., 1989. Distribution and  
11 ecology of Polychaetes in the foliar stratum of a *Posidonia oceanica* bed in the bay of Porto  
12 Conte (N.W. Sardinia). *International Workshop on Posidonia beds*. édit., GIS Posidonie publ.  
13 Fr. 2, 175-187.
- 14 Giovannetti, E., Montefalcone, M., Bianchi, C.N., Morri, C., Albertelli, G., 2006. Structural  
15 variability of the epiphytic community in a *Posidonia oceanica* meadow (Ligurian sea, NW  
16 mediteranean). *Biologia Marina Mediterranea* 13, 145-148.
- 17 Giovannetti, E., Montefalcone, M., Morri, C., Bianchi, C.N., Albertelli, G., 2010. Early  
18 warning response of *Posidonia oceanica* epiphyte community to environmental alterations  
19 (Ligurian Sea, NW Mediterranean). *Marine Pollution Bulletin* 60, 1032-1039.
- 20 Guidetti, P., 2001. Detecting environmental impacts on the Mediterranean seagrass *Posidonia*  
21 *oceanica* (L.) Delile: the use of reconstructive methods in combination with “beyond BACI”  
22 designs. *Journal of Experimental Marine Biology and Ecology* 260, 27-39.
- 23 Hamza, A., Bradai, M. N., Ghorbel, M., Abdelmoulah, A., 1995. New mentions of *Caulerpa*  
24 *racemosa* (Forsskal) J. Agardh in the Gabes Gulf (Tunisia). *Bulletins de l’Institut*  
25 *Océanographique et de Pêche de Salammbô* 22, 81-88.



- 1 Hamza-Chaffai, A., Amiard, J.C., Cosson, R.P., 1999. Relationship between metallothionein  
2 and metals in a natural population of clam *Ruditapes decussates* from Sfax coast, a non-linear  
3 model using Box-Cox transformation. *Comparative Biochemistry and Physiology* 123, 153-  
4 163.
- 5 Hannachi, I., Drira, Z., Bel Hassen, M., Hamza, A., Ayadi, H., Bouain, A., Aleya, L., 2009.  
6 Abundance and biomass of the ciliate community during a spring cruise in the Gulf of Gabes  
7 (East Mediterranean Sea, Tunisia). *Acta Protozoologica* 47, 293-305.
- 8 Hattour, A., Ben Mustapha, K., El Abed, A., Chaouch, M., 1998. L'écosystème du golfe de  
9 Gabès; dégradation de son couvert végétal et de sa pêche benthique. *Bulletins de l'Institut*  
10 *Océanographique et de Pêche de Salammbô* 25, 5-40.
- 11 Hemminga, M., Duarte, C.M., 2000. *Seagrass Biology*. Cambridge, Univ, Press, 298 pp.
- 12 Jernakoff, P., Nielson, J., 1997. The relative importance of amphipod and gastropod grazers in  
13 *Posidonia sinuosa* meadows. *Aquatic Botany* 56, 183-202.
- 14 Kchaou, N., Elloumi, J., Drira, Z., Hamza, A., Ayadi, H., Bouain, A., Aleya, L., 2009.  
15 Distribution of ciliates in relation to environmental factors along the coastline of the Gulf of  
16 Gabes, Tunisia. *Estuarine, Coastal and Shelf Science* 83, 414-424.
- 17 Kendrick, G. A., Burt, J. S., 1997. Seasonal changes in epiphyte macro-algae assemblages  
18 between offshore exposed and inshore protected *Posidonia sinuosa* Cambridge et Kuo  
19 seagrass meadows, Western Australia. *Botanica Marina* 40, 77-86.
- 20 Lavery, P., Vanderklift, M., 2002. A comparison of spatial and temporal patterns in epiphytic  
21 macroalgal assemblages of the seagrasses *Amphibolis griffithii* and *Posidonia coriacea*.  
22 *Marine Ecology Progress Series* 236, 99-112.
- 23 Lepoint, G., Havelange, S., Gobert, S., Bouquegneau, J.M., 1999. Fauna vs flora contribution  
24 to leaf epiphytes biomass in a *Posidonia oceanica* seagrass bed (Revellata Bay Corsica).  
25 *Hydrobiologia* 394, 63-67.

- 1 Leriche, A., Boudouresque, C. F., Bernard, G., Bonhomme, P., Denis J., 2004. A one-century  
2 suite of seagrass bed maps: can we trust ancient maps? *Estuarine, Coastal and Shelf Science*  
3 59, 353-362.
- 4 Libes, M., 1986. Productivity-irradiance relationship of *Posidonia oceanica* and its epiphytes.  
5 *Aquatic Botany* 26, 285-306.
- 6 Mannino, A. M., 2010. Temporal and spatial variation of the algal community in a southern  
7 Mediterranean shallow system. *Cryptogamie Algologie* 31, 255-272.
- 8 Martínez-Crego, B., Prado, P., Alcoverro, T., Romero, J., 2010. Composition of epiphytic leaf  
9 community of *Posidonia oceanica* as a tool for environmental biomonitoring. *Estuarine,*  
10 *Coastal and Shelf Science* 88, 199-208.
- 11 Mascaro, O., T. Valdemarsen, M., Holmer, M., Perez., J. Romero., 2009. Experimental  
12 manipulation of sediment organic content and water column aeration reduces *Zostera marina*  
13 (eelgrass) growth and survival. *Journal of Experimental Marine Biology and Ecology* 373, 26-  
14 34.
- 15 Mazzella, L., Scipione, M.B., Buia, M.C., 1989. Spatio-temporal distribution of algal and  
16 animal communities in a *Posidonia oceanica* (L.) Delile meadow. *PSZNI. Marine Ecology* 10,  
17 107-131.
- 18 McKinney, F. K and Jackson, J. B. C., 1989. Bryozoan evolution. *Special Topics in*  
19 *Palaeontology*. Boston, MA: Unwin Hyman.
- 20 Menez, E.G., Mathieson, A.G., 1981. *The Marine Algae of Tunisia*. Smithsonian Institution  
21 Press. 58 pp.
- 22 Meric, S., Nicola, E. D., Iaccarino, M., Gallo, M., Gennaro, A. D., Morrone, G., Warnau, M.,  
23 Belgiorno, V., Pagano, G., 2005. Toxicity of leather tanning wastewater effluents in sea  
24 urchin early development and in marine microalgae. *Chemosphere* 61, 208-217.

- 1 Montefalcone, M., 2009. Ecosystem health assessment using the Mediterranean seagrass  
2 *Posidonia oceanica*: a review. *Ecological Indicators* 9, 595-604.
- 3 Moore, T.N., Fairweather, P.G., 2006. Lack of significant change in epiphyte biomass with  
4 increasing extent of measurement within seagrass meadows. *Estuarine, Coastal and Shelf*  
5 *Science* 68, 413-420.
- 6 Neckles, H. A., Koepfler, E. T., Haas, L. W., Wetzel, R. L., Orth, R. J., 1994. Dynamics of  
7 epiphytic photoautotrophs and heterotrophs in *Zostera marina* (eelgrass) microcosms:  
8 responses to nutrient enrichment and grazing. *Estuaries* 17, 597-605.
- 9 Nelson, T.A., Waaland, J.R., 1997. Seasonality of eelgrass, epiphyte, and grazer biomass and  
10 productivity in subtidal eelgrass meadows subjected to moderate tidal amplitude. *Aquatic*  
11 *Botany* 56, 51-74.
- 12 Nesti, U., Piazzzi, L., Balata, D., 2008. Variability in the structure of epiphytic assemblages of  
13 the Mediterranean seagrass *Posidonia oceanica* in relation to depth. *Marine Ecology* 30, 276-  
14 287.
- 15 Pardi, G., Piazzzi, L., Balata, D., Papi, I., Cinelli F., Benedetti-Cecchi, L., 2006. Spatial  
16 variability of *Posidonia oceanica* (L.) Delile epiphytes around the mainland and the islands of  
17 Sicily (Mediterranean Sea). *Marine Ecology* 27, 397-403.
- 18 Pergent-Martini, C; Pergent, G., 2000. Marine phanerogams as a tool in the evaluation of  
19 marine trace-metal contamination: an example from the Mediterranean. *International Journal*  
20 *of Environment and Pollution* 13, 1-6.
- 21 Peterson, B.J., Frankovich, T.A., Zieman, J.C., 2007. Response of seagrass epiphyte loading  
22 to field manipulations of fertilization. Gastropod grazing and leaf turnover rates. *Journal of*  
23 *Experimental Marine Biology and Ecology* 349, 61-72.
- 24 Piazzzi, L., Balata, D., Cinelli, F., 2002. Epiphytic macroalgal assemblages of *Posidonia*  
25 *oceanica* rhizomes in the western Mediterranean. *European Journal of Phycology* 37, 69-76.

- 1 Piazzi, L., Balata, D., Cinelli, F., Benedetti-Cecchi, L., 2004. Patterns of spatial variability in  
2 epiphytes of *Posidonia oceanica*. Differences between a disturbed and two reference  
3 locations. *Aquatic Botany* 79, 345-356.
- 4 Prado, P., Farina, S., Tomas, F., Romero, J., Alcoverro, T., 2008. Marine protection and  
5 meadow size alter fish herbivory in seagrass ecosystems. *Marine Ecology Progress Series*  
6 371, 11-21.
- 7 Ramos-Espla, A., Ouergui, A., Bayle, J.T., Ben Mbarek, N., Fernandez-Troquemada, Y.,  
8 Gallouza, S., Khidri, R., Sanchez-lizaso, J.L., Yamak, S., 2000. Contribution à la  
9 caractérisation des herbiers à *Posidonia oceanica* (L.) Delile aux Iles Kerkennah (Est de la  
10 Tunisie, Méditerranée orientale). *Proceedings of The First Mediterranean Symposium on*  
11 *Marine Vegetation* 177-181.
- 12 Ribera, M.A., Gomez-Garreta, A., Gallardo, T., Cormaci, M., Furnari, G., Giaccone, G.,  
13 1992. Checklist of Mediterranean seaweed. I. Fucophyceae (Warming, 1884). *Botanica*  
14 *Marina* 35, 109-130.
- 15 Ruiz, J.M., Romero, J., 2003. Effects of disturbances caused by coastal constructions on  
16 spatial structure, growth dynamics and photosynthesis of the seagrass *Posidonia oceanica*.  
17 *Marine Pollution Bulletin* 46, 1523-1533.
- 18 Saunders, J. E., Attrill, M. J., Shaw, S. M., Rowden, A. A., 2003. Spatial variability in the  
19 epiphytic algal assemblages of *Zostera marina* seagrass beds. *Marine Ecology Progress Series*  
20 249, 107-115.
- 21 Sliskovic, M., Jelic-Mrcelic, G., Antolic, B., Anicic, I., 2010. The fouling of fish farm cage  
22 nets as bioindicator of aquaculture pollution in the Adriatic Sea (Croatia). *Environmental and*  
23 *Monitoring Assessment* doi: 10.1007/s10661-010-1402-y.
- 24 Smaoui-Damak, W., Hamza-Chaffai, A., Berthet, B., Amiard, J.C., 2003. Preliminary study  
25 of the clam *Ruditapes decussatus* exposed *in situ* to metal contamination and originating from

- 1 the Gulf of Gabes, Tunisia. *Bulletin of Environmental Contamination and Toxicology* 7, 961-  
2 970.
- 3 Smaoui-Damak, W., Rebai, T., Berthet, B., Hamza-Chaffai, A., 2006. Does cadmium  
4 pollution affect reproduction in the clam *Ruditapes decussates*? A one-year case study.  
5 *Comparative Biochemistry and Physiology, Part C* 143, 252-261.
- 6 Soussi, N., Mammoun, B., 1992. Contribution à l'étude de la pollution marine dans le Golfe  
7 de Gabès. Rapport de synthèse 50pp.
- 8 Terrados, J and Javier Medina Pons, F., 2008. Epiphyte load on the seagrass *Posidonia*  
9 *oceanica* (L.) Delile does not indicate anthropogenic nutrient loading in Cabrera Archipelago  
10 National Park (Balearic Islands, Western Mediterranean). *Scientia Marina* 72, 503- 510.
- 11 Trautman D. A., Borowitzka M. A., 1999. The distribution of the epiphytic organisms on  
12 *Posidonia australis* and *P. sinuosa*, two seagrasses with differing leaf morphology. *Marine*  
13 *Ecology Progress Series* 179, 215-229.
- 14 Underwood, A.J., 1994. On beyond BACI: sampling designs that might reliably detect  
15 environmental disturbances. *Ecological Application* 4, 3-15.
- 16 Van der Ben, D., 1971. Les épiphytes des feuilles de *Posidonia oceanica* Delile sur les côtes  
17 françaises de la Méditerranée. Mémoire de l'Institut Royal des Sciences Naturelles de  
18 Belgique 168, 1-101.
- 19 Vanderklift, M., Lavery, P., 2000. Patchiness in assemblages of epiphytic macroalgae on  
20 *Posidonia coriacea* at a hierarchy of spatial scales. *Marine Ecology Progress Series* 192, 127-  
21 135.
- 22 Wahl, M., 1989. Marine epibiosis. I. Fouling and antifouling: some basic aspects. *Marine*  
23 *Ecology Progress Series* 58, 175-189.

1 Zaghden, H., Kallel, M., Louati, A., Elleuch, B., Oudot, J., Saliot, A. 2005. Hydrocarbons in  
2 surface sediments from the Sfax coastal zone, (Tunisia) Mediterranean Sea. *Marine Pollution*  
3 *Bulletin* 50, 1287-1294.

4 Zaouali, J., 1993. Les peuplements benthiques de la petite Syrte, Golfe de Gabès – Tunisie.  
5 Résultats de la campagne de prospection du mois de juillet 1990. *Marine Life* 3, 47-60.

6

7

8

9

10

11

12

**Table 1.** Analysis of variance on shoot density, leaf surface area and leaf length. Bold numbers indicate significant effects. C = control locations; D= disturbed locations.

| Source of Variation                 | d.f | Shoot density        |        |             | Leaf surface area    |       |             | Leaf length              |       |             |
|-------------------------------------|-----|----------------------|--------|-------------|----------------------|-------|-------------|--------------------------|-------|-------------|
|                                     |     | MS                   | F      | P           | MS                   | F     | P           | MS                       | F     | P           |
| Locations = L                       | 3   | 2.68 10 <sup>7</sup> | 176.90 | <b>0.00</b> | 1.03 10 <sup>6</sup> | 11.71 | <b>0.00</b> | 9.31                     | 8.25  | <b>0.00</b> |
| Disturbed vs. Controls (DC)         | 1   | 6.88 10 <sup>7</sup> | 503.81 | <b>0.00</b> | 2.44 10 <sup>6</sup> | 16.55 | <b>0.02</b> | 20.15                    | 12.78 | <b>0.02</b> |
| Among Disturbed (=D)                | 1   | 1.17 10 <sup>7</sup> | 63.28  | <b>0.00</b> | 5.52 10 <sup>5</sup> | 4.579 | 0.10        | 0.07                     | 0.06  | 0.82        |
| Among Controls (=C)                 | 1   | 215.90               | 0.002  | 0.97        | 1.03 10 <sup>5</sup> | 1.868 | 0.24        | 7.71                     | 7.46  | 0.05        |
| Site (DC)                           | 4   | 1.36 10 <sup>5</sup> | 6.19   | <b>0.03</b> | 147 10 <sup>5</sup>  | 9.46  | <b>0.01</b> | 1.57                     | 0.17  | 0.94        |
| Site (D)                            | 4   | 1.85 10 <sup>5</sup> | 18.95  | <b>0.00</b> | 120 10 <sup>5</sup>  | 13.3  | <b>0.00</b> | 1.22                     | 0.24  | 0.91        |
| Site (C)                            | 4   | 1.18 10 <sup>5</sup> | 5.43   | <b>0.03</b> | 55474.20             | 7.71  | <b>0.02</b> | 1.03                     | 0.22  | 0.92        |
| Subsite (Site (DC))                 | 6   | 22030.05             | 1.19   | 0.34        | 15550.04             | 3.879 | <b>0.01</b> | 9.46                     | 3.66  | <b>0.01</b> |
| Subsite (Site (D))                  | 6   | 9767.25              | 0.97   | 0.47        | 9060.70              | 4.58  | <b>0.00</b> | 5.19                     | 4.08  | <b>0.00</b> |
| Subsite (Site (C))                  | 6   | 21758.39             | 1.30   | 0.30        | 7192.68              | 3.56  | <b>0.01</b> | 4.68                     | 3.17  | <b>0.02</b> |
| Plot (subsite (Site (DC)))          | 24  | 18454.41             | 0.82   | 0.70        | 4009.17              | 6.925 | <b>0.00</b> | 2.58                     | 3.44  | <b>0.00</b> |
| Plot (subsite (Site (D)))           | 26  | 10079.36             | 0.45   | 0.99        | 1992.08              | 7.32  | <b>0.00</b> | 1.27                     | 3.04  | <b>0.00</b> |
| Plot (subsite (Site (C)))           | 26  | 16742.5              | 1.42   | 0.13        | 2020.14              | 6.39  | <b>0.00</b> | 1.48                     | 3.82  | <b>0.00</b> |
| Quadrat (plot(subsite( Site (DC)))) | 72  | 22433.62             | 0.82   | 0.86        | 578.97               | 0.339 | 0.99        | 0.75                     | 6.76  | <b>0.00</b> |
| Quadrat (plot(subsite( Site (D))))  | 72  | 22550.45             | 12.38  | <b>0.00</b> | 271.83               | 0.802 | 0.86        | 0.42                     | 3.78  | <b>0.00</b> |
| Quadrat (plot(subsite( Site (C))))  | 72  | 11816.26             | 2.69   | <b>0.00</b> | 316.04               | 0.95  | 0.58        | 0.39                     | 5.59  | <b>0.00</b> |
| Residual                            | 432 | 3108.5               |        |             | 334.92               |       |             | 0.09                     |       |             |
| Residual D                          | 216 | 1820.99              |        |             | 339.03               |       |             | 0.11                     |       |             |
| Residual C                          | 216 | 4396.01              |        |             | 330.8                |       |             | 0.07                     |       |             |
| Transformation                      |     | None                 |        |             | None                 |       |             | Ln(x+1)                  |       |             |
| Cochran's C test                    |     | C=0.05, p<0.01       |        |             | C=0.403, p<0.01      |       |             | C=0.288, not significant |       |             |

**Table 2.** Analysis of variance on the epiphytic biomass on the leaves of *P. oceanica*. Bold numbers indicate significant effects.

| <i>Source of Variation</i>          | d.f | MS                 | F      | P           |
|-------------------------------------|-----|--------------------|--------|-------------|
| Locations = L                       | 3   | $3.46 \times 10^7$ | 30.85  | <b>0.00</b> |
| Disturbed vs. Controls (DC)         | 1   | $8.08 \times 10^7$ | 25.23  | <b>0.00</b> |
| Among Disturbed (=D)                | 1   | $8.57 \times 10^6$ | 655.01 | <b>0.00</b> |
| Among Controls (=C)                 | 1   | $1.44 \times 10^7$ | 6.48   | 0.06        |
| Site (DC)                           | 10  | $3.20 \times 10^6$ | 5.97   | <b>0.00</b> |
| Site (D)                            | 4   | 13097.61           | 0.25   | 0.89        |
| Site (C)                            | 4   | $2.23 \times 10^6$ | 2.17   | 0.19        |
| Subsite (Site (DC))                 | 12  | 537886.63          | 4.834  | <b>0.00</b> |
| Subsite (Site (D))                  | 6   | 51026.48           | 1.94   | 0.11        |
| Subsite (Site (C))                  | 6   | $1.0 \times 10^6$  | 5.22   | <b>0.00</b> |
| Plot (subsite (Site (DC)))          | 48  | 111265.64          | 1.05   | 0.40        |
| Plot (subsite (Site (D)))           | 24  | 26197.42           | 1.34   | 0.17        |
| Plot (subsite (Site (C)))           | 24  | 196333.85          | 1.02   | 0.45        |
| Quadrat (plot(subsite( Site (DC)))) | 144 | 105953.6           | 4.59   | <b>0.00</b> |
| Quadrat (plot(subsite( Site (D))))  | 72  | 19465.36           | 4.58   | <b>0.00</b> |
| Quadrat (plot(subsite( Site (C))))  | 72  | 192441.83          | 4.59   | <b>0.00</b> |
| Residual                            | 648 | 23086.88           |        |             |
| Residual D                          | 324 | 4243.37            |        |             |
| Residual C                          | 324 | 41930.39           |        |             |



**Table 3.** Non-parametric multivariate analysis of variance (NP-MANOVA) on epiphytic assemblage of *Posidonia oceanica*. Bold numbers indicate significant effects.

| <i>Source of Variation</i>          | d.f | MS      | F                     | P        |
|-------------------------------------|-----|---------|-----------------------|----------|
| Locations = L                       | 3   | 489.94  | 24.27                 | <b>0</b> |
| Disturbed vs. Controls (DC)         | 1   | 1412.48 | 64.55                 | <b>0</b> |
| Among Disturbed (=D)                | 1   | 52.46   | 3.44                  | 0.137    |
| Among Controls (=C)                 | 1   | 4.88    | 0.19                  | 0.682    |
| Site (DC)                           | 10  | 21.88   | 1.173                 | 0.391    |
| Site (D)                            | 4   | 15.23   | 0.46                  | 0.762    |
| Site (C)                            | 4   | 25.14   | 5.761                 | 0.03     |
| Subsite (Site (DC))                 | 12  | 18.66   | 0.855                 | 0.595    |
| Subsite (Site (D))                  | 6   | 32.96   | 1.16                  | 0.361    |
| Subsite (Site (C))                  | 6   | 4.36    | 0.29                  | 0.937    |
| Plot (subsite (Site (DC)))          | 48  | 21.18   | $2.15 \times 10^{13}$ | <b>0</b> |
| Plot (subsite (Site (D)))           | 24  | 28.47   | 0                     | <b>0</b> |
| Plot (subsite (Site (C)))           | 24  | 15.16   | 0                     | <b>0</b> |
| Quadrat (plot(subsite( Site (DC)))) | 144 | 0       | 0                     | <b>0</b> |
| Quadrat (plot(subsite( Site (D))))  | 72  | 0       | 0                     | <b>0</b> |
| Quadrat (plot(subsite( Site (C))))  | 72  | 0       | 0                     | <b>0</b> |
| Residual                            | 648 | 0       |                       |          |
| Residual D                          | 324 | 0       |                       |          |
| Residual C                          | 324 | 0       |                       |          |

**Table 4.** Analysis of variance on mean percentage cover of epiphytes of *Posidonia oceanica*.

Bold numbers indicate significant effects.

| Source of Variation          | df  | Filamentous algae |         |              | Bryozoans       |        |              | Hydrozoans      |         |              | Encrusting Annelida |         |              |
|------------------------------|-----|-------------------|---------|--------------|-----------------|--------|--------------|-----------------|---------|--------------|---------------------|---------|--------------|
|                              |     | MS                | F       | P            | MS              | F      | P            | MS              | F       | P            | MS                  | F       | P            |
| Locations = L                | 3   | 43.014            | 10.5    | <b>0.004</b> | 0.11            | 0.06   | 0.986        | 147.13          | 12.08   | <b>0.002</b> | 64.1                | 4.83    | <b>0.033</b> |
| Disturbed vs. Controls = DC  | 1   | 104.59            | 19.6    | <b>0.001</b> | 0.2             | 0.1    | 0.755        | 395.59          | 29.12   | <b>0</b>     | 44.75               | 1.78    | 0.211        |
| Disturbed =D                 | 1   | 12.68             | 1.85    | 0.245        | 0.02            | 0.01   | 0.929        | 31.92           | 1.54    | 0.281        | 86.09               | 6.19    | 0.068        |
| Controls = C                 | 1   | 8.812             | 7.87    | 0.049        | 0.08            | 0.03   | 0.864        | 8.12            | 2.44    | 0.194        | 59.74               | 4.85    | 0.092        |
| Site (L) = SL                | 8   | 4.07              | 0.46    | 0.861        | 2.53            | 1.8    | 0.173        | 12.18           | 1.75    | 0.183        | 13.28               | 2.59    | 0.067        |
| Site (DC) = SiDC             | 10  | 5.32              | 0.61    | 0.781        | 1.95            | 1.41   | 0.282        | 13.58           | 1.95    | 0.136        | 25.07               | 4.87    | <b>0.006</b> |
| Site (D) = SiD               | 4   | 6.83              | 0.46    | 0.759        | 2.43            | 0.95   | 0.495        | 20.61           | 2.25    | 0.178        | 13.9                | 1.94    | 0.222        |
| Site (C) = SiC               | 4   | 1.12              | 0.39    | 0.813        | 2.42            | 11.43  | <b>0.006</b> | 3.33            | 0.69    | 0.623        | 12.32               | 3.91    | 0.067        |
| Subsite (SL)                 | 12  | 8.8               | 2.3     | <b>0.02</b>  | 1.4             | 1.29   | 0.25         | 6.93            | 1.18    | 0.322        | 5.12                | 0.9     | 0.551        |
| Subsite (SiDC)               | 12  | 8.76              | 2.28    | <b>0.022</b> | 1.38            | 1.33   | 0.232        | 6.96            | 1.19    | 0.312        | 5.15                | 0.91    | 0.544        |
| Subsite (SiD)                | 6   | 14.62             | 2.56    | <b>0.046</b> | 2.55            | 1.67   | 0.17         | 9.12            | 1.17    | 0.351        | 7.14                | 0.82    | 0.567        |
| Subsite (SiC)                | 6   | 2.91              | 1.47    | 0.23         | 0.21            | 0.38   | 0.882        | 4.81            | 1.24    | 0.321        | 3.15                | 1.221   | 0.33         |
| Plot ( Subsite (SL))         | 48  | 3.81              | 0       | <b>0</b>     | 0               | 0      | <b>0</b>     | 5.87            | 0       | <b>0</b>     | 5.67                | 0       | <b>0</b>     |
| Plot (Subsite(SiDC))         | 48  | 3.83              | 1569.1  | <b>0</b>     | 1.04            | 867.34 | <b>0</b>     | 5.81            | 1346.47 | <b>0</b>     | 5.65                | 2220.02 | <b>0</b>     |
| Plot (subsite(S(D)))         | 24  | 5.69              | 1386.2  | <b>0</b>     | 1.52            | 1456.2 | <b>0</b>     | 7.75            | 1242.7  | <b>0</b>     | 8.73                | 4416.98 | <b>0</b>     |
| Plot (subsite(SiC))          | 24  | 1.97              | 2528.35 | <b>0</b>     | 0.55            | 409.47 | <b>0</b>     | 3.87            | 1616.59 | <b>0</b>     | 2.58                | 826.63  | <b>0</b>     |
| Quadrat(Plot(Subsite (SL)))  | 144 | 0                 | 0       | <b>0</b>     | 0               | 0      | <b>0</b>     | 0.001           | 0       | <b>0</b>     | 0                   | 0       | <b>0</b>     |
| Quadrat(Plot(Subsite(SiDC))) | 144 | 0.002             | 0.92    | 0.74         | 0.001           | 0.92   | 0.746        | 0.004           | 1.01    | 0.457        | 0.01                | 0.98    | 0.539        |
| Quadrat(plot(subsite(S(D)))) | 72  | 0.004             | 0.91    | 0.679        | 0.001           | 1      | 0.484        | 0.006           | 1       | 0.484        | 0.01                | 0.95    | 0.584        |
| Quadrat(plot(subsite(SiC)))  | 72  | 0.001             | 0.94    | 0.607        | 0.001           | 0.86   | 0.775        | 0.002           | 1.04    | 0.402        | 0.01                | 1.01    | 0.478        |
| Residual L                   | 648 | 0                 |         |              | 0               |        |              | 0               |         |              | 0                   |         |              |
| Residual DC                  | 648 | 0.003             |         |              | 0.001           |        |              | 0.004           |         |              | 0.003               |         |              |
| Residual D                   | 324 | 0.004             |         |              | 0.001           |        |              | 0.006           |         |              | 0.002               |         |              |
| Residual C                   | 324 | 0.008             |         |              | 0.002           |        |              | 0.002           |         |              | 0.003               |         |              |
| Cochran's C-test             |     | 0.309, p < 0.01   |         |              | 0.307, p < 0.01 |        |              | 0.406, p < 0.01 |         |              | 0.206, p < 0.01     |         |              |
| Transformation               |     | Ln (x+1)          |         |              | Ln (x+1)        |        |              | Ln (x+1)        |         |              | Ln (x+1)            |         |              |
| S-N-K test                   |     | D2<D1<C2<C1       |         |              | D2<D1<C2<C1     |        |              | D2<D1<C2<C1     |         |              | D2<C1<D1<C2         |         |              |

**Table 5.** Major species, ranked in order of importance, contributing to the average dissimilarities between the disturbed and the control locations as determined by similarity percentages (SIMPER).

| Species  |                 | C           |             | D        |           |
|--|-----------------|-------------|-------------|----------|-----------|
|  |                 | Av. % cover | Av. % cover | Av. Diss | %. Contri |
| <i>Antithamnion</i> sp                           | (Rhodophyta)    | 44.83       | 2.57        | 5.32     | 9.53      |
| <i>Polysiphonia elongata</i> (Hudson) Sprengel   | (Rhodophyta)    | 40.67       | 4.4         | 4.39     | 7.87      |
| <i>Ceramium tenuissimum</i> (Roth) Aresch        | (Rhodophyta)    | 34.96       | 0.05        | 4.02     | 7.2       |
| <i>Ceramium codii</i> (Richards) Mazoyer         | (Rhodophyta)    | 29.34       | 0           | 3.91     | 7         |
| <i>Dynamena cavolinii</i> Neppi                  | (Hydrozoa)      | 23.11       | 3.07        | 3.71     | 6.64      |
| <i>Spirorbis spirorbis</i> Linnaeus              | (Annelida)      | 16.83       | 11.11       | 3.6      | 6.45      |
| <i>Scrupocellaria</i> sp.                        | (Bryozoa)       | 4.89        | 4.13        | 3.36     | 6.02      |
| <i>Bowerbankia imbricata</i> Adams               | (Bryozoa)       | 3.09        | 4.2         | 3.29     | 5.9       |
| <i>Electra posidoniae</i> Gautier                | (Bryozoa)       | 12.7        | 15.05       | 3.15     | 5.65      |
| <i>Lichenopora radiata</i> Audouin               | (Bryozoa)       | 8.21        | 1.91        | 2.64     | 4.73      |
| <i>Micropora complanata</i> Norman               | (Bryozoa)       | 12.94       | 4.25        | 2.13     | 3.82      |
| <i>Monothecha</i> sp.                            | (Hydrozoa)      | 3.07        | 2.92        | 1.96     | 3.51      |
| <i>Obelia geniculata</i> Linnaeus                | (Hydrozoa)      | 3           | 2.97        | 1.63     | 2.92      |
| <i>Aetea truncata</i> Landsborough               | (Bryozoa)       | 0.39        | 3.62        | 1.56     | 2.8       |
| <i>Halocordyle disticha</i> Goldfuss             | (Hydrozoa)      | 0.77        | 0.1         | 1.44     | 2.58      |
| <i>Lyngbya</i> sp. C. Agardh ex Gomont           | (Cyanobacteria) | 0.71        | 0.39        | 1.29     | 2.31      |
| <i>Plumularia setacea</i> Linnaeus               | (Hydrozoa)      | 0.75        | 0           | 1.23     | 2.2       |
| <i>Rivularia bullata</i> (Poir) Berkeley         | (Cyanobacteria) | 0.7         | 0.02        | 1.03     | 1.84      |
| <i>Gloeotrichia</i> sp.                          | (Cyanobacteria) | 0           | 0.16        | 0.81     | 1.45      |
| <i>Chelidonia cordieri</i> Audouin               | (Bryozoa)       | 0           | 0.01        | 0.76     | 1.36      |
| <i>Dasya</i> sp.                                 | (Rhodophyta)    | 4.83        | 1.52        | 0.72     | 1.29      |
| <i>Phormidium</i> sp.                            | (Cyanobacteria) | 0.51        | 0           | 0.63     | 1.14      |
| <i>Griffithsia</i> sp.                           | (Rhodophyta)    | 0.4         | 0           | 0.54     | 0.97      |
| <i>Dasycladus vermicularis</i> (Scopoli) Krasser | (Chlorophyta)   | 0.17        | 0           | 0.53     | 0.95      |
| <i>Aglaophenia</i> sp.                           | (Hydrozoa)      | 0.06        | 0.02        | 0.5      | 0.9       |
| <i>Campanularia hincksi</i> Alder                | (Hydrozoa)      | 0           | 0.02        | 0.18     | 0.33      |
| <i>Pleonosporium borneri</i> (J.E.Smith) Nägeli  | (Rhodophyta)    | 0.01        | 0           | 0.18     | 0.32      |
| <i>Orthopyxis caliculata</i> (Hincks)            | (Hydrozoa)      | 0.02        | 0           | 0.15     | 0.27      |
| <i>Cribrilina radiata</i> (Smitt)                | (Bryozoa)       | 0.01        | 0           | 0.14     | 0.25      |



**Table 7.** Test of equality of mean variables studied for *P. oceanica* meadows. F:, df1, df2, Sig.:

|                     | Wilks' Lambda | F     | df1 | df2 | Sig.  |
|---------------------|---------------|-------|-----|-----|-------|
| Biomass             | 0.081         | 30.85 | 3   | 8   | 0     |
| Filamentous algae   | 0.285         | 6.673 | 3   | 8   | 0.014 |
| Bryozoans           | 0.967         | 0.092 | 3   | 8   | 0.962 |
| Hydrozoans          | 0.131         | 17.61 | 3   | 8   | 0     |
| Encrusting Annelida | 0.363         | 4.66  | 3   | 8   | 0.036 |
| Leaf length         | 0.373         | 4.476 | 3   | 8   | 0.04  |
| Shoot density       | 0.015         | 175.4 | 3   | 8   | 0     |

**Table 8.** Standardized canonical discriminant function coefficients of the studied variables for *Posidonia oceanica*.

|                     | Function |        |        |
|---------------------|----------|--------|--------|
|                     | 1        | 2      | 3      |
| Biomass             | 1.143    | 1.52   | 0.07   |
| Hydrozoans          | 2.523    | 1.287  | 0.866  |
| Encrusting Annelida | 0.608    | -0.79  | 0.984  |
| Shoot density       | -2.992   | -0.898 | -0.287 |

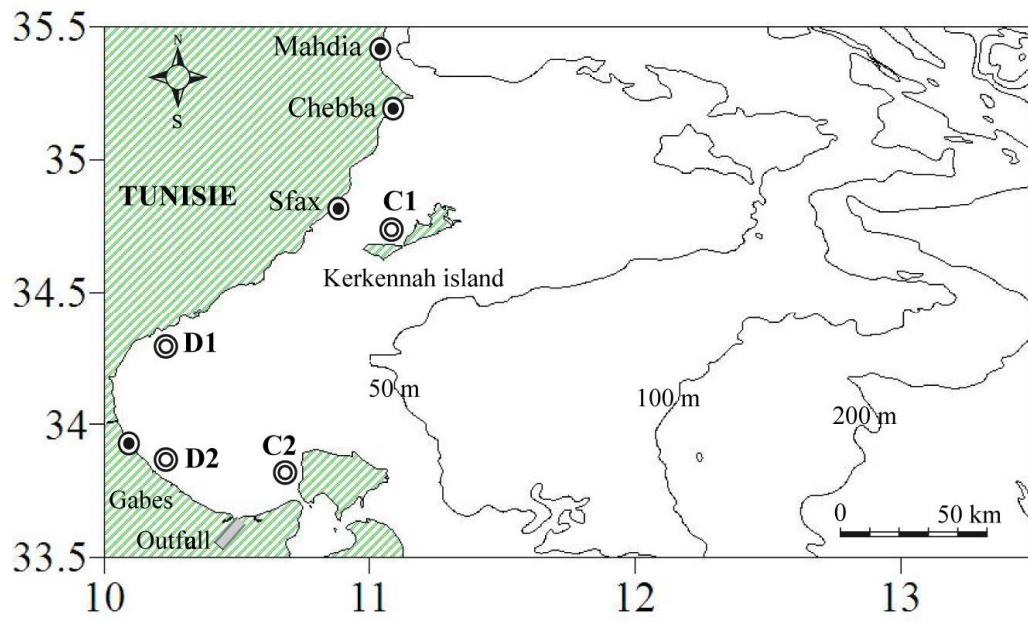


Figure 1.

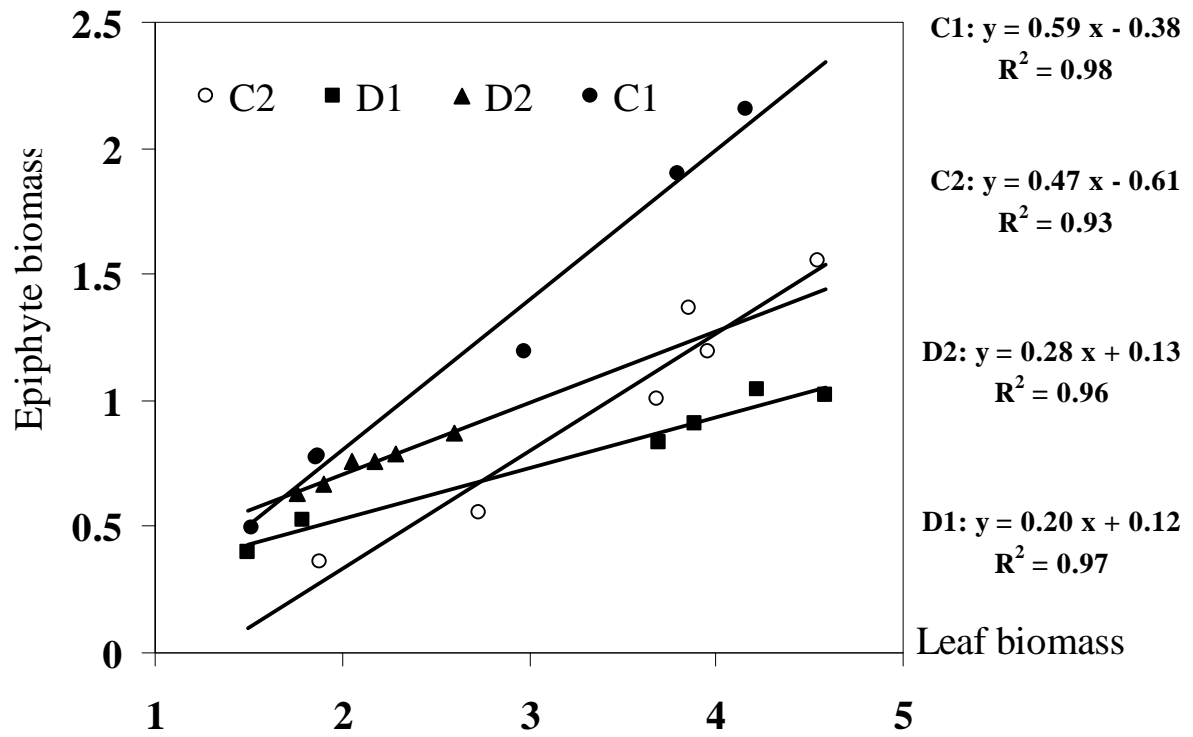


Figure 2.



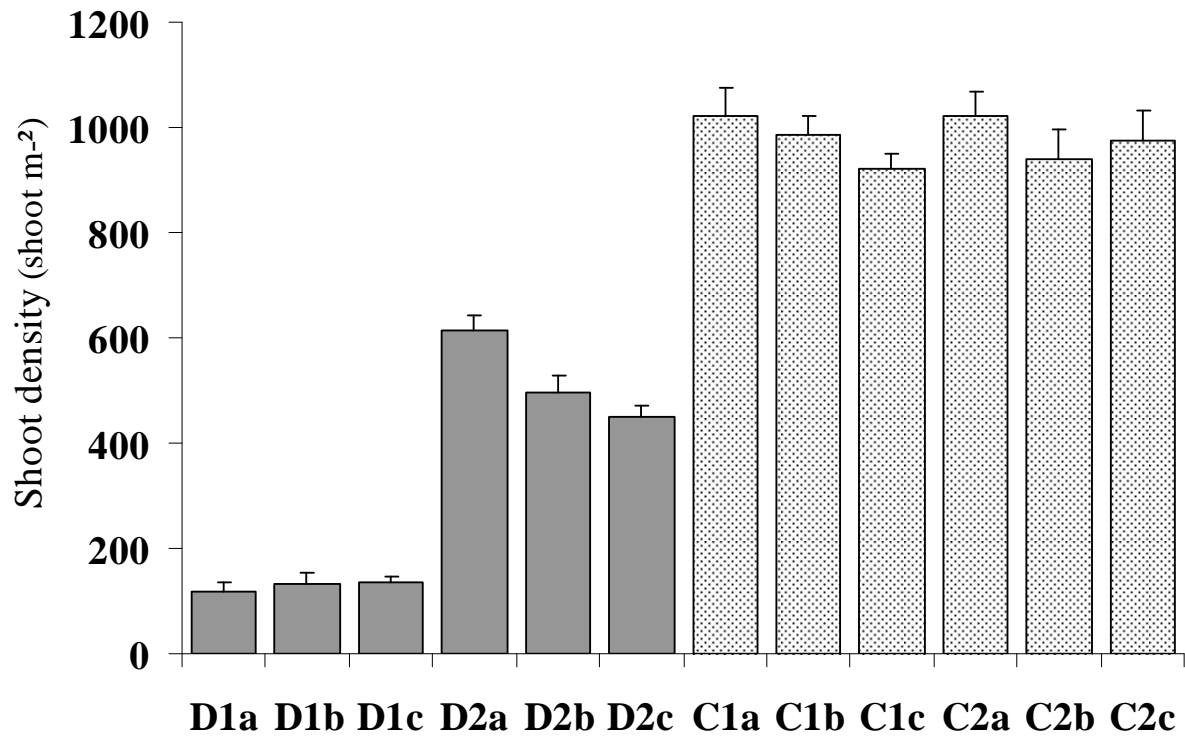


Figure 3.

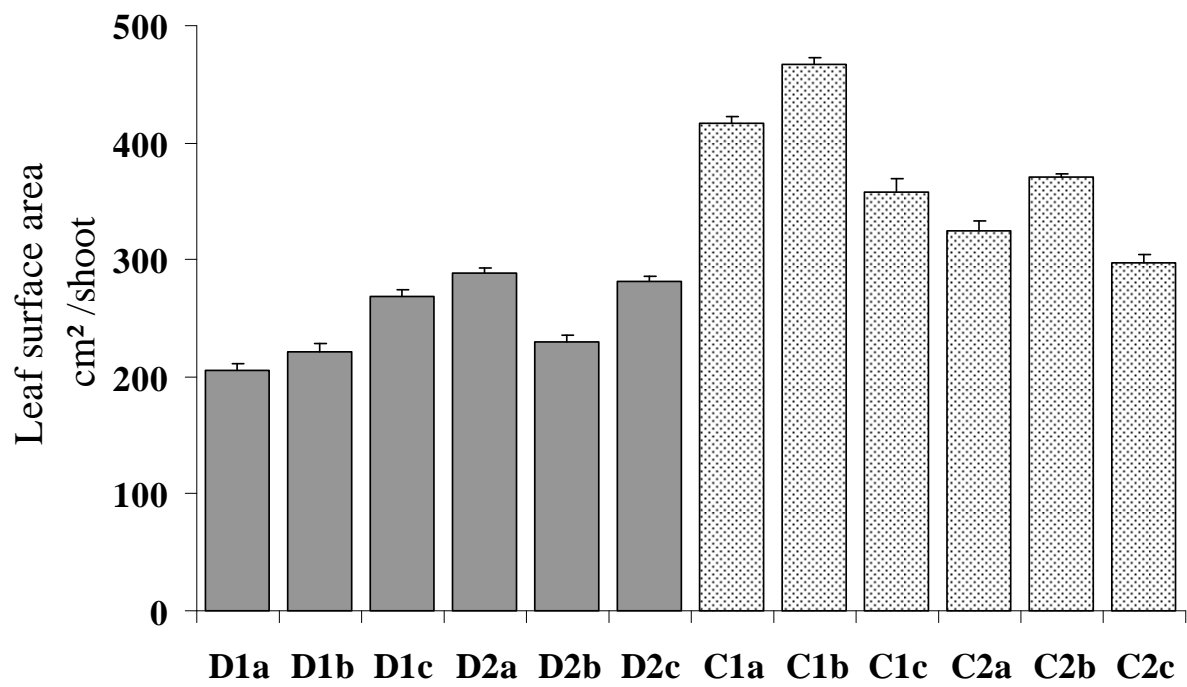


Figure 4.

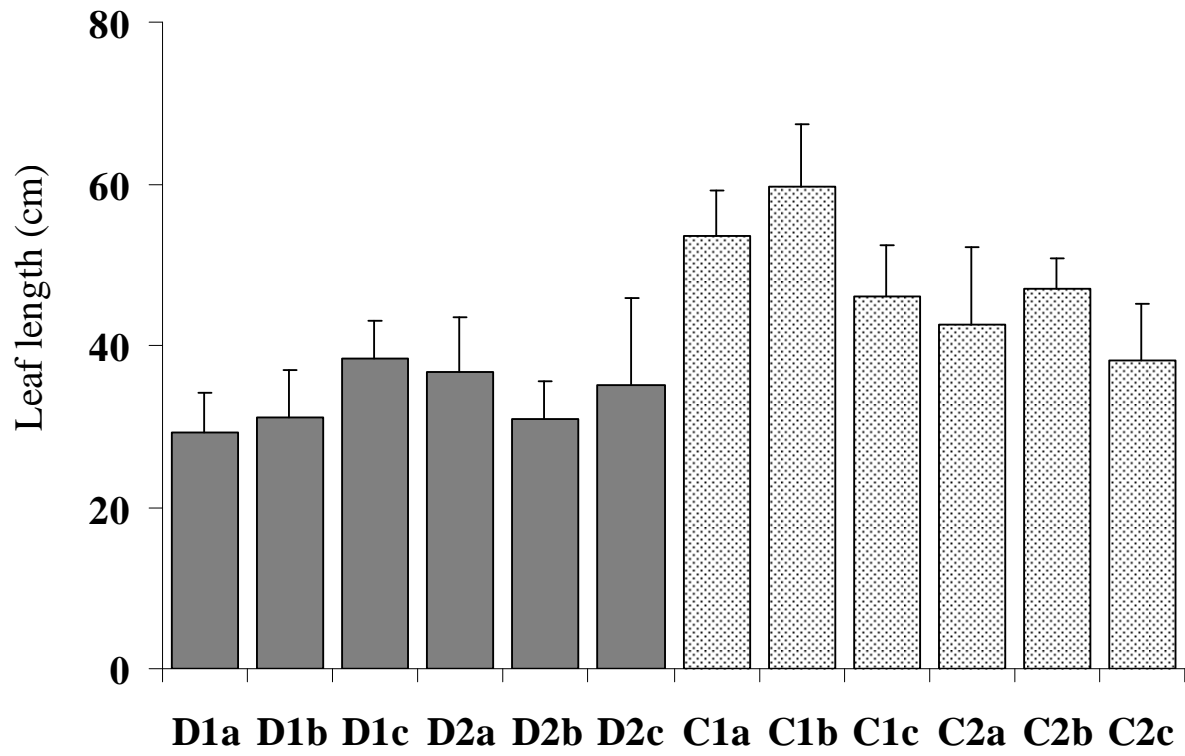


Figure 5.

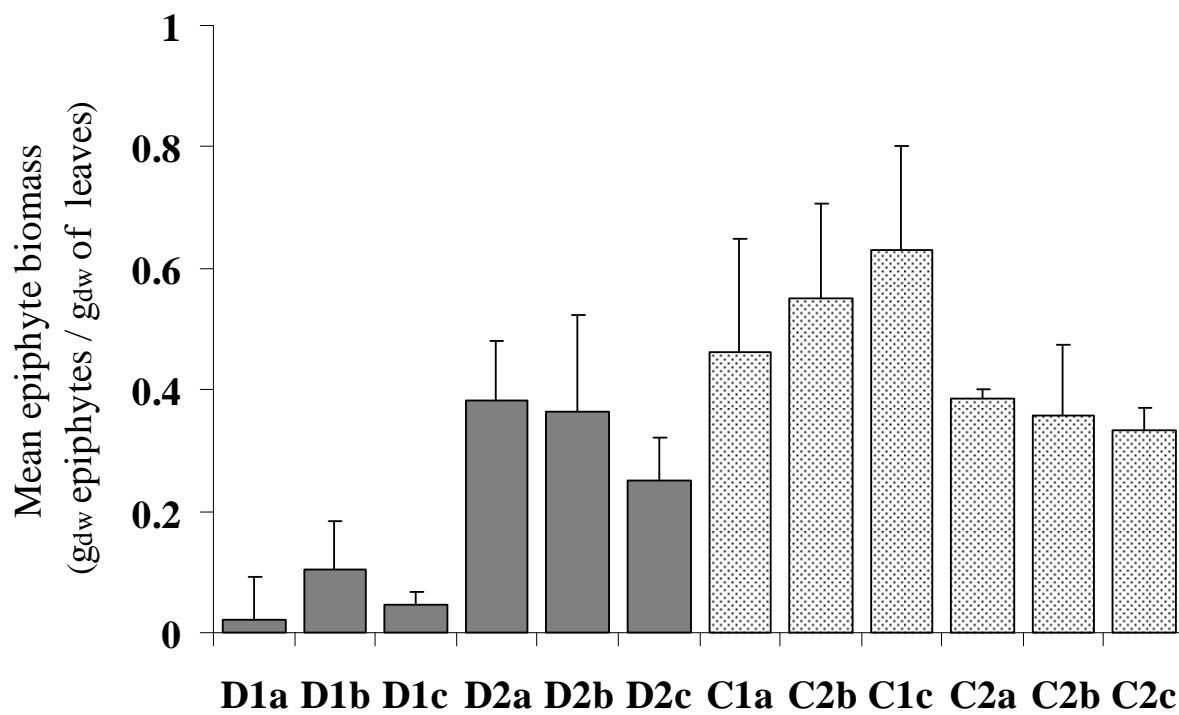


Figure 6.

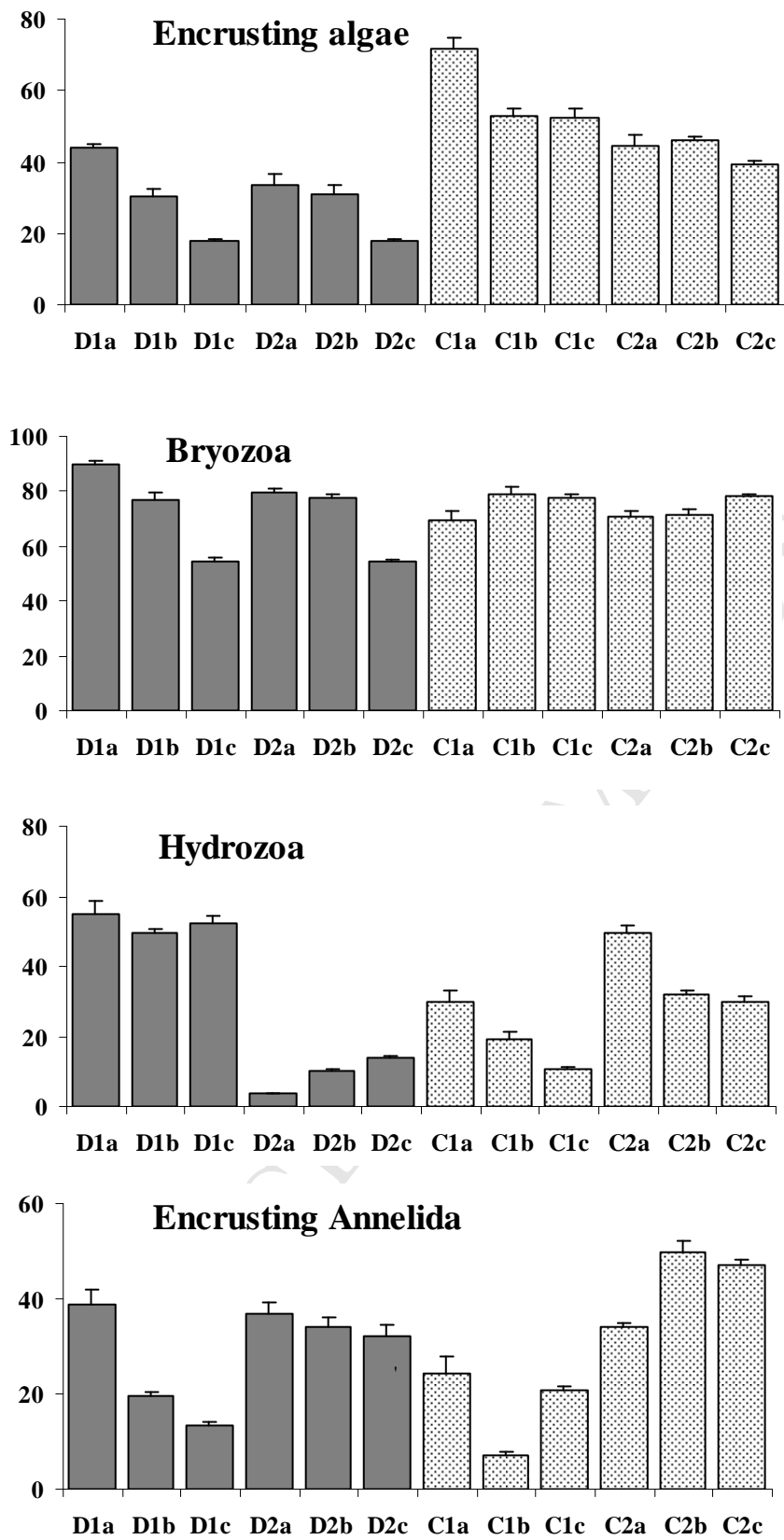


Figure 7.

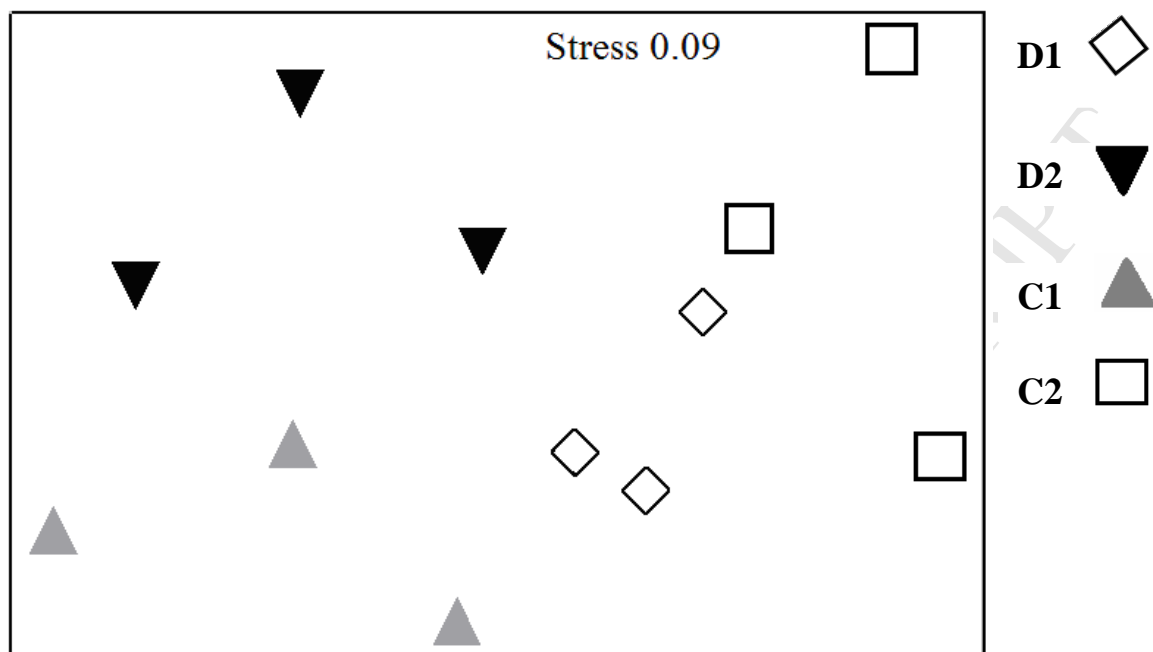


Figure 8.

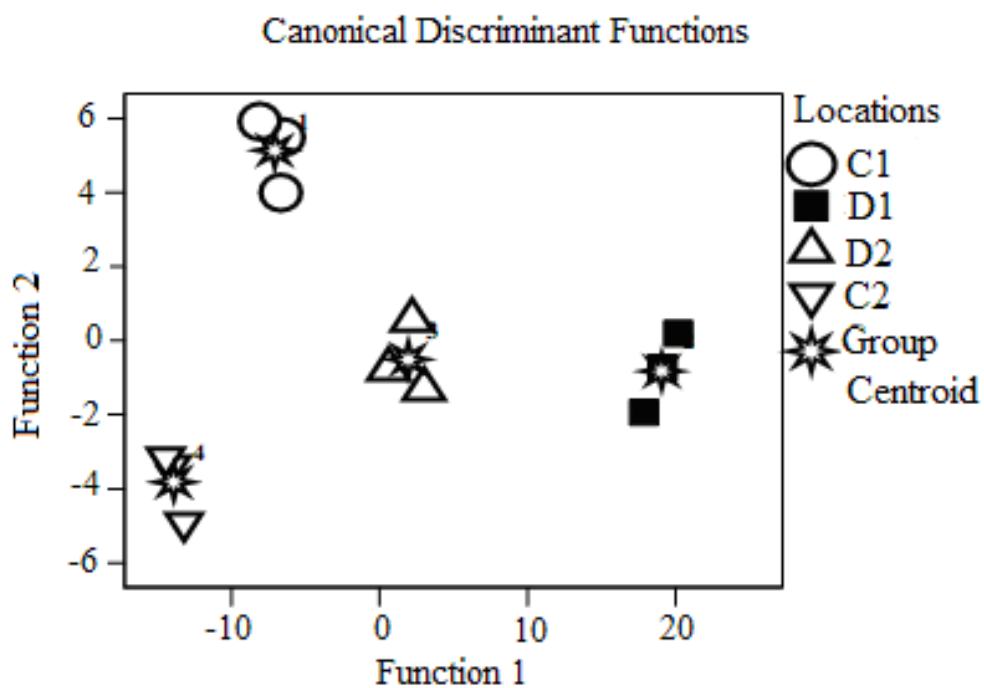


Figure 9.

List of figures:

**Figure 1.** Geographical map focussing on sampling locations in the Gulf of Gabes.

**Figure 2.** Leaf biomass vs. epiphyte biomass ( $\text{g}_{\text{dw}} \text{leaf}^{-1}$ ) for disturbed (D) and control (C) locations.





**Figure 3.** Average  $\pm$  SD values of the shoot density at the control (C1, C2) and disturbed D1, D2) locations with the three nested sites a, b and c.

**Figure 4.** Average  $\pm$  SD values of the leaf surface area at the control (C) and disturbed (D) locations with the three nested sites a, b and c.

**Figure 5.** Average  $\pm$  SD values of leaf length at the control (C) and disturbed (D) locations with the three nested sites a, b and c.

**Figure 6.** Average  $\pm$  SD values of the mean biomass of leaf epiphytes of *P. oceanica* at the control (C) and disturbed (D) locations with the three nested sites a, b and c.

**Figure 7.** Mean percentage cover of the main epiphyte groups at the control and disturbed locations with the three nested sites a, b and c. (C1: Hassar; D1: Ghannouch; D2: Zarrat and C1: Ajim).

**Figure 8.** nMDS showing the dissimilarity among centroids of sites of epiphytic assemblages on leaves. Ghannouch: D1 , Zarrat: D2 , Hassar: C1,  Ajim: C2. 

**Figure 9.** Global projection on the first factorial design discriminating of variables and group centroids.



|   | C | D |
|---|---|---|
| <b>Filamentous algae</b>                                      |   |   |
| <b>Chlorophyta</b>  |   |   |
| <i>Cladophora</i> sp.   | 1 | 0 |
| <i>Dasycladus vermicularis</i> (Scopoli) Krasser              | 1 | 1 |
| <b>Heterokontophyta</b>                                       |   |   |
| <i>Dictyota dichotoma</i> (Hudson) J.V Lamouroux              | 1 | 1 |
| <b>Rhodophyta</b>   |   |   |
| <i>Antithamnion</i> sp.                                       | 1 | 1 |
| <i>Ceramium codii</i> (Richards) Mazoyer                      | 1 | 1 |
| <i>Ceramium gracillimum</i> (Kützing) Zanardini               | 1 | 0 |
| <i>Ceramium tenuissimum</i> (Roth) Aresch                     | 1 | 1 |
| <i>Dasya</i> sp.  | 1 | 1 |
| <i>Falkenbergia rufolanosa</i> (Harvey) F. Schmitz            | 1 | 0 |
| <i>Griffithsia opuntioides</i> J. Agardh                      | 1 | 1 |
| <i>Laurencia obtusa</i> (Hudson) J.V. Lamouroux               | 1 | 0 |
| <i>Neomonospora</i> sp.                                       | 1 | 0 |
| <i>Pleonosporium borrieri</i> (J.E.Smith) Nägeli              | 1 | 1 |
| <i>Polysiphonia elongate</i> (Hudson) Sprengel                | 1 | 1 |
| <b>Cyanobacteria</b>  |   |   |
| <i>Calothrix</i> sp.  | 1 | 0 |
| <i>Gloeotrichia</i> J. Agardh ex Bornet & Flahault            | 1 | 1 |
| <i>Lyngbya</i> sp.  | 1 | 1 |
| <i>Phormidium</i> sp.   | 1 | 1 |
| <i>Rivularia bullata</i> (Poir) Berkeley ex Bornet & Flahault | 1 | 1 |
| <i>Rivularia mesenterica</i> Thuret                           | 1 | 0 |
| <b>Hydrozoa</b>   |   |   |
| <i>Aglaophenia</i> sp.  | 1 | 1 |
| <i>Campanularia hincksi</i> Alder                             | 1 | 1 |
| <i>Dynamena cavolinii</i> Neppi                               | 1 | 1 |
| <i>Gonothyrea gracilis</i> M. Sars                            | 1 | 0 |
| <i>Halocordyle disticha</i> Goldfuss                          | 1 | 1 |
| <i>Monothecca</i> sp.   | 1 | 1 |
| <i>Obelia geniculata</i> Linnaeus                             | 1 | 1 |
| <i>Orthopyxis caliculata</i> Hincks                           | 1 | 1 |
| <i>Plumularia setacea</i> Linnaeus                            | 1 | 1 |
| <b>Bryozoa</b>  |   |   |
| <i>Aetea truncata</i> Landsborough                            | 1 | 1 |
| <i>Alcyonidium</i> sp.  | 1 | 1 |
| <i>Amathia lendigera</i> Linnaeus                             | 1 | 0 |
| <i>Beania hirtissima</i> Heller                               | 1 | 0 |
| <i>Bowerbankia imbricata</i> Adams                            | 1 | 1 |
| <i>Chelidonia cordieri</i> Audouin                            | 1 | 1 |
| <i>Cribrilina radiata</i> Smitt                               | 1 | 1 |
| <i>Electra posidoniae</i> Gautier                             | 1 | 1 |
| <i>Lichenopora radiata</i> Audouin                            | 1 | 1 |
| <i>Micropora complanata</i> Norman                            | 1 | 1 |
| <i>Scrupocellaria</i> sp.                                     | 1 | 1 |
| <b>Annelida</b>   |   |   |
| <i>Aphrodita</i> sp.  | 1 | 0 |

|                        |   |    |    |
|------------------------|---|----|----|
|                        | <i>Brania clavata</i> Claparede                       | 1  | 0  |
|                        | <i>Spirorbis spirorbis</i> Linnaeus                   | 1  | 1  |
| <b><i>Porifera</i></b> |   |    |    |
|                        | <i>Halichondria</i> sp.                               | 1  | 0  |
|                        | <i>Ircinia fasciculata</i> Esper                      | 1  | 0  |
|                        | <i>Ircinia muscarum</i> Schind                        | 1  | 0  |
| <b><i>Tunicata</i></b> |   |    |    |
|                        | <i>Botryllus schlosseri</i> Pallas                    | 1  | 0  |
|                        | <i>Clavelina lepadiformis</i> (light-bulb sea squirt) | 1  | 1  |
|                        | Total number of taxa                                  | 49 | 32 |

Appendix. Presence/absence of species and/or genus found growing on *Posidonia oceanica* leaves in the disturbed (D) and control locations (C) at Gabes gulf.