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Spatial variation of summer microphytoplankton and zooplankton communities related to environmental parameters in the coastal area of Djerba Island (Tunisia, Eastern Mediterranean)

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Abstract

In the present study, we investigated the effects of pollution and anthropization on the summer distribution of phyto-zooplankton communities in relation to environmental factors in the coastal zone of DjerbaIsland. On the basis of chemical factors, the Djerba coasts can be divided into two parts: the Western Area (WA), characterized by high values of nitrogen forms of nutrients, with higher N/P ratio, and the Eastern Area (EA), poorer in inorganic nitrogen with an N/P ratio lower than the Redfield ratio (16). Strong differences in terms of plankton communities were also observed between these two areas. Bacillariophyceae was the most important microphytoplankton group in the WA whereas the proportion of Cyanobacteria was higher in the EA. High Cyanobacteria abundance in the EA may be linked to high DIP concentration. In the WA, the Bacillariophyceae *Chaetoceros, Coscinodiscus, Grammatophora, Navicula* and *Pinnularia* reached high abundance in relation with their good adaptability to adverse conditions. Copepods were the most abundant zooplankton present in the WA (54–100% of total zooplankton abundance), whereas other zooplankton were always dominant (60–90%) in the EA. The small pollution-tolerant Calanoid copepod *Paracalanus parvus* was dominant in the WA, illustrating its affinity for highly eutrophic sites. Despite human pressure and industrial activities, the coastal waters of Djerba showed a wide diversity of microphytoplankton and zooplankton.

Keywords: Djerba Island; microphytoplankton; zooplankton; environmental parameters; pollution.

Introduction

Phytoplankton account for roughly half of the world's primary productivity, and they are the base of marine food webs, strongly affecting biogeochemical processes in the sea. Since the phytoplankton represents the first trophic level in the marine ecosystems, the production achieved by its photosynthetic micro-organisms constitutes the most important source of energy supporting the marine food webs (Anderson *et al.*, 2018). They constitute a source of food for pelagic herbivores, including larval fish, (Napp*et al.*, 1996) and maintain commercial fisheries (Blanchard *et al.*, 2012). Phytoplankton abundance, biomass and species composition vary significantly with spatial distribution and seasonality (Page *et al.*, 2022). Phytoplankton vary greatly in their morphology, size and growth rate (Page *et al.*, 2022). Recent research has revealed that phytoplankton productivity and biomass fluctuate with the changing environment (Paczkowska *et al.*, 2019), with consequences for the higher trophic levels, such as marine mammals and seabirds (Scales *et al.*, 2014). Eutrophication and harmful algal blooms have been recognized as one of the major environmental problems in aquatic ecosystems (Ho & Michalak, 2015) and more specifically marine coastal areas (Kahru *et al.*, 2020). Phytoplankton sensitivity to environmental variations and the fluctuation of its specific composition are important indicators of potential alterations (Dong *et al.*, 2016). The status and changes in the phytoplankton community structure are closely related to water temperature and nutrient input (Tian *et al.*, 2021). The bioavailability of dissolved nutrients to the phytoplankton significantly influences its abundance and functional diversity, and the ecosystem-nutrient equilibrium (Cuvin-Aralar *et al.*, 2004). In addition to physico-chemical parameters, the structure of the phytoplankton community is also determined by biological factors such as selective grazing pressure, resource competition and life cycles (Lim *et al.*, 2019).

Zooplankton are important components of the matter cycle and energy flow (Gao *et al.*, 2019) and represent an important link in the food chain of marine ecosystems (Varghese *et al.*, 2015). The species composition and biodiversity of zooplankton directly reflect the structure and function (Gao *et al.*, 2019) and the health status (Sanyal *et al.*, 2015) of aquatic ecosystems. Zooplankton communities are known to quickly respond to fluctuations in environmental factors, particularly in coastal areas where the combination of land and marine influences drives strong spatial and temporal variability (Drira *et al.*, 2018a). They are thus used as bioindicators for environmental changes (Hu *et al.*, 2019; Musialik-Koszarowska *et al.*, 2019) and for water quality monitoring (Wang *et al.*, 2012). Copepods are the most abundant components of coastal zooplankton assemblages in the Mediterranean Sea (Ben Salem & Ayadi, 2016), and the investigation of their biodiversity and spatial distribution in relation to environmental factors highlights the budgets of pelagic carbon and nutrient fluxes in marine food webs (Rekik *et al.*, 2011). As organisms are mostly feeding on phytoplankton, copepods indirectly indicate changes in the trophic status, in the structure of phytoplankton, and possible eutrophic conditions (Musialik-Koszarowska *et al.*, 2019).

In the Mediterranean, the Gulf of Gabès (Eastern Mediterranean Sea, Tunisia) is one of the oceanic regions most impacted by water quality issues, particularly in its coastal area which shows signs of eutrophication in relation with increasing anthropogenic pressure since industrialization in the nineteen-seventies. Several studies focused on the characterization of phytoplankton and zooplankton assemblages have been undertaken in this region, mostly in the central open sea areas or in the western coastal waters (Drira *et al.*, 2010, 2014, 2018a; Ben Ltaief *et al.*, 2015, 2017), or in the southern coastal zone and Boughrara lagoon (Kmiha-Megdiche *et al.*, 2021; Makhlouf Belkahia *et al.*, 2021). However, there is no data concerning the coastal area as of Djerba Island, which is, however, an important zone for the Tunisian economy (tourism, fisheries), but is strongly threatened by pollution and urbanization. Its marine environment has been severely impacted by the degradation of the coastal water quality (Rabaoui *et al.*, 2014) related to urban waste discharges from Houmt-souk and Ajim, and also to tourism development at Midoun (Afli *et al.*, 2013). The major urban and industrial development along the west coast of Djerba has led to a generalized increase in pollution inducing changes in the biodiversity of benthic communities (Louati*et al.*, 2001). The aim of this study is to describe for the first time the microphytoplankton and zooplankton summer distribution along the Djerba coasts in relation with the physical and chemical parameters of the water. This approach will enable us to describe the environmental conditions of the Djerba coasts and to correlate them with the microphytoplankton community structure and biodiversity and to explore the relationships between copepods and microphytoplankton. This study will also provide a preliminary assessment of the anthropogenic impact on the eastern and western coasts of Djerba. We hypothesized that the taxonomic composition of the pelagic copepod community follows the physical parameters and exhibits interspecific differences in relation to their potential planktonic prey such as microphytoplankton. Hence this research has been undertaken with the following aims: (1) to study the summer microphytoplankton and zooplankton communities' structure and distribution along the western and eastern coasts of Djerba Island; (2) to assess their potential relationship with environmental factors; and (3) to assess the adequacy of plankton taxonomic composition as bioindicator of the marine water quality.

Material and Methods

Study site

With an area of 514 km², Djerba is the largest Island off the south-eastern coast of Tunisia and is surrounded by the Gulf of Gabes to the north and by Boughrara lagoon to the south-east (El Kateb *et al.*, 2018a). Its coasts are particularly exposed to pollution due to the discharge of domestic sewage from Houmt Souk in particular and/or to particular hydrodynamic features transporting the pollutants issued from other locations in the Gulf of Gabès (Rabaoui *et al.*, 2014). The eastern side of Djerba Island is an important tourism centre (Rabaoui *et al.*, 2014).

Field sampling

The study was carried out as part of an international project run by the *Société d'Etude de Réalisationd'Aménagement et d'Hydraulique* (SERAH). Water samples were taken in summer (July 2009-2010) along the coasts of Djerba Island at 15 stations (Fig. 1; Table 1). The stations were located at different depths due to different distances off the coast: S3, S4, S6, S7, S8 and S9 with depth < 20 m; S1, S2, S5, S13, S14 and S15 with depth > 20 m; S10, S11 and S12 with depth >30 m (Table 2). At each station, samples for chemical analyses and for microphytoplankton identification were collected from the surface water with a Van Dorn type bottle lowered to 1 m below the surface. Zooplankton were collected using a cylindrical conical net (30 cm aperture, 100 cm high, 100 µm mesh size), equipped with a Hydro-Bios flowmeter (Rekik *et al.*, 2018a). The volume of water filtered was about 1 m^3. Back in the laboratory, samples for nutrient analyses (120 ml) were immediately filtered under a low vacuum (<50 mm Hg) through pre-combusted (500°C, 4 h) GF/F (~0.7 mm) glass fibre filters (25 or 47 mm diameter, Whatman) using glassware filtration systems. Nutrients were preserved immediately upon collection at –20°C in the dark; those for microphytoplankton enumeration (1L) were preserved with Lugol 4% iodine solution. Zooplankton samples were rapidly preserved in 2% buffered formaldehyde solution after collection and stored in the dark at 4°C (Rekik *et al.*, 2018a).

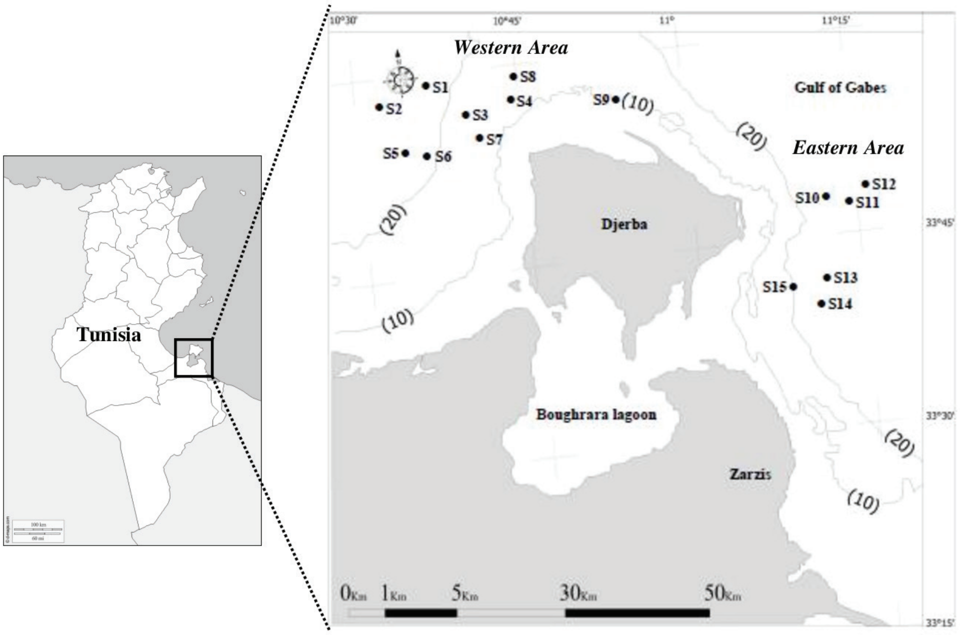

Fig. 1: Location of sampling stations along the western and eastern coasts of Djerba Island. The grey contour lines in the maps show the position of the isobaths and the numbers in parenthesis indicate the depths of these isobaths.

Table 1. Sampling date, depth, latitude and longitude of sampled stations.

Stations	Sampling date	Depth (m)	Latitude (N°)	Longitude (E°)
1	July 2009- 2010	20.2	33º 57.408’	10º 36.516’
2	July 2009- 2010	20.2	33º 56.765’	10º 31.456’
3	July 2009- 2010	14.3	33º 56.721’	10º 39.115’
4	July 2009- 2010	9.8	33º 56.189’	10º 43.332’
5	July 2009- 2010	20	33º 52.435’	10º 34.119’
6	July 2009- 2010	15.8	33º 52.772’	10º 36.184’
7	July 2009- 2010	10.7	33º 54.210’	10º 41.059’
8	July 2009- 2010	5.1	33º 59.040’	10º 43.023’
9	July 2009- 2010	8.8	33º 57.604’	10º 52.600’
10	July 2009- 2010	30.4	33º 50.467’	11º 10.518’
11	July 2009- 2010	35	33º 49.671’	11º 13.153’
12	July 2009- 2010	39.6	33º 51.370’	11º 14.032’
13	July 2009- 2010	29.8	33º 43.645’	11º 11.769’
14	July 2009- 2010	24.3	33º 42.418’	11º 09.925’
15	July 2009- 2010	20.2	33º 43.208’	11º 08.087’

Physico-chemical factors

Temperature, salinity, pH and dissolved oxygen were measured immediately after sampling using a multi-parameter kit (Multi 340 i/SET). Water transparency was measured with a Secchi disk. The concentration of suspended matter was determined by measuring the dry weight of the residue after filtration of 500 ml seawater with a Whatman glass fiber filter membrane filter. Samples for nutrient analyses were preserved immediately upon collection at −20°C in the dark. Chemical parameters such as nitrite, nitrate, ammonium, orthophosphate, silicate, total nitrogen and total phosphate were analyzed with a Bran and Luebbe type 3 autoanalyzer and concentrations were determined colorimetrically according to Grasshof (1983). We also calculated the N/P: dissolved inorganic N $=NO_2^- + NO_3^- + NH_4^+$ to dissolved inorganic P $= PO_4^{3-}$ ratio.

Table 2. Min- Max and Mean ± SD of physicochemical parameters and microphytoplankton and zooplankton communities on the west and east coasts of Djerba Island. T -values were determined by a T- test analysis, P values for differences among sites and sampled levels within each variable. Results of T-test analysis *p<0.05, **p<0.01, ***p<0.001 show significant differences between sampled stations.

Variables	**Western Area**	**Eastern Area**	**t -values**	**p**		
	Min- Max	Mean ± SD	Min- Max	Mean ± SD		
Physical variables						
Temperature (°C)	27.30 - 30.10	28.93 ± 0.87	28.50 - 31.10	29.67 ± 0.92	-1.56	0.14
Salinity (psu)	38.00 - 40.00	39.00 ± 0.87	38.00 - 40.00	38.50 ± 0.84	1.11	0.29
pH	7.97 - 8.17	8.03 ± 0.06	7.83 - 8.06	8.01 ± 0.09	0.59	0.57
Dissolved Oxygen (mg l^{-1})	2.50 - 11.70	3.87 ± 2.95	3.47 - 8.11	5.37 ± 1.85	-1.10	0.29
Transparency (m)	3.00 - 9.00	6.56 ± 1.74	7.00 - 22.00	11.83 ± 5.95	-2.55	0.02*
Depth (m)	5.10 - 20.20	13.88 ± 5.60	20.20 - 39.60	29.88 ± 7.01	-4.91	0.28×10^{-3}***
Chemical variables						
NO_2^- (µM)	0.10 - 1.31	0.67 ± 0.43	0.10 - 0.75	0.47 ± 0.23	1.03	0.32
NO_3^- (µM)	0.95 - 7.49	3.7 ± 2.30	2.29 - 4.70	3.59 ± 0.85	0.11	0.91
NH_4^+ (µM)	2.89 - 7.19	3.99 ± 1.39	1.37 - 4.59	2.84 ± 1.35	1.59	0.14
PO_4^{3-} (µM)	0.18 - 1.03	0.51 ± 0.28	0.43 - 0.85	0.61 ± 0.18	-0.78	0.45
T-N (µM)	13.97 - 26.75	21.69 ± 3.58	16.07 - 23.66	21.81 ± 2.91	-0.07	0.94
T-P (µM)	2.05 - 6.34	4.04 ± 1.50	2.94 - 4.65	3.63 ± 0.73	0.62	0.55
N/P ratio	9.21 - 53.48	22.43 ± 16.22	6.22 - 20.69	12.33 ± 5.62	1.45	0.17
$Si(OH)_4$ (µM)	0.27 - 1.90	0.88 ± 0.53	0.26 - 2.12	1.15 ± 0.74	-0.84	0.42
Biological variables						
T- Microphytoplankton (× 10^2 cells l^{-1})	7.00 - 159.00	41.78 ± 52.04	2.00 - 60.00	24.33 ± 25.94	0.75	0.46
Dinophyceae (%)	0.00 - 45.45	17.26 ± 15.08	0.00 - 37.50	12.85 ± 14.20	0.57	0.21
Bacillariophyceae (%)	10.00 - 97.17	47.86 ± 29.00	0.00 - 100.00	42.71 ± 38.29	0.30	0.23
Cyanophyceae (%)	0.00 - 80.00	20.59 ± 30.92	0.00 - 100.00	44.09 ± 39.82	-1.29	0.60
Dictyochophyceae (%)	0.00 - 43.33	13.68 ± 17.11	0.00 - 0.00	0.00 ± 0.00	1.93	0.03*
Euglenophyceae (%)	0.00 - 3.33	0.60 ± 1.23	0.00 - 2.08	0.35 ± 0.85	0.43	0.45
Phytoplankton species richness	4.00 - 21.00	10.56 ± 6.56	1.00 - 22.00	8.33 ± 8.14	0.58	0.57
Microphytoplankton species diversity (H')	1.36 - 3.49	2.38 ± 0.73	0.00 - 3.95	1.83 ± 1.41	1.01	0.33

Continued

Table 2 continued

Variables	Western Area	Eastern Area	t -values	p		
T- Zooplankton (×10^2 ind m^{-3})	2.45 - 644.25	90.82 ± 209.45	3.28 - 41.14	19.54 ± 12.39	0.82	0.42
Copepod (×10^2 ind m^{-3})	2.14 - 622.52	84.58 ± 203.27	1.34 - 13.27	4.98 ± 4.51	0.90	0.36
Copepod nauplii (×10^2 ind m^{-3})	0.00 - 5.45	1.14 ± 1.82	0.00 - 0.60	0.15 ± 0.25	1.30	0.22
Copepodit (×10^2 ind m^{-3})	0.61 - 457.91	61.70 ± 149.91	0.60 - 10.62	3.72 ± 3.75	0.87	0.37
Adult females (×10^2 ind m^{-3})	0 -18.38	3.22 ± 5.93	0.15 - 1.05	0.41 ± 0.32	1.22	0.29
Adult males (×10^2 ind m^{-3})	0.72 - 143.72	18.52 ± 47.01	0 - 1.66	0.59 ± 0.68	0.85	0.37
Cyclopoid (%)	17.86 - 100.00	58.65 ± 34.45	18.18 - 68.18	30.75 ± 19.09	7.93	0.01*
Calanoid (%)	0.00 - 78.57	36.58 ± 32.06	22.73 - 80.00	55.76 ± 23.32	0.01	0.97
Harpacticoid (%)	0.00 - 23.08	3.85 ± 7.65	0.00 - 33.33	8.55 ± 12.60	0.17	0.68
Poecilostomatoid (%)	0.00 - 3.85	0.92 ± 1.47	0.00 - 18.18	4.94 ± 6.79	1.37	0.26
Copepod species richness	2.00 - 7.00	4.67 ± 2.00	4.00 - 9.00	5.83 ± 1.94	1.25	0.28
Copepod species diversity (H')	0.76 - 2.16	1.43 ± 0.46	1.63 - 2.27	1.92 ± 0.29	5.38	0.04*
Other zooplankton (× 10^2 ind m^{-3})	0.00 - 21.73	6.24 ± 7.36	1.94 - 27.87	14.56 ± 8.41	4.12	0.06

Microphytoplankton and zooplankton enumeration

Subsamples for microphytoplankton (50 ml) were counted under an inverted microscope using the Utermöhl method after settling for 24 to 48 hr (Utermöhl, 1958). Counts were carried out on the entire sedimentation chamber at 40× magnification for microphytoplankton species. Microphytoplankton were identified from morphological criteria after consulting various keys (Balech, 1959; Tomas *et al.*, 1996). For zooplankton enumeration, subsamples were counted under a vertically mounted deep-focus dissecting microscope (Olympus TL 2) after being coloured with Bengalrose, to identify internal tissues of the different zooplankton species and also to facilitate copepod dissection such as various appendices and leg 5 of the different species. The different copepod species were sorted into four demographic classes (nauplii, copepodids, adult males and adult females).The mean number of counted organisms in the subsamples is 50 individuals (1- 200 ind). Zooplankton, especially planktonic copepods, were identified to genus or species level based on the works of Rose (1933), Costanzo *et al.* (2000) and Boxshall & Halsey (2003). The level of community structure was assessed with the Shannon diversity index H′ (Shannon & Weaver, 1949).

$$H' = -\Sigma\, Ni/N \log_2 Ni/N$$

N– total number of individuals over all species in the sample,
Ni/N– frequency of species i in the sample,
n– total number of species in the sample.

Statistical analysis

The physico-chemical factors, microphytoplanktonand zooplankton abundance assessed at the 15 stations were subjected to a normalized principal component analysis (PCA) (Dolédec & Chessel, 1989). Simple log (x+1) transformation was applied to data in order to correctly stabilize variance (Frontier, 1973). Means and standard deviations (SD) were reported when appropriate. A bilateral unequal variances t-test was applied to identify significant differences between the western and eastern coasts of Djerba Island. Simple relationships between the abundance of various zooplankton and microphytoplankton groups and environmental conditions were analyzed using Pearson's coefficient correlations. These statistical analyses were carried out using the XLStat software.

Results

Environmental parameters

The range (min–max) and mean values of the physical, chemical and biological parameters recorded in the surface layer along the Djerba coasts are given in Table 2.

Water temperature was relatively similar between Western (28.93 ± 0.87 °C) and Eastern (29.67 ± 0.92°C) Areas (Table 1). The lowest temperature (27.30 °C) was recorded at station 9 from the Western Area and the highest one (31.10 °C) at station 15 from the Eastern Area (Fig. 2). The salinity was in the range 38–40 and showed low variation between stations (Fig. 2). Mean value was lower in the Eastern Area (38.50 ± 0.84) than in the Western Area (39.00 ± 0.87), but the difference was not significant. pH also showed low variation, the lowest values (7.83) being observed at station 13 in the Eastern Area and the highest (8.17) at station 8 in the Western Area. Dissolved Oxygen value varied between 2.50 mg l^{-1} at station 1 and 11.70mg l^{-1} at station 9 (Fig. 2), and showed a higher mean value in the Eastern Area (5.37 ± 1.85 mg l^{-1}) than in the Western Area (3.87 ± 2.95 mg l^{-1}), but the difference was not significant due to the strong variability among stations (Table 2).Water transparency ranged from 3 to 22 m, (Fig. 2) and was significantly higher in the Eastern Area which also displayed a higher mean depth (29.88 ± 7.01) compared to the Western Area (13.88 ± 5.60; see Fig. 2 and Table 1) (T-test, P <0.05, Table 2).

Nutrient concentrations showed neither clear spatial patterns nor significant differences between the Western and the Eastern Areas (T-test, P >0.05, Table 2), due to high variability between stations. However, nitrite, nitrate, ammonium and total phosphate spatial distribution exhibited slight increase in Western Area compared to Eastern Area, whereas orthophosphate and total nitrogen concentrations tended to be higher in Eastern Area (Table 2). The N/P: DIN (DIN = NO_3^- + NO_2^- + NH_4^+) to DIP (DIP = PO_4^{3-}) ratio ranged from 6.89 in the Eastern Area (station 11) to 53.48 in the Western Area (station 4) (Fig. 3). It was on average higher in the Western Area than in the Eastern Area, but the difference between the two areaswas not significant. Silica concentration was slightly higher in the Eastern Area (1.15 ± 0.74 µM) than in the Western Area (0.88 ± 0.53 µM) (Table 1).The highest concentration of silica was recorded at station 12 (12.12 µM), and the lowest (0.26 µM) at station 15 in the Eastern Area (Fig. 3).

Microphytoplankton community structure and spatial distribution

During the investigated period, microphytoplankton abundance varied from 159 × 10^2 cells l^{-1} at st 7 in the Western Area to 2 × 10^2 cells l^{-1} at st 11 in the Eastern Area (Fig. 4). The highest cell number recorded at station 7 corresponded to a bloom of the chain-forming diatom *Thalassiosira* sp. The species composition of the microphytoplankton community differed radically between the two Areas (Fig. 4), shifting from a predominance of Bacil-

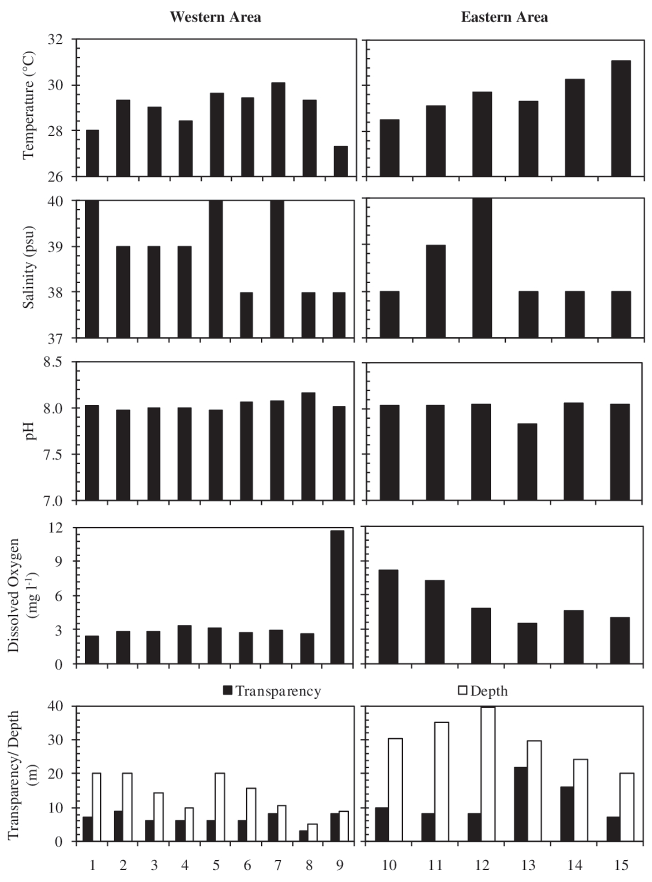

Fig. 2: Spatial variations of physical-chemical parameters: temperature, salinity, pH, Dissolved Oxygen and/ Depth Transparency along the western and eastern coasts of Djerba Island.

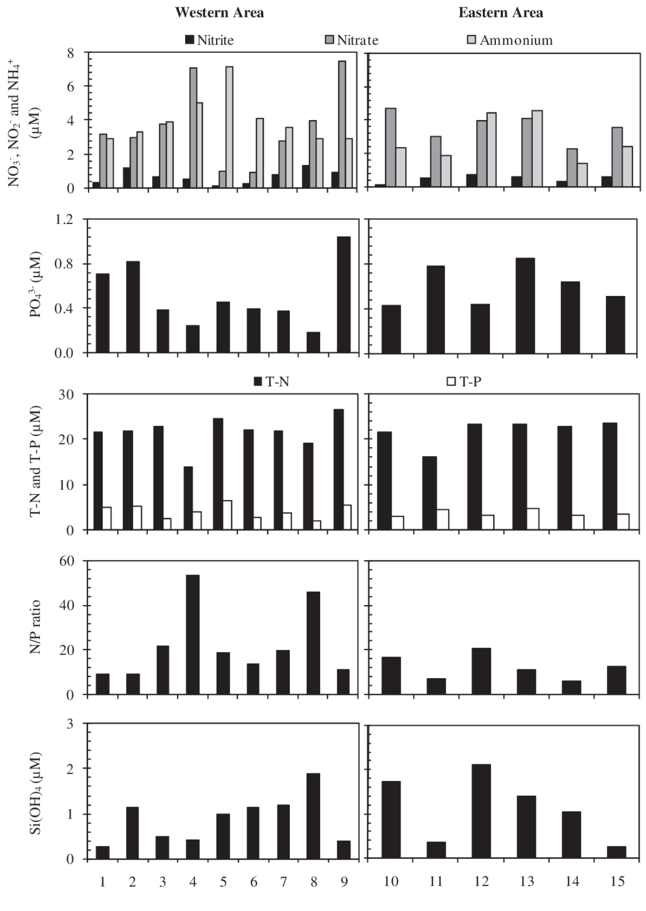

Fig. 3: Spatial variations of nutrient concentrations: nitrite (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+), total nitrogen (T-N), orthophosphate (PO_4^{3-}), total phosphate (T-P), N/P ratio, and silicate along the west and east coasts of Djerba Island.

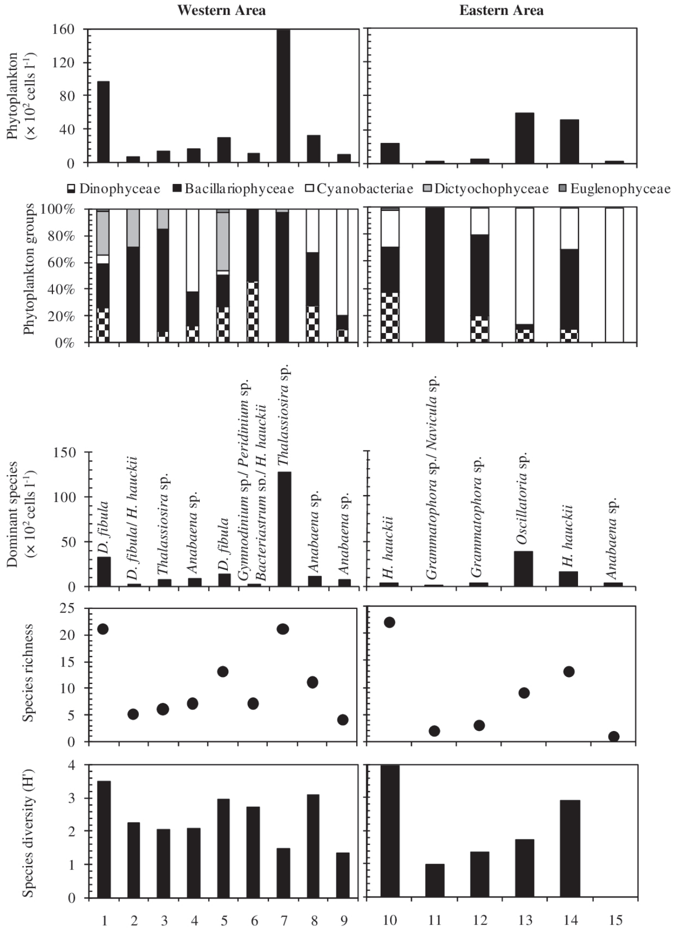

Fig. 4: Spatial variations of microphytoplankton abundance, microphytoplankton groups, dominant species, species richness and species diversity index along the west and east coasts of Djerba Island.

lariophyceae, particularly *Thalassiosira* sp., *Coscinodiscus* sp., *Hemiaulus hauckii* and *Bacteriastrum* sp. (48% on average and even up to 97% of total microphytoplankton abundance) in the Western Area, to a predominance of Cyanophyceae such as *Oscillatoria* sp., *Anabaena* sp. and *Merismopodia* sp. in the Eastern Area. In addition, the Dictyochophyceae that represented up to 43% of microphytoplankton abundance in the Western Area (14% on average) were absent from the Eastern Area.

The microphytoplankton individuals were classified into 50 taxa from the 15 samples (40 taxa in the Western Area and 31 taxa in the Eastern Area), belonging to five taxonomic classes (Cyanophyceae, Dinophyceae, Bacillariophyceae, Dictyochophyceae and Euglenophyceae), and 50% of which were identified at species level. Bacillariophyceae was the most diverse class (23 species) followed by Dinophyceae (20 species) and Cyanophyceae (5 species). Other groups, including Euglenophyceae and Dictyochophyceae, were represented by only one species each (Table 3). Bacillariophyceae dominated the microphytoplankton assemblage in the Western Area, with a peak of 154.5 ×10^2 cells l^{-1} at station 7 (Fig. 4). Bacillariophyceae were represented by 21 taxa among which ten species (*Bacteriastrum* sp., *Cocconeis* sp., *Coscinodiscus granii*, *Coscinodiscus* sp., *Odontella* sp., *Skeletonema costatum*, *Striatella unipunctata*, *Tabellaria* sp., *Thalassionema nitzschoides* and *Thalassiosira* sp.) were exclusively detected at the Western stations and eleven other species (*Amphora* sp., *Biddulphia alternans*, *Chaetoceros* sp., *Grammatophora* sp., *Hemiaulus hauckii*, *Licmophora* sp., *Navicula* sp., *Nitzschia longissima*, *Pinnularia* sp.,*Pleurosigma* sp. and *Rhizosolenia* sp.) were present in both Areas (Table 3). Cyanophyceae abundance was higher in the Eastern Area with densities varying from 0 to 52 × 10^2 cells l^{-1} at stations 11 and 13 respectively (Table 2). Two Cyanophyceae species (*Merismopodia* sp. and *Oscillatoria* sp.) were only recorded in the Eastern Area, whereas *Anabaena* sp. was recorded in both Areas. Dinophyceae were more abundant in the Western Area with mean abundance (5.67 ± 8.00 × 10^2 cells l^{-1}). Eight Dinophyceae species (*Ceratium furca*, *Ceratium lineatum*, *Ceratium pentagonum*, *Gymnodinium* sp., *Peridinium*sp., *Prorocentrum lima*, *Prorocentrum micans* and *Scrippsiella trochoidae*) were common to the two Areas, including the potentially toxic species *Prorocentrum lima*. Dictyochophyceae appeared only in the Western Area and were represented by one species *Dictyocha fibula* (between 0% and 43% of total microphytoplankton abundance, Fig. 4). Euglenophyceae showed the lowest abundances among all stations, representing from 0% to 3% (at station 5) of the microphytoplankton abundance (Fig. 4). The microphytoplankton species richness varied from 4 taxa at station 9 in the Western Area to 22 taxa at station 10 in the Eastern Area (Fig. 4). The species diversity (Shannon index (H′)) of the microphytoplankton community was lower in the Eastern than in the Western Area, but with no significant differ-

Table 3. List and frequency of the microphytoplankton species observed along the west and east coasts of Djerba Island.

	Western Area	Eastern Area
Dinophyceae		
Amphidinium sp. (Claparède and Lachmann, 1859)	R	-
Ceratium furca (Claparède and Lachmann, 1859)	R	R
Ceratium fusus (Dujardin, 1841)	-	R
Ceratium lineatum (Cleve, 1899)	R	R
Ceratium pentagonum (Gourret, 1883)	R	R
Gonyaulax spinifera (Diesing, 1866)	-	R
Gymnodinium aureolum (Hulburt, 1957)	R	-
Gymnodinium sp. (Stein, 1878)	R	R
Hermesinium sp. (Zacharias, 1906)	R	-
Mesoporos perforates (Lillick, 1937)	-	R
Peridinium sp. (Ehernberg, 1832)	C	R
Prorocentrum gracile (Schütt, 1895)	R	-
Prorocentrum lima (Dodge, 1975)	R	R
Prorocentrum micans (Ehrenberg, 1833)	R	R
Prorocentrum rathymum (Loeblich et al, 1979)	-	R
Protoperidinium curvipes (Balech, 1974)	-	R
Protoperidinium ovatum (Pouchet, 1883)	-	R
Protoperidinium ovum (Balech, 1974)	R	-
Scrippsiella subsalsa (Balex and Loeblich, 1965)	R	-
Scrippsiella trochoidae (Stein, 1883)	R	R
Bacillariophyceae		
Amphora sp. (Ehrenberg, 1840)	R	R
Bacteriastrum sp. (Shadbolt, 1854)	C	-
Biddulphia alternans (Van Heurck, 1885)	R	R
Chaetoceros sp. (Ehrenberg, 1844)	R	R
Cocconeis sp. (Ehrenberg, 1837)	R	-
Coscinodiscus granii (Gough, 1905)	R	-
Coscinodiscus sp. (Ehrenberg, 1838)	C	-
Grammatophora sp. (Ehrenberg, 1839)	R	R
Gyrosigma sp. (Hassall, 1845)	-	R
Hemiaulus hauckii (Ehrenberg, 1844)	C	C
Leptocylindrus danicus (Cleve, 1889)	-	R
Licmophora sp. (Agardh, 1827)	R	R
Navicula sp. (Bory de St. Vincent, 1822)	R	R
Nitzschia longissima (Pritchard, 1861)	R	R
Odontella sp. (Agardh, 1832)	R	-
Pinnularia sp. (Ehrenberg, 1841)	R	R
Pleurosigma sp. (Smith, 1852)	C	R
*Rhizosolenia*sp. (Ehrenberg, 1841)	R	R

Continued

Table 3 continued

	Western Area	Eastern Area
Skeletonema costatum (Cleve, 1873)	R	-
Striatella unipunctata (Agardh, 1832)	R	-
Tabellaria sp. (Ehrenberg, 1840)	R	-
Thalassionema nitzschoides (Merseschkowsky, 1902)	R	-
Thalassiosira sp. (Cleve, 1873)	A	-
Cyanobacteria		
Anabaena sp. (Bornet and Flahault, 1888)	C	C
Chroococcus sp. (Nägeli, 1849)	R	-
Merismopodia sp. (Meyen, 1839)	-	C
Oscillatoria sp. (Ehernberg, 1830)	-	C
Spirulina sp. (Gomont, 1892)	R	-
Dictyochophyceae		
Dictyocha fibula (Ehrenberg, 1839)	C	-
Euglenophyceae		
Euglena sp.	R	R

(–) not detected.
(R) Rare "0–100 cells l^{-1}".
(C) Common "100–1000 cells l^{-1}".
(A) Abundant ">1000 cells l^{-1}".

ence due to high variability between stations. A nil value was recorded at station 15 where microphytoplankton was represented by only one taxon (*Anabaena* sp.). Maximum was recorded at station 10 in the East (H′ = 3.95, 22 taxa, station 10) and at stations 1 (H′ = 3.49) and 8 (H′ = 3.08) in the Western Area (Fig. 4).

Zooplankton community structure and spatial distribution

Figure 5 and Table 1 report the abundances of the zooplankton dominant groups and species for the two Areas. Zooplankton density ranged from 2.45 to 644.25 × 10^2 ind m^{-3}, with maxima at stations 7 (644.25 × 10^2 ind m^{-3}) and 8 (92.72 × 10^2 ind m^{-3}) in the Western Area (Fig. 5). Copepods clearly dominated the zooplankton community in the Western Area, accounting for 54%–100% of total zooplankton abundances (Fig. 5), whereas their mean density showed a 16–17 fold drop in the Eastern Area (4.98 ± 4.51 × 10^2 ind m^{-3}, Table 2), compared to the Western Area (Fig. 5). The highest copepod abundances were observed at stations 7 (622.52 × 10^2 ind m^{-3}) and 8 (81.82 × 10^2 ind m^{-3}) in the Western Area. Their abundance did not exceed 13 × 10^2 ind m^{-3} in the Eastern Area (Table 2). Other zooplankton (Cladocera, Polychaeta larvae, Amphipoda, Appendicularia, Euphausiacea and Neogasteropoda) presented low relative abundances in the western stations (0–45% of total zooplankton abundance), whereas they were always dominant (60–90%) in the eastern stations (Fig. 5), showing densities between 1.94 × 10^2 and 27.87 × 10^2 ind m^{-3} (Table 2).

Copepods composition and abundance showed four groups: Calanoids (on average 67% of the total copepod abundance), Cyclopoids (29%), Harpacticoids (3%) and Poecilostomatoids (1%). Abundances of Calanoids and Cyclopoids peaked at station 7 on the west coast. Calanoids contributed to the largest fraction of copepods with abundances varying from 0 to 427.83 ×10^2 ind m^{-3}(0–79% of the total copepod in the Western Area) and from 0.5 to 9.6 ×10^2 ind m^{-3}(23–80%) in the Eastern Area. They were followed by Cyclopoids, which were mostly concentrated in the Western Area (1.8–180.5 ×10^2 ind m^3 – 18 to 100%– in the West; 0.2–4.3 ×10^2 ind m^3 – 18–68% in the East) (Table 2). Harpacticoids varied from 0 to 11.70 ×10^2 ind m^{-3} (0–33%) and Poecilostomatoids from 0 to 1.36 ×10^2 ind m^{-3} (0–18% of the copepod total) (Fig. 5).

A total of 27 copepod species were found at all stations (Table 4), with *Paracalanus parvus* dominating the total abundance of copepod (67%). *Oithona similis* and *Oithona nana* abundances were also high in both Areas (Fig. 5). Copepod richness was slightly higher on the east coast (4–9 species) than on the west coast (2–7 species) (Fig. 5) but the difference between the two Areas was not significant. The copepod species diversity was significantly higher (p= 0.04) in the Eastern Area (1.92 ± 0.29) than in the Western Area (1.43 ± 0.46). It varied between 0.76 (station 5) and 2.16 (station 9) in the west and between 1.63 (station 10) and 2.27 (station 14) in the East (Fig. 5). Among copepods, copepodite stages dominated (23%–85% of total copepod), followed by adults (11%–71%) and nauplii (0%–44%) (Fig. 6). All stages were on average more numerous on the west coast but the differences between the two zones were not significant. The

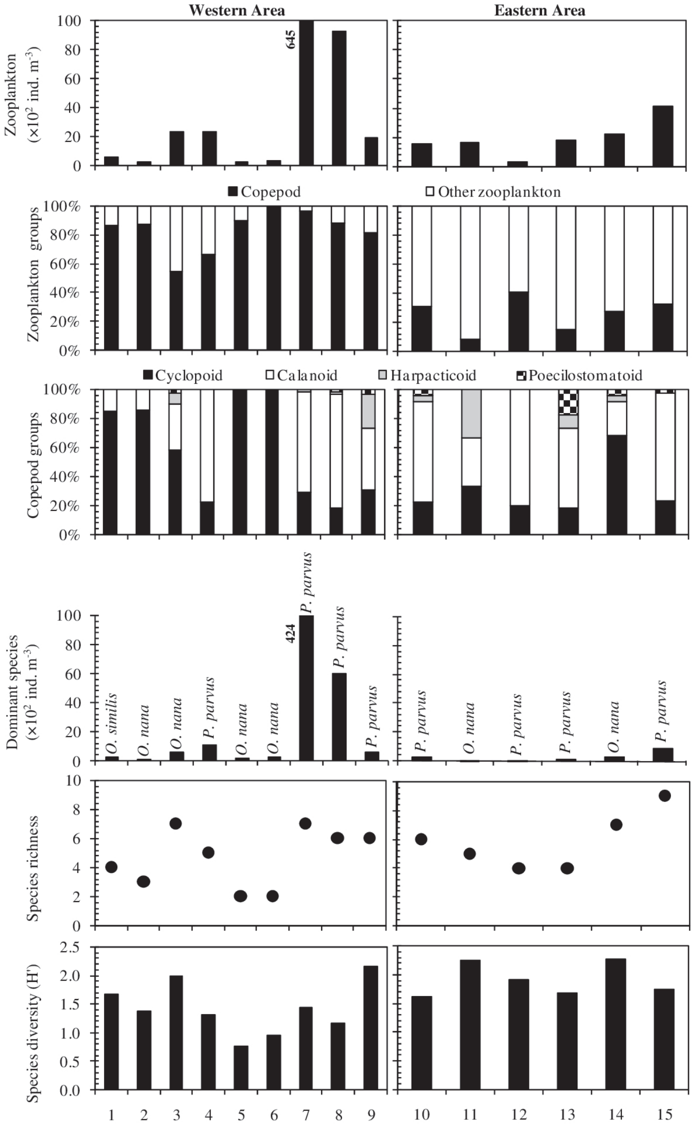

Fig. 5: Spatial variations of zooplankton abundance, zooplankton groups, dominant species, species richness and species diversity index along the west and east coasts of Djerba Island.

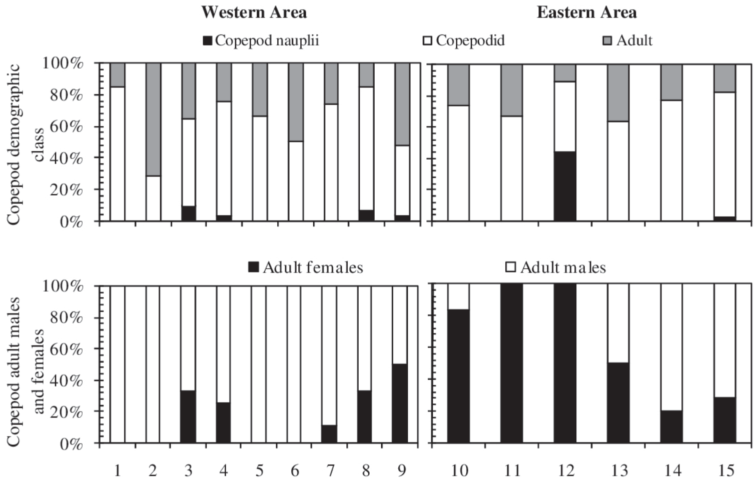

Fig. 6: Spatial variation of copepod demographic class density: copepod nauplii, copepodit and adult males and females along the west and east coasts of Djerba Island.

majority of adult females were found in the Eastern Area (47% of adult abundance, Fig.6). Their abundance varied from 0 to 18.38 × 10^2 ind m^{-3}; the highest value observed at station 7 in the Western Area, associated with a strong proliferation of *Paracalanus parvus* (Fig. 6).Adult males were relatively more abundant in the Western Area (85%

Table 4. List and frequency of the zooplankton species observed along the west and east coasts of Djerba Island.

	Western Area	Eastern Area
Copepod nauplii	C	R
Cyclopoida		
Oithona nana (Giesbrecht, 1892)	A	R
Oithona similis (Claus, 1866)	A	R
Oithona helgolandica (Claus, 1863)	-	R
Oithona plumifera (Baird, 1843)	C	R
Conaea rapax (Giesbrecht, 1891)	-	R
Calanoida		
Acartia clausi (Giesbrecht, 1889)	R	-
Paracartia latisetosa (Dana, 1846)	R	-
Centropages kroyeri (Giesbrecht, 1892)	-	R
Centropages typicus (Lilljeborg, 1853)	R	R
Centropages hamatus (Lilljeborg, 1853)	R	-
Temora sp. (Baird, 1850)	R	-
Paracalanus parvus (Claus, 1863)	A	C
Calanus helgolandicus (Claus, 1863)	-	R
Labidocera brunescens (Czernjavsky, 1868)	R	-
Labidocera wollastoni (Lubbock, 1857)	-	R
Harpacticoida		
Euterpina acutifrons (Dana, 1852)	C	R
Microsetella norvegica (Brady, 1864)	R	-
Clytemnestra scutellata (Dana, 1852)	-	R
Poecilostomatoïda		
Oncaea conifera (Giesbrecht, 1891)	-	R
Oncaea mediterranea (Claus, 1863)	R	-
Corycaeus clausi (Dana, 1894)	R	R
Other zooplankton	C	A

(–) not detected.
(R) Rare “0–100 ind m^{-3}”.
(C) Common “100–1000 ind m^{-3}”.
(A) Abundant “>1000 ind m^{-3}”.

of adult abundance) and their abundance varied between 0 and 144 $\times 10^2$ ind m^{-3}.

Relationships between biotic and abiotic variables

The first factorial plane (axis 1, axis 2) of the PCA analysis on environmental, microphytoplankton and zooplankton variables explained 41.7% of the total variance, 22.9% of it for the first component and 18.7% for the second component (Fig. 7). Four groups of stations can be distinguished on this first factorial plane. Group 1 includes most of the stations of the Eastern Area, namely those located farthest east in this area (st 10, 11, 13, 14, 15) associated with the Eastern-most station in the Western Area (st 9). This group is positively correlated with NO_2^-, NO_3^-, PO_4^+ and negatively with N/P ratio and is characterized by the importance of Cyanophyceae, Poecilostomatoids and Other zooplankton. The stations of the Western Area, except st 9, are spread over two groups. Group 2 includes the deepest stations in this area (st 1, 2, 5 and 6; 15-20 m depth) and is positively correlated with salinity, and phytoplankton groups other than Cyanophyceae (Euglenophycae, Dinophycae, Bacillariophycaea and Dictyochophycaea), and negatively correlated with all zooplankton taxa. Group 3 includes the shallowest stations of the Western Area (st 3, 4, 7 and 8; 5-14 m depth) and is correlated positively with pH, N/P, Nauplii and Cyclopids and negatively with all phytoplankton taxa. Finally, Group 4 includes only st 12 which is the furthest offshore and deepest station and whose position close to the barycenter indicates a low correlation with all environmental and biological variables. The differentiation between the Western and the Eastern Areas only appears on the second axis with (i) the western part correlated to nitrogen forms of nutrients (NO_2^-, NO_3^- and NH_4^+), N/P ratio, Bacillariopphyceae, Dicyophyceae, Cyclopids and nauplii (and (ii) the Western Area correlated with trans-

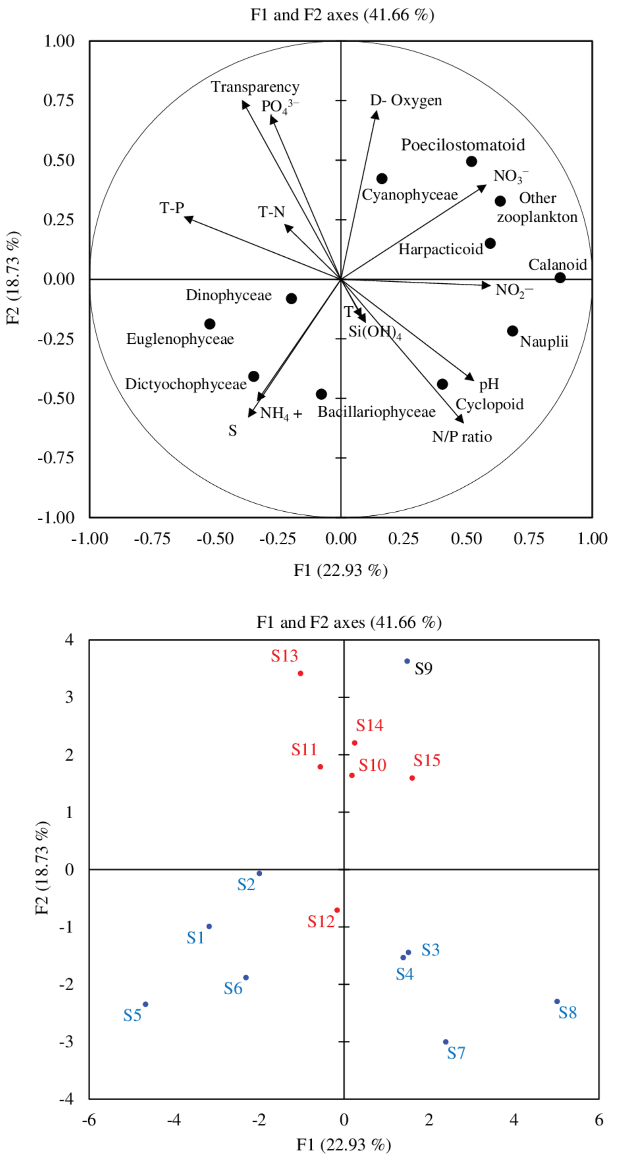

Fig. 7: Principal component analysis (PCA) (axis I and II) of microphytoplankton and zooplankton communities' abundance and selected environmental variables along the west and east coasts of Djerba Island.

parency, PO_4^+, low N/P ratio Cyanophyceae and Poecilostomatoid. However, two stations do not follow this spatial trend: St9, closer to Eastern stations and St 12 closer to Western stations.

Highly significant correlations were found between Bacillariophyceae abundance and Cyclopoid ($r = 0.97$; $p < 0.05$; $N = 15$), Calanoid ($r = 0.96$; $p < 0.05$; $N = 15$) and Harpacticoid ($r = 0.91$; $p < 0.05$; $N = 15$) (Fig. 8). Physical parameters appeared to have a major role in Cyanophyceae distribution since transparency and pH were significantly correlated to Cyanophyceae abundance ($r = 0.82$; $p < 0.05$; $N = 15$) and ($r = -0.59$; $p < 0.05$; $N = 15$), respectively (Fig. 8). Significant correlations were found between other zooplankton and temperature ($r = 0.58$; $p < 0.05$; $N = 15$) and between Dinophyceae and Euglenophyceae ($r = 0.89$; $p < 0.05$; $N = 15$) or Dictyochophyceae ($r = 0.83$; $p < 0.05$; $N = 15$). Highly significant correlations were also found between Poecilostomatoid and copepod nauplii abundances ($r = 0.74$; $p < 0.05$; $N = 15$) and between Poecilostomatoidand salinity ($r = -0.57$; $p < 0.05$; $N = 15$) (Fig. 8).

Discussion

The high-water temperature and salinity recorded in this study were typical of a semi-arid to arid Mediterranean climate (Rekik *et al.*, 2011; Ben Ltaief *et al.*, 2015). The arid climate in southern Tunisia has an important impact on the environmental conditions of the Djerba coasts (El Kateb *et al.*, 2018b). High temperature and salinity, low precipitation and changing circulation patterns on the littoral may impact and influence environmental conditions of the ecosystems (El Kateb *et al.*, 2018a). Furthermore, in summer, increased evaporation may increase salinity to hypersaline values (Kjerfve *et al.*, 1996).

In coastal regions, chemical factors have a major impact on the distribution and density of plankton (Rekik *et al.*, 2015b). The high concentration of major chemical elements and the importance of ammonium compared with nitrite and nitrate on the Djerba coasts is typical of coastal eutrophic waters due to anthropogenic pollution, mainly linked to untreated sewage (Bouchouicha-Smida *et al.*, 2012). On the basis of chemical concentration, the Djerba coats showed high variability in terms of nitrogen forms of nutrients (NO_2^-, NO_3^- and NH_4^+), with highest values found in some western stations corresponding to N/P ratio higher than the typical Redfield N/P ratio (16). Wide disparities in the N/P ratio can be expected in coastal waters, particularly under eutrophic conditions which generate situations far from the relative equilibrium established in the open sea providing the basis of the Redfield ratios (Rekik *et al.*, 2015a).

Diverse factors were shown to influence the microphytoplankton community, such as water physical factors, nutrient concentration, human activities and predation (Rekik *et al.*, 2015b). The spatial changes in the summer microphytoplankton composition on the Djerba coasts were clearly linked to fluctuations in environmental factors. The proportion of Cyanobacteria was high in several stations, particularly in the Eastern Area where it could constitute the bulk of phytoplankton (egst 13 and 15). An increase in the abundance of Cyanobacteria in the summer microphytoplankton was observed on the north coast of Sfax (Rekik *et al.*, 2012), in the western part of the Gulf of Finland and in various parts of the Gulf of Bothnia (Golubkov *et al.*, 2021). Many authors suppose that the growth of Cyanobacteria is mostly controlled by water temperature (Obolewski *et al.*, 2018). On the other hand, Golubkov *et al.* (2021) showed that temperature did not significantly influence the Cyanobacteria abundance in the Neva Estuary (Baltic Sea). In our study, we did not find any significant correlation between Cyanobacteria and temperature. The high proportion of Cyanobacteria in some stations of the east coast of Djerba may be linked to high DIP concentration and low N/P ratio. Cyanobacteria are known to store phosphate internally when DIP is available (Wang *et al.*, 2019), reducing their

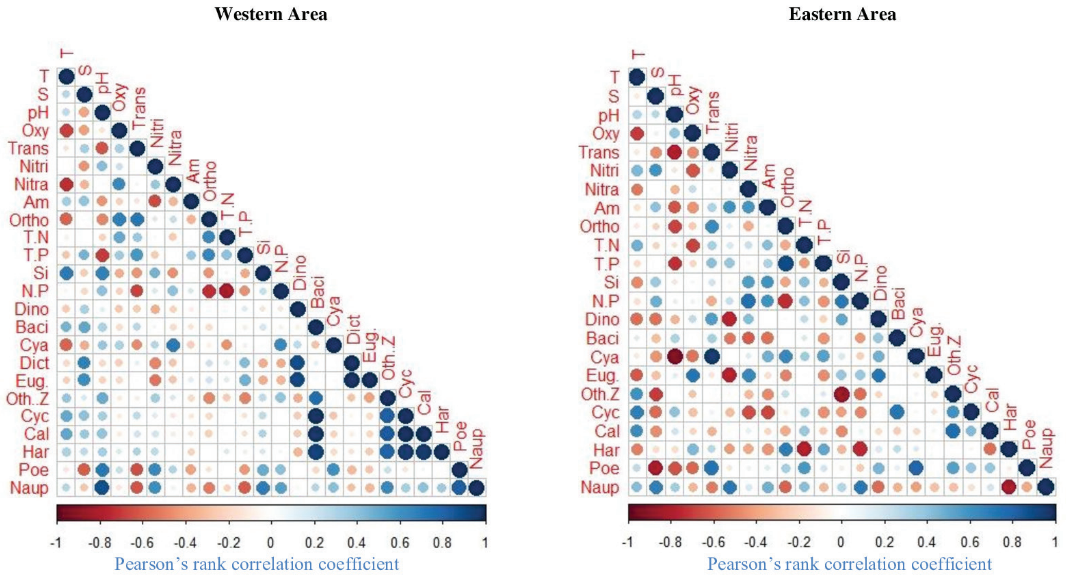

Fig 8: Correlation matrix (Pearson test) for biological variables in relation to abiotic variables determined along the west and east coasts of Djerba Island.

growth when DIP is depleted (Mur *et al.*, 1999). They are good competitors for nutrients due to their nitrogen fixation ability giving them a competitive advantage (Hu & Wei, 2006). However, low N/P ratio which characterizes summer bloom does not always imply a shift in the dominance of the microphytoplankton community to the nitrogen fixing Cyanobacteria (Lv *et al.*, 2011). In fact, in the Eastern Area, Cyanobacteria may also have been favored by the presence of a low concentration of organic matter inducing high water transparency, due to the ability of some species (*Anabaena* sp., *Merismopodia* sp.,*Oscillatoria* sp. and *Spirulina* sp.) to accumulate dust particles (Rubin *et al.*, 2011) crucial for their high iron demand to ensure intensive photosynthesis (Roe *et al.*, 2012). However, since Cyanobacteria blooms can produce toxic substances, dangerous to marine fauna and human beings (Metcalf & Codd, 2009), their proliferation is critical for water quality and environmental improvement (Tian *et al.*, 2021).

On the other hand, Bacillariophyceae was the most important group of microphytoplankton in many stations particularly in the Western Area, as also observed in summer microphytoplankton in other regions such as Curonian Lagoon situated in the south-eastern part of the Baltic Sea (Krevs *et al.*, 2007) and the Chukchi Sea (Wang *et al.*, 2020) in the Western Mediterranean Sea (Mercado *et al.*, 2019). Bacillariophyceae have thus excellent adaptability to different ecosystems, which may have accounted for the relative stability in their species composition (Pan *et al.*, 2012). In the Western Area this community was mainly dominated by marine taxa, such as *Chaetoceros, Coscinodiscus, Grammatophora, Navicula* and *Pinnularia.* We also noted the presence of benthic species such as *Amphora*, *Cocconeis*, *Licmophora* and *Nitzschia* indicating a mixing of the water column with a resuspension of bottom particles favored by the shallow depth along the coast and the hydrodynamic regime (Somoue *et al.*, 2020). The highest Bacillariophyceae species richness (>21 species) and density (>25.83 × 102 cells l^{-1}) were foundin the Western Area, particularly at station 7 with a bloom of zonary or chained pelagic diatoms groups such as *Thalassiosira*. The higher average concentration of nitrogen forms in this Area may have favored the proliferation of Bacillariophyceae that exhibit a maximum preference to NO_3^- uptake which could stimulate their development (Swarbrick *et al.*, 2019). Bacillariophyceae can also exploit high molecular weight organic matter from microbial degradation and photodegradation (Deininger *et al.*, 2017). Hence, the accumulation of the organic matter from human activities on the west coast also plays an essential role in phytoplankton production (Liu *et al.*, 2020), and partially supports the high abundance of Bacillariophyceae in the summer phytoplankton community.

Potential toxic species (Lassus*et al.*, 2016), which appear in the 'harmful algal bloom' list of the Intergovernmental Oceanographic Commission of UNESCO, belonging to different genera such as *Dictyocha*, *Gonyaulax*, *Gymnodinium* and *Prorocentrum,* were present on the coasts of Djerba Island, particularly in the Western Area. Even if their abundance were relatively low in our study, these species should be subject to a regular monitoring program since the Djerba coasts host intensive tourism activities. In the present study, the impact of local factors (i.e. socio-economic context, industry, etc.) on the phytoplankton community was indirect, with regional factors (water quality) serving as indicators. The space distribution of microphytoplankton indicate that the Djerba coasts should be roughly divided into two different ecological sub-systems in terms of communities with dominance of Bacillarophyceae in the Western Area, and co-occurrence of Bacillariopyceae and Cyanobacteria in the Eastern Area. It appears likely that all of these observed differences may propagate further up the food chain, extending to the zooplankton as well.

Zooplankton community structure is strongly influenced by physico-chemical and biological factors such as temperature, salinity, predation and competition in coastal ecosystems. The zooplankton abundance was primarily characterized by the predominance of copepods in all the stations in the Western Area of the Djerba coasts. The dominance of copepods has already been reported in several studies in the Gulf of Gabes region: on the southern coast of Sfax (66 - 82% of the total zooplankton; Ben Salem *et al.*, 2015; Drira *et al.*, 2018a; Drira *et al.*, 2018b); on the northern coast of Sfax (61-82%; Rekik *et al.*, 2011, 2013; Drira *et al.*, 2018a); in Ghannouch and Zarrat (46 - 83%; Baccar, 2014; Drira *et al.*, 2018a); in offshore waters of the Gulf of Gabes (83%; Drira *et al.*, 2014; Ben Ltaief *et al.*, 2015); along the southern coast of Kerkennah Islands in summer (98%; Rekik *et al.*, 2018a), in Kneiss Islands in summer (30–96%; Rekik *et al.*, 2018b) and in Boughrara lagoon (62%–92%; Makhlouf-Belkahia *et al.*, 2020). Among copepods, Calanoids were highly dominant (up to 79% of copepod abundance), which is very similar to what was observed by Drira *et al.* (2018a) on the coast at Ghannouch (51% of total copepod abundance) and on the Sfax coast (43% of total copepod abundance).The high dominance of *Paracalanus parvus* in the Djerba copepod community in summer also corresponds to what was reported in Kneiss islands, Tunisia (Rekik *et al.*, 2018b), in Kerkennah islands, Tunisia (Rekik *et al.*, 2018a) and in Boughrara lagoon, Tunisia (Makhlouf-Belkahia *et al.*, 2020). The summer dominance of this species was also reported in other areas such as Fukuyama Harbour, Japan (Wang *et al.*, 2002), Jiaozhou Bay, China (Sun *et al.*, 2008) and in the Yellow Sea (Zhang *et al.*, 2006). The dominance of such small herbivorous copepods in many stations of the Western Area might be related to the occurrence of *Thalassiosira.* A similar association has been recorded by Zhang *et al.* (2020) in the Dan'ao River estuary and by Xiang *et al.* (2021) in Daya Bay, South China Sea. Small copepods were shown to graze actively on diatom blooms of chain-shaped species in the Southern Yellow Sea (Li *et al.*, 2013). They are known to be very selective about the size of their food, having a feeding preference for diatoms of 5–15 µmdiameter (Guinder *et al.*, 2012). An experimental study reported that *P. parvus* consumed 53–82% of phytoplankton in a mixed diet with phytoplankton and rotifers, meaning that the phytoplankton was the principal food for *P. parvus* (Jagadeesan *et al.*, 2017). Moreover, this small Calanoid is pollution-tolerant, resistant to unfavorable conditions and has a high capacity to develop in eutrophicated and polluted areas (Arfi *et al.*, 1981; Drira *et al.*, 2018a). The high frequency of *P. parvus* in the highly anthropized Western Area of the Djerba coast is thus not surprising, since this species was already reported at very high and unusual abundance in highly polluted urban Areas (Sun *et al.*, 2008). Among copepod demographic classes, the adult males predominated over females, maybe due to the higher mortality rate of females which are more vulnerable to pollution. Pollution may have strong physiological effects on copepods, since it was suggested that it could explain the differential longevity of females and males which may be important in determining the sex ratio (Mendes-Gusmao *et al.*, 2013). More generally, the anthropogenic pressure may also strongly influence the taxonomic diversity (Danilov & Ekelund, 1999). In the present work, we showed that the Western Area, considered as a polluted environment, was characterized by lower taxonomic diversity than the Eastern Area. The taxonomic diversity of copepods was quite low (*H*' <1.5 for 40% of stations) in some western stations (S2 and S4–8), indicating a pioneer community at the colonization stage, and was higher (H' between 1.5 and 2.5) in other stations, representing a transition phase towards the diversification stage (Shannon & Weaver, 1963; Frontier & Pichod-Viale, 1991). According to Mukhopadhyay *et al.* (2007), a high *H*' characterizes less polluted ecosystems, whereas low *H*' values are linked to stressed environments. In contrast, the copepod community of the Eastern Area was characterized by higher mean diversity as a result of lower anthropization compared to the Western Area.

Conclusion

In our study, with regard to nutrients and H' values for phytoplankton, we may consider that the water quality was highly degraded in most stations of the littoral zone of Djerba, characterized by high concentrations of DIN linked to high human pressure and industrial activities. However, signs of recovery include relatively high diversity and abundance of Bacillariophycea in some other stations that could be due to well-stratified water conditions, the high percentage of nitrogen-fixing forms and their excellent adaptability to different marine ecosystems. The copepod community was characterized by an overall low diversity (particularly in the Western Area) reflecting a rather poor health status. However high copepod abundance observed sporadically possibly highlights stimulation of growth rate by enhanced food concentration (microphytoplankton) in relation to eutrophication.

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