

Original Research Paper

Ecological Studies of Epiphytic Microalgae and Epiphytic Zooplankton on Seaweeds of the Eastern Harbor, Alexandria, Egypt

Shams El-Din, N.G., N.A. Shaltout, M.Z. Nassar and A. Soliman

National Institute of Oceanography and Fisheries, Alexandria, Egypt

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Corresponding Author:

Shams El-Din, N.G.

National Institute of

Oceanography and Fisheries,

Alexandria, Egypt

Email: nihalsamseldin@yahoo.com

Abstract: A qualitative and quantitative study on the epiphytic microalgae and epiphytic zooplankton were conducted in order to follow up their community structures on seaweeds in relation to some physico-chemical variables in the coastal waters of the Eastern Harbor of Alexandria. Water and macroalgal samples were collected seasonally during two years successively: Winter, summer, autumn (2012) and spring (2013). The collected seaweeds were *Ulva fasciata* (green alga), *Corallina mediterranea*, *Corallina officinalis*, *Gelidium sp.*, *Pterocladia capillacea*, *Hypnea musciformis* and *Grateloupia doryphora* (red alga). The studied water quality parameters were pH, salinity, dissolved oxygen, oxidizable organic matter and nutrient salts. The abundance of epiphytes were significantly different between morphotypes (two-way ANOVA), $p \leq 0.05$; ranking the branched thalli as the first preference for microalgal epiphytes, sheet-like thalli with a smooth surface as the second one, while the lowest rank was for the mucilaginous species. The same result was found for epiphytic zooplankton. The results of the statistics revealed insignificant seasonal variations in the epiphytic microalgae and very weak correlations between the abundance of microalgae and the physico-chemical parameters. In contrast, there were significant differences for epiphytic zooplanktonic seasonal variations. Whereas, the zooplankton count was correlated preferably with environmental water salinity, followed by nutrients.

Keywords: Epiphytic Microalgae, Epiphytic Zooplankton, Seaweeds, Water Quality, Alexandria

Introduction

Epiphytism is a widespread phenomenon in marine benthic communities, especially in the rocky intertidal zone (Kraberg and Norton, 2007). Although most epiphytic algae are essentially facultative and are not specifically associated with a host species (Wahl and Mark, 1999), some are known as specific and obligate epibionts on certain hosts (Pearson and Evans, 1990). Actually, algal epiphytes play an important role in coastal benthic communities. They provide potential for mutualistic interspecific associations (Stachowicz and Whitlatch, 2005), as well as food and habitats for animals and they are considered as primary producers

in the food chain (Danilov and Ekelund, 2000). They enter the second level of the food chain when they are grazed by invertebrates (Navarro, 1987). Moncreiff *et al.* (1992) reported that the production of epiphytic algae often exceeded that of macroalgae and seagrass itself.

On the other hand, epiphytes growing on the seaweeds cover the photosynthetic area of the seaweeds blade and therefore reduce the photosynthetic capabilities of the host algae. Another disadvantage of epiphytes is that; they decrease the host growth rates and result in loss of biomass through direct competition with the host algae for space, nutrients and inorganic carbon from the water column (Buschmann and Gómez, 1993). The rapid growth of

epiphytes, such as diatoms, which are considered the most important structural elements of the epiphyton on seaweeds or seagrass (Jacobs and Noten, 1980), is usually the result of high nutrients. These high nutrient salts levels are usually caused by human activities in the area (Lobban and Harrison, 1994).

In fact, environmental parameters highly affect the population and growth rate of epiphytes. Temperature and light intensity have a significant effect on the growth of the epiphytic organisms. There is indirect evidence from seasonal studies which show that the epiphyte biomass increases with increasing light and temperature (Lepoint *et al.*, 1999). Epiphyte growth rate is highly correlated with dissolved oxygen and inorganic carbon. Observational and experimental studies have, indeed, reported an increase in epiphyte biomass in response to nutrient loading (Tomasko and Lapointe, 1991). While others have demonstrated shifts in composition of epiphytes under nutrient loading (Wear *et al.*, 1999). This led implicitly to the assumption that epiphytes could be useful indicators of environmental conditions and, in particular, of nutrient concentrations (Lü and YongJian, 2009).

Currently, many land-based activities such as industrial and agricultural processes have contributed to the contamination of water systems in many coastal areas, increasing nutrient loads, leading to eutrophication and causing in turn adverse effects on aquatic biota and human health. These effects and their consequences have attracted recently the attention of researchers all over the world (David *et al.*, 2009).

Considerably little literature was concerned about the distribution and effects of epiphytic populations on macroalgal hosts and their species composition on macroalgal tissues and the relationships between them and their hosts. In fact, these literatures focused on the epiphytic macroalgal species (Rindi and Guiry, 2004; Muñoz and Fotedar, 2009; Kersen *et al.*, 2011), whereas very few literatures dealt with epiphytic microalgae and/or epifauna. Tanaka *et al.* (1984) conducted a study on epiphytic microalgal communities on *Sargassum piluriferum* and artificial seagrasses in *Sargassum* bed. Totti *et al.* (2009) conducted a survey on epiphytic diatom communities on ten species of seaweeds belonging to brown, red and green macroalgae from Iceland coastal waters. Gestoso *et al.* (2010) investigated the variability of epifaunal assemblages associated with native and invasive macroalgae.

Noticeably, many areas in Egypt have been reported to be polluted principally due to the discharge of untreated wastes into the coastal areas by many land based sources. Pollution in the Eastern Harbor is attributed to discharge of untreated domestic waste water through several

submerged minor sewage outfalls distributed along the harbor coast. Along with, various small industries such as: Car cleaning and repairing, some foodstuff plants, gas stations, small dairy plants and some foundries. Also, the harbor water receives additional waste effluents from fishing ships and the shipyard situated on its western side. Other wastewater discharges occur through two marine outfalls lying at the outer sides of the harbor, the Qayet Bay and Silsila marine outfalls (Abdallah, 2007). Accordingly, the Eastern harbor was classified in the previous research as a very high eutrophic estuary (EEAA, 2008). In view of the enormous discharge of mixed effluents into this Harbor, it becomes imperative to investigate the extent of pollution in the Harbor and its consequences on biota.

However, the studies conducted on epiphytic microalgae are scarce in Egypt, focusing on one or two classes only, without studying the effect of ecological conditions on these organisms, thus lacking much information, especially on associated fauna which was not studied before. Madkour and El-Shoubaky (2007) investigated the epiphytic diatoms growing on seaweeds inhabiting the Port Said coast (Mediterranean Sea) seasonally (2004-2005). El-Zayat (2012) carried out a study on epiphytic harmful microalgae along Alexandria Coast; whereas Ismael (2012) and Hegazy (2013) focused only on the benthic bloom of Cyanobacteria associated with macroalgae in Alexandria waters.

The objective of this study was to conduct a qualitative and quantitative study on the epiphytic microalgae and epiphytic zooplankton on seaweeds, which is the first one in consideration of epiphytic zooplankton assemblages and their relationship with epiphytic microalgae and both of them in relation to their macroalgal host. This study, also attempts to emphasize the effect of the quality of coastal waters of the Eastern Harbor on these biota and to assess condition index for macroalgae and epiphytes.

Materials and Methods

Study Area

Samples were performed seasonally during two years successively: Winter, summer, autumn (2012) and spring (2013), covering the study area, the Eastern Harbor (E.H.), which is a shallow semi-enclosed basin receiving sewage effluents coming from several minor sewers in addition to shipping activities, fisheries and other sources of pollution (Abdallah, 2007) (Fig. 1). However, the site sheltered four or five common seaweeds, which were recorded previously (Shams El-Din *et al.*, 2007) and were found along the Egyptian Mediterranean coast.



Fig. 1. The study area and sampling station during 2012-2013

Water Samples

Surface water samples were collected seasonally, from the same areas and during the same time of sampling of algae. Water pH was measured in situ using Metrohm (827 pH) pH electrode calibrated with TRIS buffer on total scale (pH_T) following Dickson *et al.* (2007). The water samples were collected directly then brought to laboratory for determinations of all studied parameters: Salinity, oxidizable organic matter (O.M.), chlorophyll-*a* and nutrient salts. Dissolved oxygen was fixed in field and measured according to the modified Winkler's method according to Strickland and Parsons (1972) taking all the required precautions. Measurements of salinity was done using a Bekman Induction Salinometer (Model RS-7C), which is standardized with Standard Seawater Copenhagen, Denmark, of chlorinity 39.377 g l^{-1} . The conductivity ratio was measured to the nearest 1×10^{-5} and converted to salinity, up to the nearest 0.01 g l^{-1} using the tables of salinity/conductivity conversions. Nutrient salts (nitrite, nitrate, ammonium, phosphate and silicate) were measured spectrophotometrically in filtered samples, using 6800UV/VIS Spectrophotometer (JENWAY) according to Grasshof *et al.* (1975). Chlorophyll was measured to illustrate water productivity according to Strickland and Parsons (1972). Oxidizable organic matter was measured according to the method of Carlberg (1972). The readings of temperature were obtained by personal communication (Tarek El Gezery).

Collection of Macroalgae

Each host algal species was collected from the study area at the sublittoral zone at a 0.5-1 m depth, representing the algal groups present in this area. Thereafter, algal samples were separated in the field and put in polyethylene plastic bags, then kept in ice-box. In the laboratory, Herbarium sheets with a preliminary identification of separated host species were done and/or preserved in 4% formalin. Microscopic identification of the investigated host algae was carried out according to Aleem (1993) and Braune (2008). The collected algae were *Ulva fasciata*, *Corallina mediterranea*, *Corallina officinalis*, *Gelidium sp.*, *Pterocladia capillacea*, *Hypnea musciformis* and *Grateloupia doryphora*.

Separation of Epiphytes

Separation of Epiphytic Microalgae

Three replica of each algal host were prepared for microalgae estimation. About 5 gm of host algae were weighed for each replica and then were put in plastic bottles containing about 30 ml filtered seawater; they were then, vigorously shook and finally washed with little filtered seawater. The shacking procedure was repeated several times to ensure that most of the attached organisms were separated. This method was used by previous researchers to remove microepiphytic species (Mabrouk *et al.*, 2011). Thereafter, the samples were passed through $100 \mu\text{m}$ mesh sieves to remove host

algae and large particles and were completed to 50 ml to obtain a concentrate of microalgae, which were finally preserved with 4% neutralized formalin. An estimation of the microalgal count was carried out in a counting cell (Sedgewick Rafter Cell) and was expressed as units per gm fresh weight of macroalgae (units comprised of cells, colonies and filaments), using a binocular microscope. The reported results are the means of triplicate count for epiphytic microalgae on each host for each sampling period. The identification of microalgal taxa followed Peragallo and Peragallo (1897-1908), Cupp (1943), Heurk (1962), Hendey (1964), Sournia (1968; 1986), Dodge and Hart-Jones (1982) and Mizuno (1990). The phytoplankton species are updated according to the taxonomic database sites, like *algaebase.com* (ab), World Register of Marine Species (WoRMS), Canadian Register of Marine Species (CaRMS), Nordic microalgae and aquatic protozoa (NOD) and Integrated Taxonomic Information System (ITIS).

Separation of Associated Zooplankton

The associated zooplankton was also estimated in the same samples used for estimation of epiphytic microalgae and was expressed as organisms per gm fresh weight of macroalgae. The reported results are the means of triplicate count for epiphytic zooplankton on each macroalgal species for each sampling period. The identification of epiphytic zooplankton taxa followed Jorgensen (1924), Rose (1933) and Tregouboff and Rose (1957).

The zooplankton species are updated according to the taxonomic database sites, like World Data base for Protozoa, IOMS and integrated Marine Observing System for Copepoda.

Statistical Analysis

Correlation coefficient of total count on each host, total count of each class, total count of dominant species of epiphytic microalgae and epiphytic zooplankton separately with physico-chemical parameters (temperature, pH, salinity, dissolved oxygen, nitrite, nitrate, reactive soluble phosphate, silicate, oxidizable organic matter and chlorophyll-*a*) were calculated at confidence limit 95% ($p \leq 0.05$), using Excel program 2007. Also the correlation between the epiphytic microalgae and the epiphytic zooplankton was calculated at confidence limit 95%.

Macroalgal thalli were subdivided in three groups and defined on the basis of both thalli morphology and surface characteristics as follows: Branched thalli, sheet-like thalli with smooth surface and flat thalli with mucilaginous surface. Differences between seaweed morphotypes coupled with the abundance of epiphytes seasonally were assessed through a two-way Analysis Of Variance (ANOVA) separately for epiphytic microalgae

and epiphytic zooplankton groups to examine the effect of seasonal variations for each host species (4 levels) and different morphotypes of host species (3 levels), using Excel program 2007.

Results

Water Quality

The measured water quality of surface sea water samples collected from the Eastern Harbor during 2012-2013 is as shown in Table 1. During the study period, surface water temperature varied following the variation of air temperature. It fluctuated between 22.76°C in autumn to 28.85°C in summer.

The recorded pH was the highest during winter (8.48) and the lowest during summer (7.93). The readings of salinity were typical to that of the Mediterranean Sea during the three seasons, ranging from 38.25‰ during spring 2013 to 39.23‰ during summer 2012. Sea water in E.H. showed dissolved oxygen content of a moderate values during all seasons except the autumn (2.59 mg O₂ l⁻¹), with an annual average of 3.92±0.90 mgO₂ l⁻¹.

Chlorophyll-*a* attained a maximum value of 5.06 µg l⁻¹ during spring (2013), indicating the high photosynthesis activity during this season and which synergized with a high oxygen content. On the other hand the lowest chlorophyll content was recorded during winter (2012) (2.86 µg l⁻¹). The oxidizable organic matter ranged between (0.80 mgO₂ l⁻¹) during winter and (4.80 mgO₂ l⁻¹) during summer. The annual average oxidizable organic matter was of 3.58±1.87 mgO₂ l⁻¹.

As far as nutrients are concerned, nitrite and nitrate showed the maximum content during summer (1.75 and 3.28 µmol l⁻¹), respectively; whereas, the minimum content was recorded during winter (0.45 and 0.93 µmol l⁻¹), with an annual average of 1.27±0.58 and 2.31±1.04 µmole l⁻¹, respectively. Inorganic phosphate concentration was minimal during summer and autumn (0.04 µmole l⁻¹) and maximal during winter (0.26 µmol l⁻¹), with an annual average of 0.11±0.10 µmol l⁻¹. On the other hand, inorganic silicate's annual average was (5.41±2.62 µmol l⁻¹) and its concentration ranged between (3.02 µmol l⁻¹) during winter and (8.69 µmol l⁻¹) during autumn.

Species Composition of Seaweeds

A total of 63 host algal samples were collected during (2012-2013) at the depths (0.5-1 m), representing 7 species belonging to two algal classes. Chlorophyceae was represented by the order Ulvales comprising of one family: Ulvaceae which was, represented by one species; *Ulva fasciata* Delile, whereas the second class, Rhodophyceae was represented by four orders (Corallinales, Gelidiales,

Gigartinales and Halymeniales) comprising of one family each (Corallinaceae, Gelidiaceae, Hypneaceae and Halymeniaceae). The family Corallinaceae was represented by two species *Corallina mediterranea* and *Corallina officinalis* Linnaeus whereas, the family Gelidiaceae was represented by two species *Gelidium sp.* and *Pterocladia capillacea* (S.G.Gmelin) Santelices and Hommersand. The family Hypneaceae was represented by one species *Hypnea musciformis* (Wulfen) Lamouroux and the family Halymeniaceae was represented by the species *Grateloupia doryphora* (Montage) M.A. Howe, which is introduced in the Mediterranean Sea and considered as invasive species (Gavio and Fredricq, 2002). *G. doryphora* was introduced recently in the Egyptian Mediterranean Sea (personal communication with Nihal Shams El-Din).

Epiphytic Microalgae

Community Composition

During the study period, a total of 152 microalgal taxa belonging to 68 genera were identified to the genus or species level (Table 2). These taxa included 68 freshwater and brackish forms and 84 marine forms. Five algal groups were represented in the Harbor; namely Bacillariophyceae (88 species), Chlorophyceae (24 species), Dinophyceae (18 species), Cyanophyceae (15 species) and Euglenophyceae (7 species). There were no marked differences among the host species during the same season in respect to species number. In contrast, the species number differed seasonally in respect to each host species (Fig. 2). The maximum number of species was determined on the species *C. officinalis* during summer (2012) (45 species) and on *C. mediterranea* during spring (2013) (42 species) (Table 2). However, the typical freshwater forms contributed by a very low number to the total number of species attached on the surface of each host. This number did not exceed 7 species on all the host algae, except on *G. doryphora* during winter, *C. mediterranea*, *C. officinalis*, *P. capillacea* during summer and on *U. fasciata* during autumn (Fig. 2). However, only few species were recorded on all host algal species (*Chroococcus sp.*, *Actinoptychus undulatus*, *Gramatophora oceanica*, *Licmophora dalmatica*,

licmophora gracilis, *Navicula cryptocephala* and *Nitzschia kütziginiana*). In contrast, there were epiphytic species that showed selectivity and were specific to a definite host (Table 2).

Relative Abundance

There is a great difference in the relative abundance of the epiphytic microalgal groups temporally and specifically. However, the host species *U. fasciata* recorded high percentage of diatoms during all the seasons except during autumn, where the Cyanophyceae was dominant (61.90%). The two groups, Euglenophyceae and Dinophyceae were scarcely present on *U. fasciata* and all the other host species during the four seasons, except one case of high dinoflagellates contribution (Fig. 3). The two corallinates *C. mediterranea* and *C. officinalis* showed similar patterns of groups' distribution, since during winter (2012) the diatoms were dominant contributing 96.58% on the former species and 98.52% on the latter. The diatoms lead to the succession of Cyanophyceae during summer (2012), contributing 92.23% on *C. mediterranea* and 88.22% on *C. officinalis*. During autumn, Chlorophyceae was dominant on *C. officinalis* (75.58%), whereas, *C. mediterranea* was not found. The spring season was characterized by the contribution of the different groups with different percentages on the surface of both host algae (Fig. 3). *Gelidium sp.* was recorded only during winter (2012), where Chlorophyceae was co-dominant with Bacillariophyceae. However, diatoms prevailed during the study period. They were dominant on *P. capillacea* during winter, (86.25%), summer (70.53%) and autumn (83.55%), against dinoflagellates, which attained for the first time (87.92%) during spring (2013). The rhodophyte *H. musciformis* showed different patterns during the three seasons, where Cyanophyceae predominated during summer (85.49%), during autumn (78.96%) and co-shared the dominance with diatoms during spring (2013) (48.40 and 49.76%), respectively. The last species during this study, *G. doryphora* was found only during winter (2012) and spring (2013), where the different groups of epiphytic microalgae co-shared with different percentages (Fig. 3).

Table 1. The water quality of sea water samples collected from the macroalgal ambiance in the Eastern Harbor during (2012-2013)

	T (°C)	pH	Salinity (%)	D.O. mg O ₂ /l	μmol l ⁻¹				OM mg O ₂ /l	Chlorophyll (μg l ⁻¹)
					NO ₂	NO ₃	PO ₄	SiO ₄		
Winter (2012)	-	8.48	38.35	4.41	0.45	0.93	0.26	3.02	0.80	2.86
Summer (2012)	28.85	7.93	39.23	4.49	1.75	3.28	0.04	6.31	4.80	4.50
Autumn (2012)	22.76	8.09	-	2.59	1.60	2.13	0.04	8.69	4.48	2.96
Spring (2013)	-	8.29	38.25	4.20	1.26	2.90	0.10	3.60	4.25	5.06
max	28.85	8.48	39.23	4.49	1.75	3.28	0.26	8.69	4.80	5.06
min	22.76	7.93	38.25	2.59	0.45	0.93	0.04	3.02	0.80	2.86
average	25.81	8.20	38.61	3.92	1.27	2.31	0.11	5.41	3.58	3.84
SD	-	0.24	0.54	0.90	0.58	1.04	0.10	2.62	1.87	1.10

Table 2. Check list of the epiphytic microalgae during the study period (2012-2013)

	<i>U. fasciata</i>				<i>C. mediterranea</i>				<i>C. officinalis</i>				<i>Gelidium sp.</i>				<i>P. capillacea</i>				<i>H. musciformis</i>				<i>G. doryphora</i>			
	w	s	A	P	w	S	a	P	w	S	A	P	w	s	a	p	w	S	A	P	w	S	A	P	w	s	a	P
Cyanophyceae																												
<i>Chroococcus disperses</i> (Kessel.) Lemm.			+				*				*		*	*	*		+		*		+				*	*		
<i>Chroococcus minutus</i> (Kütz.) Nägeli			+				*	+			*		*	*	*			+	*						*	*		
<i>Chroococcus sp.</i>	+	+			+	*	+		+	+	+		*	*	*		+	+	+		*	+	+		+	*	*	+
<i>Chroococcus limneticus</i> Lemm.							*				*		*	*	*				*		*	+			*	*		
<i>Merismopedia elegans</i> A. Br.					+	*					*		*	*	*				*						*	*		
<i>Merismopedia glauca</i> (E.) Nägeli							*				*		*	*	*				*						*	*		
<i>Merismopedia punctata</i> Meyen							*				*		*	*	*		+		*						*	*		
<i>Merismopedia tenuissima</i> Lemm.							+	*			*		*	*	*				*						+	*	*	
<i>Oscillatoria limosa</i> C. Agardh Gomont	+	+	+		+	*			+	+			*	*	*				+	*	+	+	+		*	*	*	*
<i>Oscillatoria sp.</i>	+	+			+	*			+	+			*	*	*				+	*	+	+	+		*	*	*	*
<i>Oscillatoria tenuis</i> C. Agardh (WoRMS)	+	+	+		+	*			+				*	*	*		+	+	+	*	+	+	+		*	*	*	*
<i>Phormidium tenue</i> Anagn. Kom.							*				*		*	*	*		+		*						*	*		
<i>Planktothrix aghardhii</i> (Gomont) Anagn. Kom.			+				*		+				*	*	*		+	+	*						+	*	*	*
<i>Planktothrix formosum</i> Bory							*				*		*	*	*				*		+				*	*	*	*
<i>Planktothrix planctonica</i> (Elenkin) Anagn. Kom.			+		+	*			+				*	*	*				+	*			+		*	*	*	*
Chlorophyceae																												
<i>Ankistrodesmus falcatus</i> (Corda) Ralfs	+				+	*		+	+	+	+		*	*	*		+	-	+	*					+	*	*	+
<i>Chlamydomonas snowii</i> Printz							*	+	+	+			*	*	*				*						*	*	*	*
<i>Chlamydomonas sp.</i>					+	*					+		*	*	*				*						*	*	*	*
<i>Chlorella vulgaris</i> Beij		+	+			*			+	+	+		*	*	*		+	+	*						*	*	*	*
<i>Clorogonium elegans</i> Playt							*				*		*	*	*				*						+	*	*	*
<i>Cosmarium reniforme</i> (Ralfs) W. Archer.							*	+			*		*	*	*				*						*	*	*	*
<i>Cosmarium sp.</i>							*				*		*	*	*				*						*	*	*	+
<i>Crucigenia cuneiformis</i> Brun.							*		+				*	*	*				*						*	*	*	+
<i>Crucigenia quadrata</i> Morren							*				*		*	*	*		+		*						*	*	*	+
<i>Crucigenia rectangularis</i> Nägeli						+	*				*		*	*	*				*						*	*	*	*
<i>Crucigenia tetrapida</i> Kirchner			+				*		+		*		*	*	*		+		*						*	*	*	*
<i>Kirschneriella obesa</i> W. West							*				*		*	*	*		+		*						*	*	*	+
<i>Oocystis solitaria</i> Witt.	+					*	+				*		*	*	*		+		*						*	*	*	*
<i>Pediastrum clathratum</i> (Schröder) Lemm.							*		+		*		*	*	*				*						*	*	*	*
<i>Pediastrum simplex</i> (Meyen) Lemm.							*		+		*		*	*	*				*						+	*	*	*
<i>Phacotus lenticularis</i> Ehrenberg							*				*		+		*				*						*	*	*	*
<i>Scenedesmus bijugatus</i> Kütz.						+	*		+		*		*	*	*		+		*						+	*	*	*
<i>Scenedesmus dimorphus</i> (Turpin) Kützing						+	*		+		*		+		*				*						*	*	*	*
<i>Scenedesmus quadriquadra</i> (Turpin) Bréb.	+				+	*			+	+	*		+		*				*						+	*	*	*
<i>Schroderia setigera</i> (Schröder) Lemm.							*				*		*	*	*				*						+	*	*	*
<i>Staurastrum paradoxum</i> Meyen ex Ralfs							*		+		*		*	*	*		+		*						*	*	*	*
<i>Staurastrum sp.</i>							*		+		*		*	*	*				*						*	*	*	*
<i>Stigeoclonium sp.</i>	+	+			+	*		+	+	+	*		*	*	*		+		*						+	*	*	*
<i>Ulothrix sp.</i>							*		+		*		*	*	*				*						*	*	*	*
Euglenophyceae																												
<i>Euglena acus</i> Ehrenberg							*		+		*		*	*	*				*						+	*	*	*
<i>Euglena clara</i> Skuja						+	*				*		*	*	*				*						*	*	*	*
<i>Euglena gracilis</i> G.A. Klebs							*		+		*		*	*	*				*						+	*	*	*
<i>Euglena klebsii</i> Lemmermann Mainx						+	*		+		*		*	*	*		+		*						+	*	*	*
<i>Euglena pisciformis</i> Klebs.					+	+	*				*		*	*	*				*						+	*	*	*
<i>Euglena sp.</i>							*				*		*	*	*				*						+	*	*	*
<i>Phacus curvicauda</i> Svirengo							*				*		*	*	*			+	*	+					*	*	*	*
Bacillariophyceae																												
<i>Achnanthes brevipes</i> C. Agardh	+						*	+			*		*	*	*		+		*						*	*	*	*
<i>Actinocyclus adriaticus</i> Grunow			+	+	+	+	*	+	+		*		*	*	*			+	+	*					+	*	*	*
<i>Actinocyclus glabratus</i> Grunow							*				*		*	*	*				*						+	*	*	*
<i>Actinocyclus sp.</i>							*		+	+	+	+	*	*	*		+	+	*						+	*	*	*
<i>Actinocyclus undulatus</i> (Bailey) Ralfs	+	-	+	+	+	+	*	+	+	+	+	+	*	*	*		+	+	*		+	+	+		+	*	*	+
<i>Actinocyclus vulgaris</i> Schumann							*	+	+	+	+	+	*	*	*		+	+	*						+	*	*	+
<i>Amphiprora sp.</i>							*		+		*		*	*	*				*						*	*	*	*
<i>Amphora marina</i> W. Smith							*		+		*		*	*	*				*						*	*	*	*
<i>Amphora sp.</i>						+	+		+	+	*		*	*	*		+	+	*						+	*	*	*
<i>Asterionellopsis glacialis</i> (Castracane) Round						+	*				*		*	*	*				*						+	*	*	*
<i>Bacillaria paradoxa</i> J.F. Gmelin							*				*		*	*	*				*						*	*	*	*
<i>Climacospheia monilifera</i> Ehrenberg							*		+		*		*	*	*				*						*	*	*	*
<i>Cocconeis lyra</i> A. Schmidt	+	+		+	+	+	*	+	+	+	+	+	*	*	*		+	+	*						+	*	*	*
<i>Cocconeis placentula</i> Ehrenberg	+	+		+	+	+	*	+	+	+	*		*	*	*		+	+	*						*	*	*	*
<i>Cocconeis scutellum</i> Ehrenberg	+			+	+	+	*		+	+	*		*	*	*				*						*	*	*	*
<i>Coscinodiscus centralis</i> Ehrenberg				+			*	+			*		*	*	*				*						*	*	*	*
<i>Coscinodiscus concinnus</i> W. Smith	+			+			*				*		*	*	*				*						+	*	*	*
<i>Coscinodiscus curvulatus</i> Ehrenberg				+			*		+		*		*	*	*				*						*	*	*	*
<i>Coscinodiscus excentricus</i> Ehrenberg				+			*	+			*		*	*	*		+		*						*	*	*	*
<i>Coscinodiscus marginatus</i> Ehrenberg	+			+			*	+			*		*	*	*				*						*	*	*	*
<i>Coscinodiscus radiatus</i> Ehrenberg				+			*	+			*		*	*	*				*						*	*	*	*
<i>Coscinodiscus sp.</i>	+			+			*	+			*		*	*	*				*						*	*	*	*
<i>Cyclotella comta</i> Ehrenberg				+			*				*		*	*	*				*						*	*	*	*
<i>Cyclotella glomerata</i> H. Bachm.				+			*		+		*		*	*	*		+		*						+	*	*	*
<i>Cyclotella kützingiana</i> Thwaites				+			*		+		*		*	*	*		+	+	*						+	*	*	*
<i>Cyclotella menghemiana</i> Kützing				+			*	+			*		*	*	*		+		*						+	*	*	*
<i>Cyclotella sp.</i>				+			*	+			*		*	*	*		+		*						*	*	*	*
<i>Cymbella affinis</i> Kützing	+	+	+	+	+	*	+	+	+	+	+		*	*	*		+	+	*		+	+	+		+	*	*	+
<i>Cymbella sp.</i>	+	+		+	+	*	+	+	+	+	+		*	*	*				*						*	*	*	*
<i>Cymbella ventricosa</i> (C. Agardh) C. Agardh	+	+		+	+	*	+	+	+	+	+		*	*	*				*		+	+	+		*	*	*	*
<i>Diploneis bombus</i> (Ehrenberg) Ehrenberg				+			*	+			*		*	*	*				*						*	*	*	*
<i>Diploneis littoralis</i> Donkin Cleve				+			*	+			*		*	*	*				*						*	*	*	*
<i>Eutonia sp.</i>				+			*				*																	

species with different percentages (Fig. 4). The rhodophyte *C. mediterranea* showed a peak during summer, where the total count attained a maximum of 5.414×10^5 units/gm f.w., so that *Chroococcus sp.* overwhelmed the other epiphytes and recorded 89.28% (Table 3 and Fig. 4). The species *C. officinalis* recorded two peaks of epiphytic microalgae. The summer peak was amounted to be (6.202×10^5 units/gm f.w.) due to the prevalence of *Chroococcus sp.* (87.02%) and the autumn peak

(6.659×10^5 units/gm f.w.) due to the dominance of *Stigeoclonium sp.* (75.51%). The two last host species *H. musciformis* and *P. capillacea* recorded their peaks during summer attaining a maximum of 7.992×10^4 and 2.170×10^4 units/gm f.w., respectively (Table 3). Again, the cyanophyte *Chroococcus sp.* was dominant on *H. musciformis* (80.35%) but retrograded on *P. capillacea* (12.00%) and co-dominated with four diatoms to form the main bulk of epiphytic community (Fig. 4).

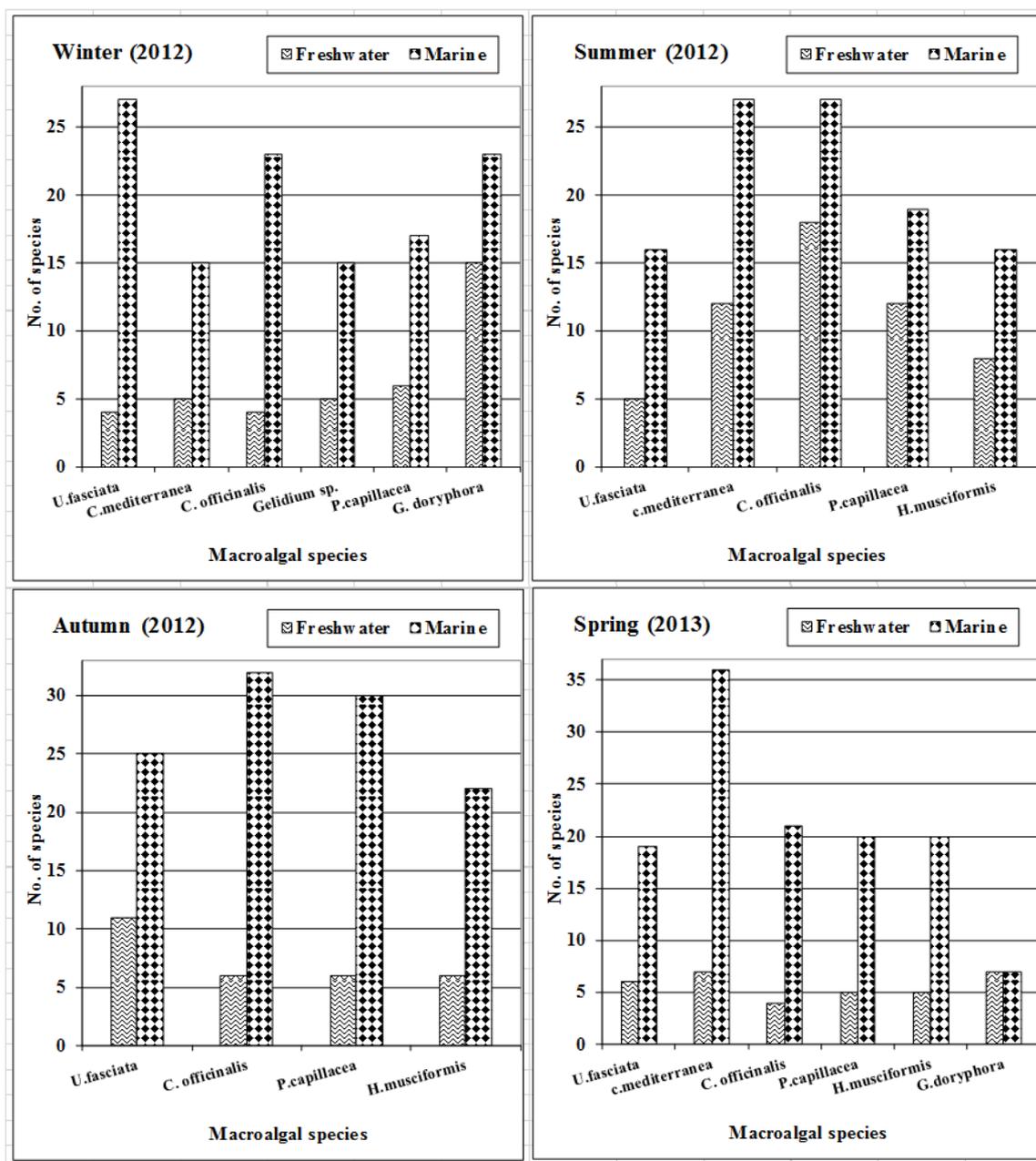


Fig. 2. The number of epiphytic fresh and marine microalgal species during the study period (2012-2013)

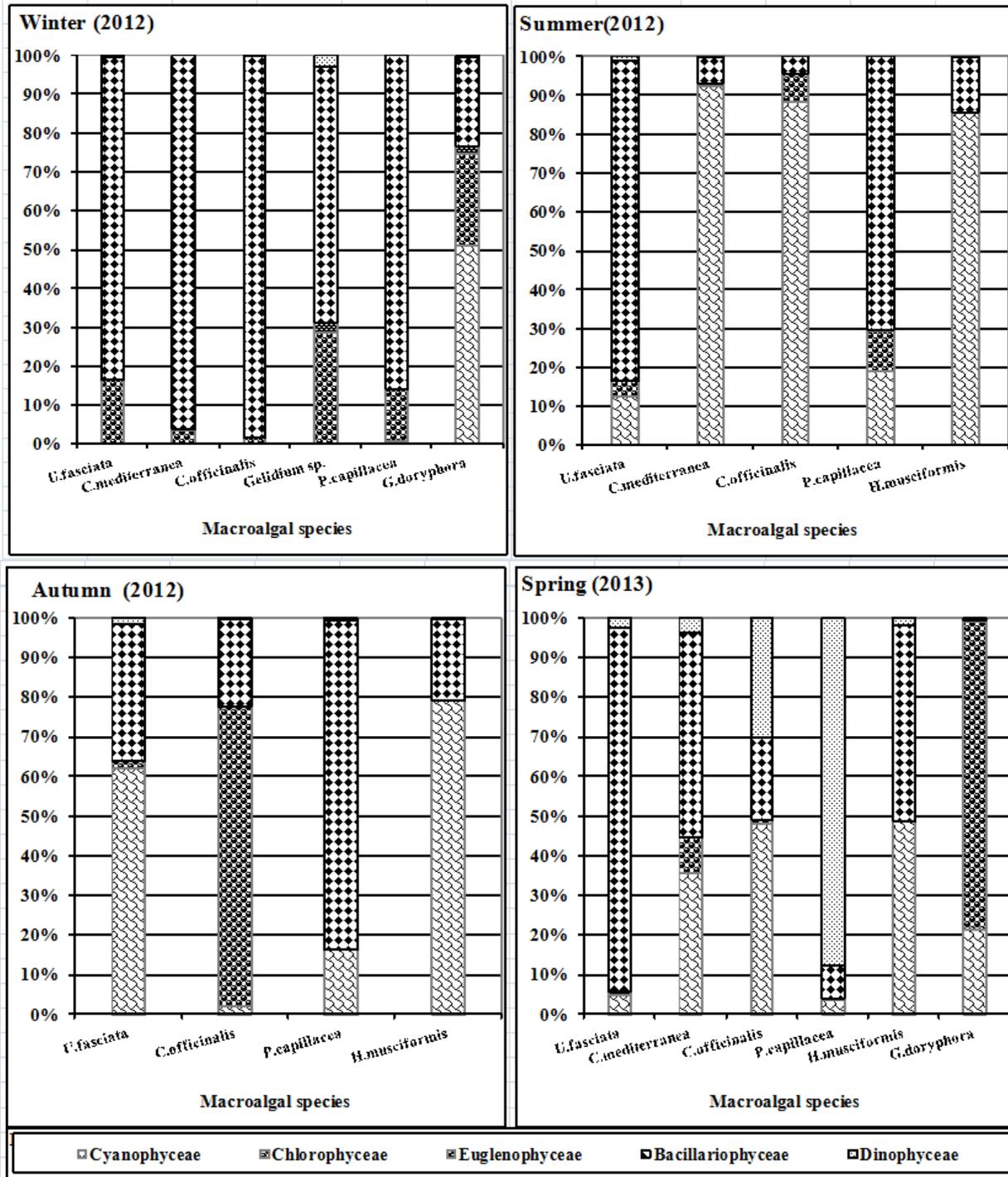


Fig. 3. The distribution of different classes of epiphytic microalgae during the study period (2012-2013)

Actually, the summer season was almost the most productive one. Whereas, the cyanophytes especially *Chroococcus sp.* and chlorophytes played an important role in the main bulk during all seasons. On the other hand, there were some harmful epiphytes, which were recorded during this study on

different host species (Table 4). Many of them contributed very low percentages and appeared occasionally, except the cyanophytes *Oscillatoria limosa*, *O. tenuis* and *Planktothrix aghardhii*, which appeared frequently and during different seasons (Table 2 and Fig. 4).

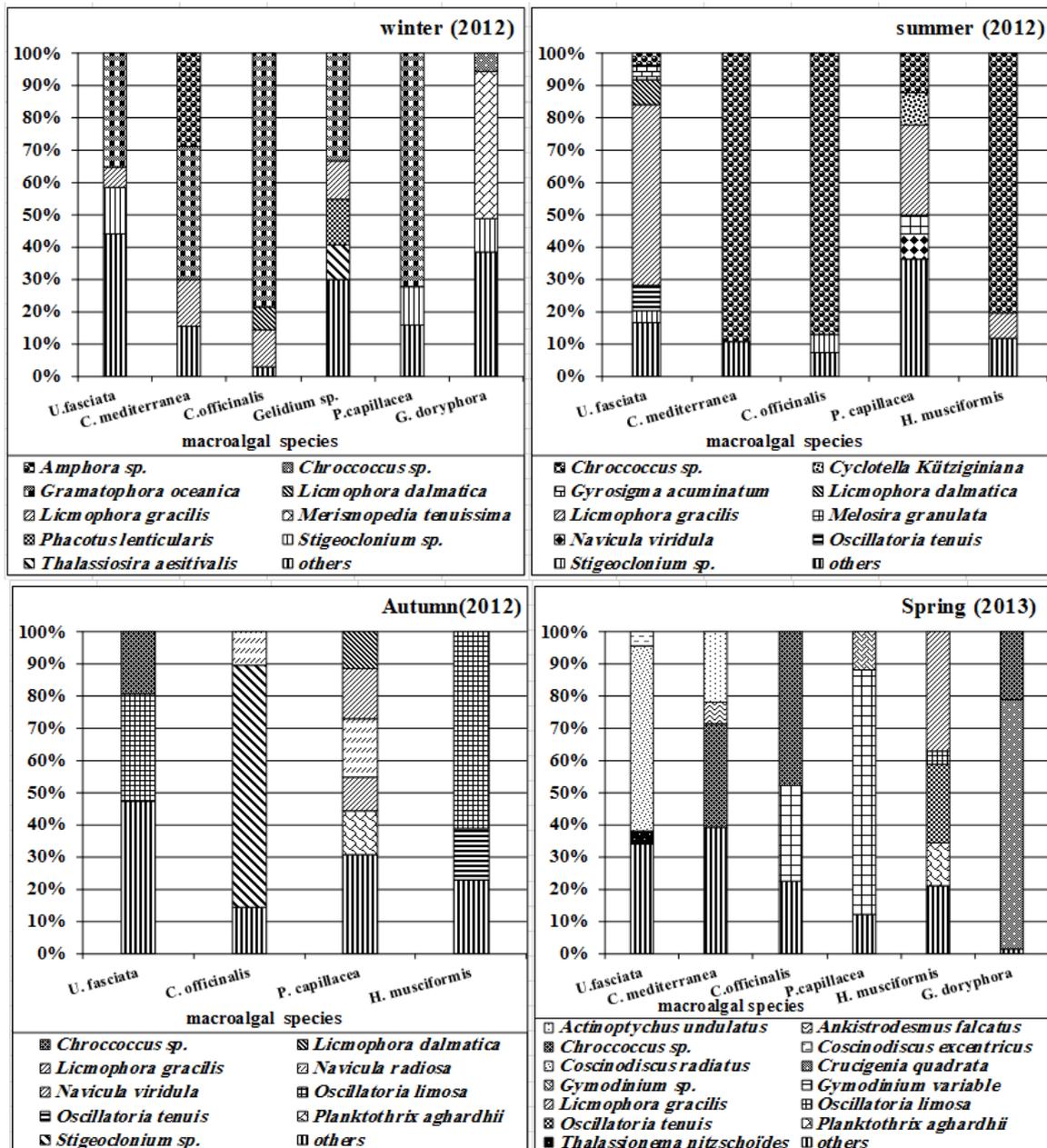


Fig. 4. The Distribution of dominant species of epiphytic microalgae during the study period (2012-2013)

Epiphytic zooplankton

Community Composition

During the study period, in total, 50 zooplankton taxa including 32 genera were identified. Most of them were Protozoa (33 species: 17 Tintinnida, 14 Foraminifera and 2 non tintinnid ciliates), Copepoda (7species) in addition to its larval stages and Rotifera (6 species). Acantharia, Radiolaria and Tardigrada were represented only by one species each besides

free living nematodes. Other groups (polychaetes, amphipods, decapods, cirripedes, echinoderms, isopods and lamellibranchs) were represented by their larval stages (Table 5). The maximum number of species were determined on the species *C. officinalis* during all seasons except winter (2012) (only 7 species) and on *U. fasciata* during winter and autumn (Table 5). However, only few taxa were recorded on most host algal species (*Spirillina vivipora*, *Euterpina acutifrons*, free living nematodes and amphipods).

Table 3. The total count (units/gm f.w.) of epiphytic microalgae on the different macroalgal species during (2012-2013)

	Winter (2012)	Summer (2012)	Autumn (2012)	Spring (2013)
Chlorophyceae				
Order: Ulvales				
Family: Ulvaceae				
<i>Ulva fasciata</i>	1769±478	2908±2903	4694±3463	735±472
Rhodophyceae				
Order: Corallinales				
Family: Corallinaceae				
<i>Corallina mediterranea</i>	5608±3299	541444±23383	*	6346±3144
<i>Corallina officinalis</i>	79842±116412	620243±976778	665903±130443	2602±2158
Order: Gelidiales				
Family: Gelidiaceae				
<i>Gelidium sp.</i>	2308±665	*	*	*
<i>Pterocladia capillacea</i>	15608±9228	21700±17817	19170±7915	10341±5143
Order: Gigartinales				
Family: Hypneaceae				
<i>Hypnea musciformis</i>	*	79927±94037	28143±30928	3602±1471
Order: Halymeniales				
Family: Halymeniaceae				
<i>Grateloupia doryphora</i>	1460±1279	*	*	7558±6194

Note: The sign (*) means that the species was not found

Table 4. Potentially harmful epiphytic microalgae species recorded during the study period (2012-2013)

Species	Trophic state	Toxin	Harmful effect	References
Cyanophyceae				
<i>Oscillatoria limosa</i>	autotrophic	microcystins		Newcombe (2009)
<i>Oscillatoria tenuis</i>	autotrophic	microcystins		
<i>Phormidium tenue</i>	autotrophic	-	Toxic to mice	Mohamed <i>et al.</i> (2006)
<i>Planktothrix aghardhii</i>	autotrophic	microcystins, anatoxin	non-toxic or toxic	Sivonen <i>et al.</i> (1989)
<i>Planktothrix formosa</i>	autotrophic	Microcystins, homoanatoxin-a	neurotoxic	Steffensen <i>et al.</i> (2001)
<i>Planktothrix planctonica</i>	autotrophic	microcystins		Nogueira and Vasconcelos (2001)
Bacillariophyceae				
<i>Asterionellopsis glacialis</i>	autotrophic	-	Bloom-forming	Ismael (2014)
<i>Cyclotella mengheniana</i>	autotrophic	-	Bloom-forming	
<i>Odontella aurata</i>	autotrophic	-	Bloom-forming	Özman-Say and Balkis (2012)
<i>Proboscia alata</i>	autotrophic	-	Bloom-forming	
<i>Pseudo-nitzschia pungens</i>	autotrophic	domoic acid	ASP	IOC, Casteleyn <i>et al.</i> (2008)
<i>Pseudo-nitzschia seriata</i>	autotrophic	domoic acid	ASP	IOC, Fehling <i>et al.</i> (2004)
<i>Thalassionema nitzschoides</i>	autotrophic	-	Bloom-forming	Özman-Say and Balkis (2012)
<i>Thalassiosira aestivalis</i>	autotrophic	-	fish gill lesions and mortality	Yao <i>et al.</i> (2006)
Dinophyceae				
<i>Dinophysis caudata</i>	autotrophic	DSP toxin, ichthyotoxins	Bloom-forming	Özman-Say and Balkis (2012)
<i>Neocecaratium furca</i>	Mixotrophic	-	Bloom-forming, fish-killing, anoxia	
<i>Neoceratium fuscum</i>	Mixotrophic	-	Fish-killing	
<i>Prorocentrum micans</i>	autotrophic	-	non-toxic or toxic, DSP	Tilstone <i>et al.</i> (2010)
<i>Prorocentrum triestinum</i>	autotrophic	-	Bloom-forming, fish-killing	Özman-Say and Balkis (2012)

Relative Abundance

There is a great difference in the relative abundance of the epiphytic zooplankton groups temporally and specifically. However, the host species *U. fasciata* was characterized by the contribution of the different groups with different percentages during winter and summer (Fig. 5). During autumn Protozoa was dominant (43%) which lead to the succession of Copepoda during spring (50%). The two corallinates *C. mediterranea* and *C. officinalis* showed different

pattern of groups' distribution, where *C. mediterranea* recorded a high percentage of Protozoa during winter (55%). The two groups, Copepoda and nematodes co-shared the dominance during summer (2012) and spring (2013). While on the surface of *C. officinalis*, the Protozoa was dominant during winter (51%), autumn (41%) and co-shared the dominance with Copepoda during spring (2013) (35 and 36% respectively), against free living nematodes, which attained (62%) during summer (2012). *Gelidium sp.* was recorded only during winter (2012), where Protozoa (42%) was co-dominant

with Copepoda (32%). The host species *P. capillacea* recorded a high percentage of free living nematodes during all the seasons except during spring (2013), where Copepoda was co-dominant with Protozoa. The rhodophyte *H. musciformis* showed different patterns during the three seasons, where free living nematodes predominated during summer (55%) and autumn (74%); Copepoda co-shared the dominance with

Rotifera and nematodes (41, 27 and 21%), respectively during spring. The last species during this study, *G. doryphora* was found only during winter (2012) and spring (2013), where Prorozoa predominated during winter and co-shared the dominance with Copepoda and nematodes which attained (26 and 13%), respectively, during spring. Rotifera was scarcely present on all other host species during all seasons.

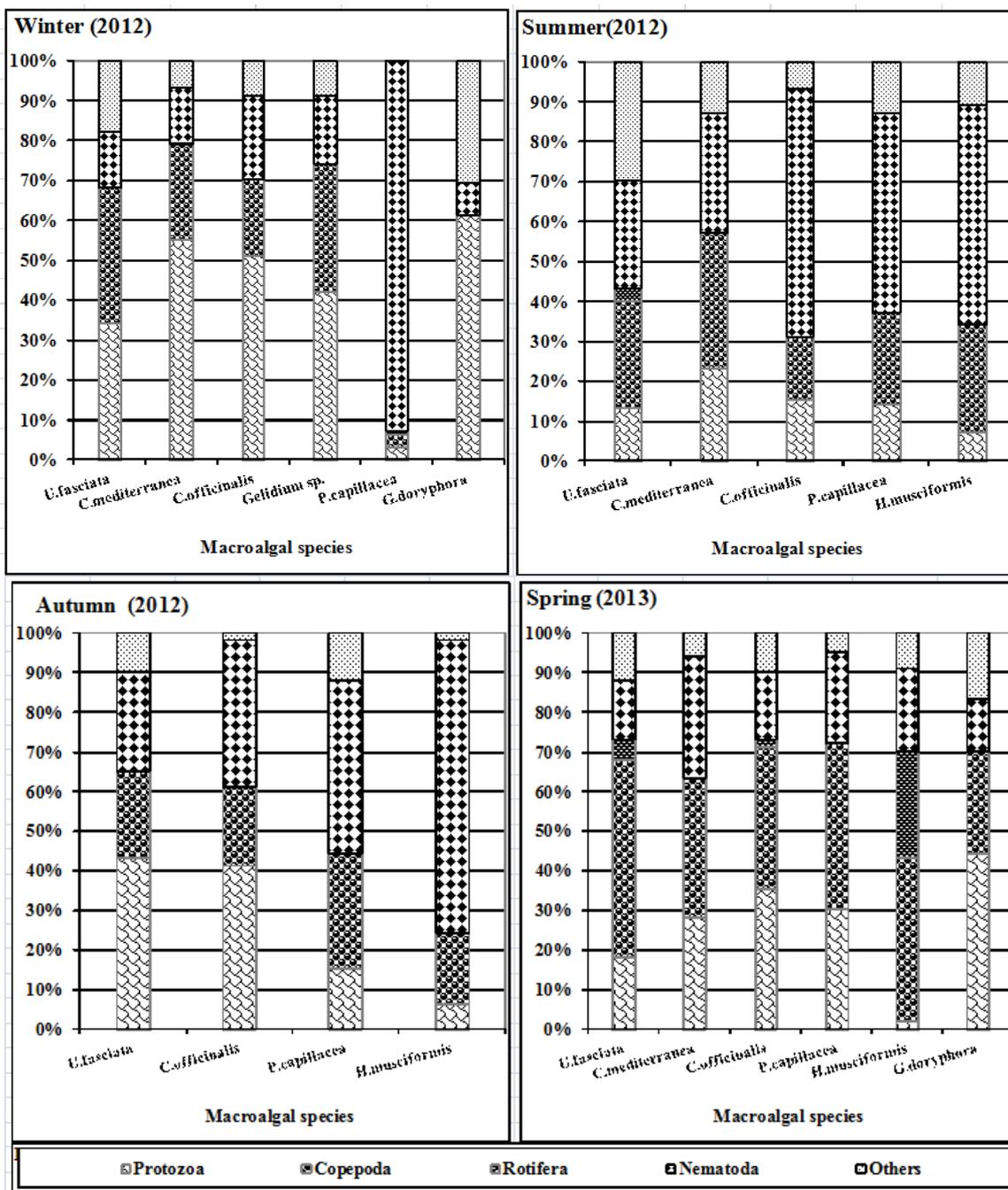


Fig. 5. The distribution of different classes of epiphytic zooplankton during the study period (2012-2013)

Table 5. Check list of the epiphytic zooplankton during the study period (2012-2013)

	<i>U.fasciata</i>				<i>C.mediterranea</i>				<i>C.officinalis</i>				<i>Gelidium sp.</i>				<i>P.capillacea</i>				<i>H.musciformis</i>				<i>G.doryphora</i>				
	w	s	A	P	w	S	a	P	w	S	A	P	w	s	a	p	w	S	A	P	w	S	A	P	w	s	a	P	
Foraminifera																													
<i>Adelisia longirostra</i> d'Orbigny							*		+	+			*	*	*					*						*	*		
<i>Bolivina inflata</i> Heron-Allen&Earl.					+		+				+				*					*							*		
<i>Bolivina laevigata</i> Karrer	+					+	*		+	+	+	+	*	*	*					*						*	*		
<i>Bolivina robusta</i> Brady	+		+				*	+			+				*					*						*	*		
<i>Discorbis floridana</i> Cushman	+						*		+				*	*	*					*						*	*		
<i>Elephidium sp.</i>			+				*			+	+		*	*	*					*						*	*		
<i>Globigerina bulloides</i> d'Orbigny			+			+	*		+	+	+	+	*	*	*					*						*	*		
<i>Globigerina humilis</i> Brady	+						*						*	*	*					*						*	*		
<i>Globigerina inflata</i> d'Orbigny							*	+	+				*	*	*					*						*	*		
<i>Globigerinata glutinita</i> Egger	+						*						+	*	*	*				*						*	*		
<i>Globorotalia tumida</i> Brady							*		+				*	*	*					*						*	*		
<i>Globorotalia truncatuloidea</i> d'Orbigny						+	+	*	+				*	*	*					*						*	*		
<i>Miliolina elegans</i> Williamson			+				*		+		+		*	*	*					*						*	*		
<i>Spiroloculina depressa</i> d'Orbigny	+						*				+		*	*	*					*						*	*		
<i>Spirillina vivipora</i> Ehrenberg	+	+	+		+	+	+	*	+	+	+	+	*	*	*		+	+	+	*				+	*	*	*		
Tintinnidae																													
<i>Acanthostomella elongata</i> Kof.&Camp			+			+	*		+				*	*	*		+			*				+	*	*	*		
<i>Acanthostomella gracilis</i> Brandt							*		+	+			*	*	*					*						*	*		
<i>Acanthostomella norvegica</i> Daday							*			+			*	*	*					*		+				*	*		
<i>Coxiella annulata</i> Daday							*			+			*	*	*					*						*	*		
<i>Favella azorica</i> Cleve							*						*	*	*		+			*		+				*	*		
<i>Favella campanula</i> Schmidt							*				+		*	*	*					*						*	*		
<i>Helicostomella subulata</i> Ehrenberg			+				*						*	*	*		+			*		+		+	*	*	*		
<i>Metacyclis lucasensis</i> Kof.&Camp.							*	+					*	*	*					*				+	*	*	*		
<i>Parafavella digitalis</i> Kof.&Camp.							*				+		*	*	*					*						*	*		
<i>Parundella lachmanni</i> Daday			+				*		+	+			*	*	*		+			*		+		+	*	*	*		
<i>Proplectella angustior</i> Jorgensen	+	+				+	*						*	*	*					*		+	+			*	*		
<i>Tintinnopsis beroidea</i> Stein							*						*	*	*		+			*						*	*		
<i>Tintinnopsis lobiancoi</i> Daday							*	+			+		*	*	*		+	+		*						*	*		
<i>Undella attenuata</i> Jorgensen			+			+	*		+	+			*	*	*		+	+		*						*	*		
<i>Undella dilatata</i> Kof.&Camp	+	+				+	*	+			+		*	*	*		+			*		+	+			*	*		
<i>Undella hyaline</i> Daday						+	*				+		*	*	*		+			*		+				*	*		
<i>Xystonella lohmanni</i> Brandt							*		+				*	*	*					*				+	*	*	*		
Ciliata																													
<i>Euplotes sp.</i>				+			*						*	*	*		+			*						*	*		
<i>Ciliophora sp.</i>							*	+					*	*	*					*						*	*		
Acantharia																													
<i>Heliolithium aureum</i>							*						*	*	*					*				+	*	*	*		
Radiolaria																													
<i>Silyoclamyidium sp.</i>							*						*	*	*					*				+	*	*	*		
Rotifera																													
<i>Brachionus angularis</i> Gosse							*				+		*	*	*					*				+	*	*	*		
<i>Brachionus calyciflorus</i> Pallas			+				*				+		*	*	*					*				+	*	*	*		
<i>Brachionus plicatilis</i> Muller				+			*						*	*	*					*				+	*	*	*		
<i>Colurella obtuse</i> Gosse							*						*	*	*		+			*						*	*		
<i>Keratella quadrata</i> Muller							*						*	*	*					*				+	*	*	*		
<i>Lepadella patella</i> Muller			+				*						*	*	*		+			*						*	*		
Copepoda																													
<i>Copepod larvae</i>	+	+	+		+	+	+	*	+	+	+	+	+	+	+	*	+	+	+	+	*	+	+	+	+	+	*	*	+
<i>Copepodite</i>	+				+	+	*		+	+	+	+	+	+	+	*	+	+	+	+	*	+	+	+	+	+	*	*	+
Harpacticoid																													
<i>Clytemnestra scutellata</i> Dana							*				+		*	*	*					*						*	*		
<i>Euterpina acutifrons</i> Dana	+	+	+		+	*	+		+	+	+	+	+	+	+	*	+	+	+	+	*	+	+	+	+	+	*	*	+
<i>Macrosetella sp.</i>	+						*						*	*	*					*						*	*		
<i>Microsetella norvegica</i> Boeck	+		+		+	*	+		+	+			*	*	*		+	+		*						*	*		
<i>Onchocampus mohammed</i>							*						*	*	*					*						*	*		
<i>Blanchard&Richard</i>							*						*	*	*					*		+				*	*		
Cyclopoid																													
<i>Oithona nana</i> Giess							*						*	*	*		+			*				+	*	*	*		
<i>Oithona plumifera</i> Baird							*				+		*	*	*					*				+	*	*	*		
Tardigrada																													
<i>Hypsibius sp.</i>	+		+		+	*			+	+			*	*	*		+	+		*				+	*	*	*		
Free living nematodes																													
Larvae																													
Amphipod		+	+		+	*	+		+	+	+	+	*	*	*		+	+	+	*		+	+		*	*	+		
Cirriped	+				+	*			+				*	*	*					*				+	*	*	*		
Decapod		+				*					+		*	*	*					*	+				*	*	*		
Echinoderm		+				*							*	*	*					*					*	*	*		
Gastropod	+				+	*	+		+	+			*	*	*					*					*	*	*		
Isopod		+				*							*	*	*					*					*	*	*		
Lamellibranchs						*		+	+	+	+		*	*	*					*				+	*	*	*		
Polychaetes	+	+			+	*	+		+	+			*	*	*					*		+			*	*	*		

Note: The sign (+) means that the epiphytic species is present; The sign (*) means that the algal host was not found during this season; w = winter; s = summer; a = autumn and p = spring

Standing Crop

The total count of the epiphytic zooplankton displayed wide variations among host species during each season. The four host species *U. fasciata*, *G. doryphora*, *H. musciformis* and *Gelidium sp.* maintained relatively low count of epiphytic

zooplankton during the seasons in which they were recorded. The highest zooplankton count on *U. fasciata* was recorded during autumn (358 organisms/gm fresh weight) (Table 6), where the dominant species were the two tintinnid *Undella dilatata* (18%) and *Acanthostomella elongata* (12%) beside the free living nematodes (25%) (Fig. 6). The

maximum number of zooplankton on *G. doryphora* (131 organisms/gm f.w.) was recorded during winter. The dominant species was the tintinnid *U. hyalina* (21%). Whereas, *Gelidium sp.* appeared only during winter and was dominated by the foraminiferan *Spirillina vivipora* (31%) (Fig. 6). The two corallinates, *C. mediterranea* and *C. officinalis* recorded their peaks during summer attaining a maximum of 2097 and 1497 organisms/gm f.w. respectively. Free living nematodes were dominant on *C. officinalis* (62%) but retrograded

on *C. mediterranea* (30%) and co-dominated with the copepod *Euterpina acutifrons* and its larvae to form the main bulk of epiphytic zooplankton community (Table 6 and Fig. 6). The species *H. musciformis* showed a peak during summer (317 organisms/gm f.w.) due to the dominance of nematodes (55%). The last host species *P. capillacea* recorded the highest peak during winter attaining a maximum of 4158 organisms/gm f.w. due to the prevalence of free living nematodes (93%) (Table 6 and Fig. 6).

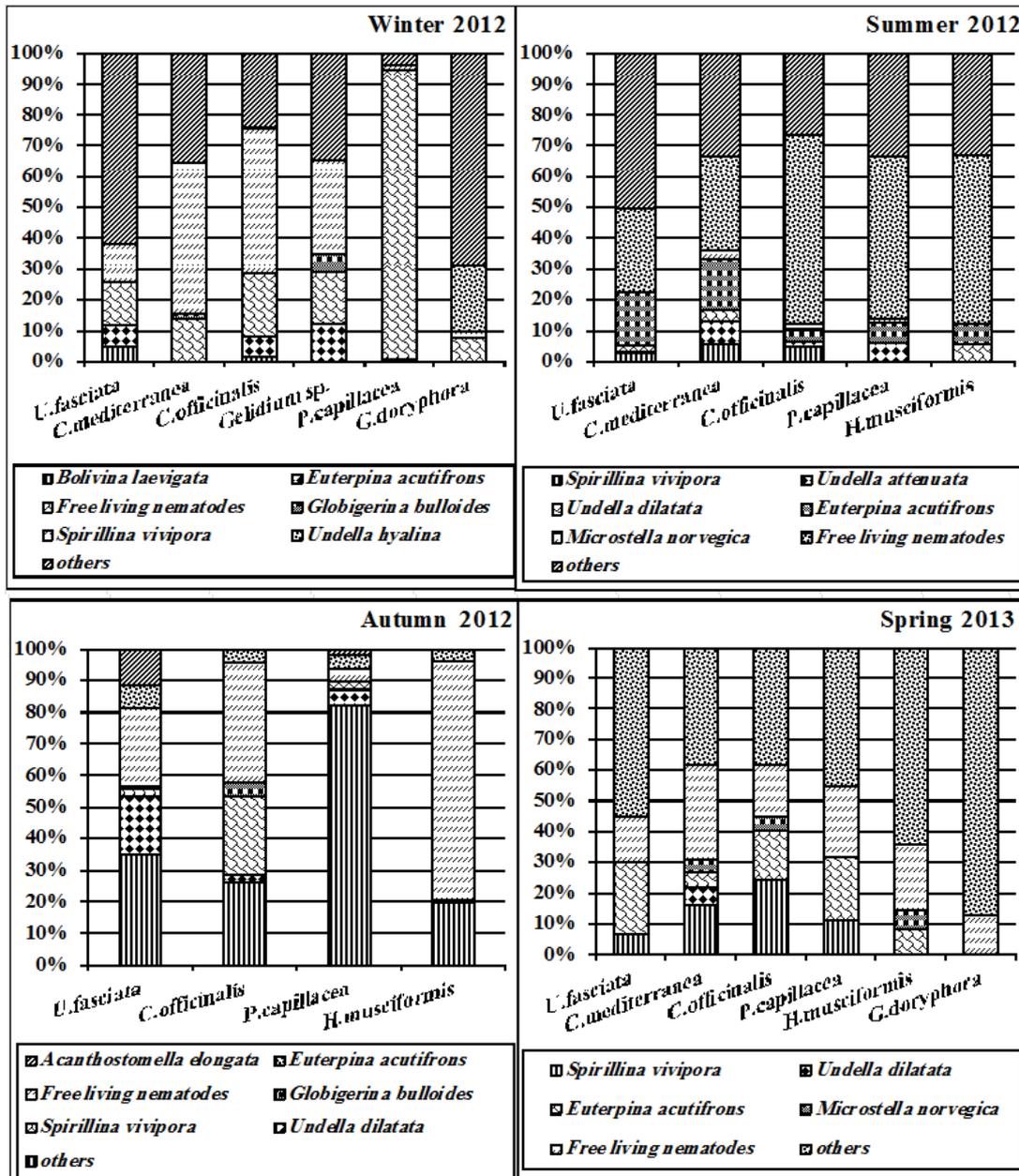


Fig. 6. The distribution of dominant species of epiphytic zooplankton during the study period (2012-2013)

Table 6. The total count (organisms/gm f.w.) of epiphytic zooplankton on the different macroalgal species during (2012-2013)

	Winter (2012)	Summer (2012)	Autumn (2012)	Spring (2013)
Chlorophyceae				
Order: Ulvales				
Family: Ulvaceae				
<i>Ulva fasciata</i>	305±56	139±61	358±45	94±39
Rhodophyceae				
Order: Corallinales				
Family: Corallinaceae				
<i>Corallina mediterranea</i>	691±207	2097±1299	*	1270±153
<i>Corallina officinalis</i>	1044±603	1497±537	1289±461	380±72
Order: Gelidiales				
Family: Gelidiaceae				
<i>Gelidium sp.</i>	310±53	*	*	*
<i>Pterocladia capillacea</i>	4158±1345	375±67	534±74	457±146
Order: Gigartinales				
Family: Hypneaceae				
<i>Hypnea musciformis</i>	*	317±11	309±138	251±82
Order: Halymeniales				
Family: Halymeniaceae				
<i>Grateloupia doryphora</i>	131±51	*	*	23±2

Note: The sign (*) means that the species was not found

Table 7. Two way Analysis of variance (ANOVA) carried out on the morphotypes of the host species and the seasonal variations of epiphytic microalgae groups

Source of Variation	Difference effect	df	MS	F	P-value	F crit
Sample (Morphotypes)	2>1>3 In 2 (A>B>C>D>E)	2	2815306828.0	2.859	0.068	3.204
Sample (Groups)	-	4	804379824.2	0.817	0.521	2.579
Columns (Season)	-	8	745793180.9	0.757	0.641	2.152
Within		45	984692427.7			
Total		59				

Note: The morphotypes no.1 = sheet-like with smooth surface, no. 2 = branched thalli, no. 3 = mucilaginous surface. In the branched group: A = *C. officinalis*, B = *C. mediterranea*, C = *H. musciformis*, D = *P. capillacea*, E = *Gelidium sp.*; n = 12, p>0.05

Table 8. Two way analysis of variance (ANOVA) carried out on the morphotypes of the host species and the seasonal variations of epiphytic zooplankton groups

Source of Variation	Difference effect	df	MS	F	P-value	F crit
Sample (Morphotypes)	2>1>3 In 2 (D>A>B>C>E)	2	45243.500	12.700	0.000	3.080
Sample (Groups)		11	20532.050	5.763	0.000	1.878
Columns (seasons)	w>s>a>p	22	14489.640	4.067	0.000	1.642
Within		108	3562.432			
Total		143				

Note: The morphotypes no.1 = sheet-like with smooth surface, no.2 = branched thalli, no. 3 = mucilaginous surface. In the branched group: A = *C. officinalis*, B = *C. mediterranea*, C = *H. musciformis*, D = *P. capillacea*, E = *Gelidium sp.* W = winter, s = summer, a = autumn, p = spring; n = 12, p>0.05

Statistical Analysis

The abundance of epiphytes were significantly different between morphotypes (two-way ANOVA), $p \leq 0.05$; ranking the branched thalli (*C. mediterranea*, *C. officinalis*, *Gelidium sp.*, *H. musciformis* and *P. capillacea*) as the first preference for microalgal epiphytes, sheet-like thalli with smooth surface (*U. fasciata*) as the second one, while the lowest rank was for the mucilaginous species *G. doryphora*, which was

based on the average of the total count of each group. Among the branched species, the order of preference of epiphytic microalgae was as follows: *C. officinalis* > *C. mediterranea* > *H. musciformis* > *P. capillacea* > *Geldium sp.*, based on their average of total count (Table 7). The same result was found for epiphytic zooplankton except that the order of preference among branched group was as follows: *P. capillacea* > *C. officinalis* > *C. mediterranea* > *H. musciformis* > *Gelidium sp.* (Table 8). On the other hand, no

significant differences were observed for epiphytic microalgal seasonal variations. In contrast, there were significant differences for epiphytic zooplanktonic seasonal variations (Table 8).

Discussion

Epiphytic algae has significant role in energy and nutrient transformation as well as being a bio-indicator of pollution (Davies, 2009). Various factors affect the distribution of epiphyte loads across both seasonal and regional scales. Structural factors of macroalgae affect the space and time signal because of their importance for epiphyte colonization and growth. Physico-chemical factors affecting epiphyte loads include nutrient availability, temperature, salinity, water quality and current and light availability. Epiphyte abundance has been experimentally demonstrated to be the function of nutrient availability (Frankovich and Fourqurean, 1997).

pH measurements in the Eastern Harbor (2012-2013) showed seasonal variation revealing the effect of discharging water to the harbor. Low pH value during summer is attributed to the mineralization of organic matter and release of CO₂ which causes a decrease in pH value. pH showed a highly significant negative correlation with salinity ($r = -0.91$), nitrite ($r = -0.95$) and organic matter ($r = -0.86$). All of these correlations confirm that the seasonal variation in pH is resulted from the microbial activity via organic matter mineralization processes. On the other hand, pH showed a high positive correlation with phosphate ($r = 0.91$) indicating that discharged waste water is another factor controlling water pH in such polluted harbor.

Temperature is an important physical factor influencing the growth of planktonic plants as well as its productivity and its community structure and species abundance. Water temperature during the current study showed seasonal pattern that is exactly similar to predominating in the Egyptian coastal water which is directly affected by the air temperature seasonal pattern and solar radiation. The annual average of sea water temperature is approximately similar to the recorded by (El-Geziry and Maiya, 2006) in the Eastern Harbor that was 22.10°C with amplitude of 14.9°C.

The salinity variations are of particular significance as they reflect changes caused by the mixing of both fresh and sea water. During the investigation period the readings of salinity were typical to that of the Mediterranean Sea during the three seasons, ranging from 38.25‰ during spring 2013 to 39.23‰ during summer 2012 with an annual average 38.61±0.54. According to Said *et al.* (2007) salinity in the upper

layer for the whole Egyptian Mediterranean Sea water ranged from 38.8 to 39.2‰.

Dissolved Oxygen concentration (DO) in natural water is generally changeable and represents a momentum balance between the rate of supply and consumption. In the biologically active coastal zone the net concentration of dissolved oxygen is highly variable depending on this balance. During the study period in Eastern Harbor, dissolved oxygen concentration showed a wide seasonal variation with approximately low annual average 3.92±0.9 mgO₂ l⁻¹. Although dissolved oxygen is supposed to be high in relation to the intensive growth of epiphytic microalgae, surprisingly it recorded content less than <4.5 mgO₂ l⁻¹. The saturation state of the recorded dissolved oxygen in Eastern Harbor ranged from 30 to 58.25%. These recorded contents were less than the range of dissolved oxygen in open sea water (0-5.6 mgO₂ l⁻¹) (Talley *et al.*, 2011) and much less than the recorded by Abdel-Halim and Khairy (2007) (7.58 mgO₂ l⁻¹) in Eastern Harbor. This could be attributed to the increase in the biochemical oxygen demand to break down organic matter brought to the bay by the sewage (Owili, 2003).

According to Satpathy *et al.* (2010), the distribution and behavior of nutrients in the coastal environment exhibit considerable variations due to rainfall, tidal incursion, quantum of fresh water inflow and biological activities. This agrees with the present study where the lowest nutrient recorded was during winter as a result of strong mixing, low residence time, low fresh water discharge and low biological activities during this season. Nitrite plays an intermediate role in several biological processes such as ammonium oxidation, assimilation and excretion of nitrite by phytoplankton and bacteria (Satpathy *et al.*, 2010). The nitrite concentration in the study area indicated that it's not biogenic; they were mainly produced via the biological processes. This was verified by the strongly negative correlation with phosphate ($r = -0.99$), while the positive correlation with nitrate ($r = 0.85$) indicates that there is oxidation of ammonia to nitrite and then nitrate by nitrifying bacteria in addition to releasing from biodegradable organic matter via mineralization.

Phosphorus is a very important factor for the growth and reproduction of both plant and micro organisms. In the E.H. phosphate concentrations were usually below 1 μmol l⁻¹ (Abdel-Halim and Khairy, 2007). Phosphate sustained relatively low concentrations in the present study (0.04-0.26 μmol l⁻¹). The lowest phosphate content 0.04 μmol l⁻¹ was during summer coincided with the highest sum of total epiphytic count (1266219 units/gm f.w.) (Table 3) confirming the phosphorous preferentially uptake in photosynthetic process. The

biological activity during winter was the lowest coupled with the highest phosphate concentration due to low photosynthetic uptake. This is supported by the measurements of the lowest sum of total epiphytic microalgae (106595 units/gm f.w.) (Table 3). The annual average content of phosphate $0.11 \pm 0.1 \mu\text{mol l}^{-1}$ is much lower than that recorded by Abdel-Halim and Khairy (2007) in Eastern Harbor which was $0.51 \mu\text{mol l}^{-1}$. The strongly negative correlations between inorganic phosphate and oxidizable organic matter ($r = -0.98$) revealed the phosphorous replenishment as a result of microbial decomposition of organic matter (Enoksson *et al.*, 1996).

Silicate concentration in the study area showed variations ($3.02\text{-}8.69 \mu\text{mol l}^{-1}$) with an annual average $5.4 \mu\text{mol l}^{-1}$ that is higher than the recorded in the study of Abdel-Halim and Khairy (2007). Inorganic silicate in Eastern harbor during the study period showed a significant correlation with salinity ($r = 0.91$) indicating the anthropogenic source of silicate.

Marine macroalgae are conspicuous and dominant features of temperate intertidal and subtidal ecosystems and have important direct and indirect effects on coexisting species (Schmidt and Scheibling, 2006; Gestoso *et al.*, 2010). Macroalgae are considered ecosystem engineers because they add spatial complexity to the substratum, modulating availability of resources and can affect assemblages of associated epibiota (Schmidt and Scheibling, 2006; Gestoso *et al.*, 2010).

In the present study, the epiphytic microalgae were highly diversified in the study area, indicating the richness of associated epiphytic communities and the important role of the host algae, which offer a highly suitable natural substratum to these organisms (Romagnoli *et al.*, 2007). However, the number of typical freshwater forms was relatively low compared to marine forms and only few of them were dominant and formed the epiphytic peaks. These species were the widespread cyanophyte *Chroococcus sp.* and the chlorophyte *Stigeoclonium sp.* The latter species is usually found as attached tufts or mats on submerged rocks or aquatic plants. It is sometimes abundant in polluted waters, such as the outflow of sewage treatment plants and is tolerant of heavy metals (Person, 1989). However, Palmer (1969) has shown that *Stigeoclonium* and other genera, which are recorded during this study like *Oscillatoria*, *Euglena*, *Scenedesmus*, *Chlamydomonas*, *Navicula*, *Nitzschia* and *Ankistrodesmus* are the species found in organically polluted waters. These results are supported by Jafari and Gunale (2006). In the present study, *Chroococcus sp.* was not influenced by any of the physico-chemical parameters, whereas,

Stigeoclonium sp. was negatively correlated with dissolved oxygen ($r = -0.98$, $p \leq 0.05$).

Although, the cyanophytes and chlorophytes were responsible for epiphytic peaks, the diatoms were the dominant group and prevailed during the study period. Sullivan and Currin (2000) reported that epiphytic diatoms are ubiquitous in shallow water environments and may be the most taxonomically diverse group of organisms in estuarine ecosystems. Vegetated ecosystems are ideal habitats for benthic diatoms and other epiphytes (Frankovich *et al.*, 2006). Algal thalli may represent an order of magnitude greater surface area relative to sediments (Zieman *et al.*, 1989) for the colonization and growth of diatoms. However, the successful behavior of diatoms to attach themselves to the algal host is the main factor to this mutualistic relationship (Romagnoli *et al.*, 2007). This may be attributed to those pennate diatoms attaching themselves to seaweeds by mucilage stalks and sheaths or gelatinous pads such as *Achnanthes*, *Gramatophora*, *Licmophora*, *Tabellaria* and *Synedra* or by the attachment of the cell along its entire valve face such as *Navicula* and *Pleurosigma*. The centric forms like *Biddulphia*, *Cosinodiscus* and *Cyclotella*, were often trapped by the thallus of seaweeds or held in the tangle of attached forms. This is in agreement with many authors (Madkour and El-Shoubaky, 2007; Totti *et al.*, 2009). Noticeably, the other factors that affect the occurrence of diatoms or other groups are the environmental conditions such as light availability, hydrodynamic regime, salinity and nutrients (Frankovich *et al.*, 2006) and biological processes such as grazing (Hillebrand *et al.*, 2000), chemical interactions with the host (Amsler *et al.*, 2005) and physiological responses (Ruesink, 1998), which may explain the succession of other groups on each algal host during the study period. In the present study, the measured physico-chemical parameters were not limiting factors to all the epiphytic groups except Chlorophyceae, which was negatively correlated with D.O. ($r = -0.98$, $p \leq 0.05$).

On the other hand, the total count was relatively lower on *U. fasciata* and *G. doryphora* for epiphytes than the other hosts namely; corallinates, *H. musciformis* and *P. capillacea*; whereas *Gelidium sp.*, is a branched thallus, which was recorded only during winter, harbored relatively higher total count than epiphytes growing on smooth and mucilaginous hosts during the same season. Our results were supported by the significant correlation between total count of epiphytic microalgae and morphotypes of hosts (two-way ANOVA), $p \leq 0.05$, giving the order of preference first to the branched thalli, followed by smooth surface and then the mucilaginous one, with the order of preference among

the branched thalli as follows: *C. officinalis* > *C. mediterranea* > *H. musciformis* > *P. capillacea* > *Geldium sp.*, which may be due to the increase of surface area of the algal host in this direction. These findings agreed with Totti *et al.* (2009), who reported that host algae with a filamentous or branched structure usually present a high degree of structural complexity and might therefore increase their suitability as habitats for epibiotas. In this trend, Madkour and El-Shoubaky (2007) found that there was a relationship between the architecture of seaweeds and the associated epiphytes. Most of the foliose and flattened macroalgal thallus was nearly not preferred as a substrate. By contrast, the fine and sometimes branched thallus hosted many epiphytic diatoms. Whereas, Wuchter *et al.* (2008) reported that smooth and slimy surfaces offer little protection against grazing.

Considering the species composition of epiphytic microalgae, the enumerated species showed different patterns of preference. Some epiphytes showed host specificity giving unique epiphytic flora on few hosts. Other ones did not reflect the previous preference pattern and existed on the majority of the macroalgae indicating the absence of selectivity. Our results agreed with the findings of Madkour and El-Shoubaky (2007). In fact, there is no rule for the selectivity of epiphytes and there is a great debate about the reason of the preference of one species to a definite host. Many authors reported different results. For instance, Patrick *et al.* (1968) found variation in species composition as a function of substrate indicating the presence of selectivity between epiphytic algal species and the respect substrate, whereas Fontaine and Nigh (1983) and Sullivan (1984) found similarities in epiphytic communities, demonstrating non selectivity between epiphytes and the hosts. Ismael (2012) found that in general Oscillatoriales preferred green algae to red algae and on the species level they showed selectivity for each host of green algae. In this trend, El-Zayat (2012), found that the abundance of *Oscillatoria spp.* was most important on green algae than red algae. He concluded that no macroalgae appeared to be overall “best” or “worst” host, indicating that host specificity does not depend on the morphology of the algae but may involve specific requirements between epiphytic and host either by site or by host.

Regarding the harmful algae, all the recorded species in the present study were previously recorded as epiphytes in the Eastern Harbor (El-Zayat, 2012; Ismael, 2012) and/or as planctonic species (Ismael and Halim, 2000; Ismael *et al.*, 2005; Ismael, 2014). Noticeably, many species of them were included in the list of Harmful Algae in North Africa (HANA) endorsed by the Intergovernmental Oceanographic Commission of

UNESCO like *Dinophysis caudata*, *Prorocentrum micans*, *Prorocentrum triestinum*, *Pseudo-nitzschia pungens* and *Pseudo-nitzschia spp.* In addition to *Oscillatoria spp.* and *Planktothrix spp.* which were newly separated as two genera according to Anagnostidis and Komárek (1988). The other species were recently included in the list of harmful algae over the world *Phormidium tenue* (Mohamed *et al.*, 2006), *Odontella aurata*, *Proboscia alata*, *Thalassionema nitzschoides*, *Neoceratium furca*, *Neoceratium fusus* (Özman-Say and Balkis, 2012) and finally, *Thalassiosira aestivalis* (Yao *et al.*, 2006). Although, they all contributed by a very low count to the main bulk, except *Oscillatoria limosa*, *Oscillatoria tenuis* and *Planktothrix aghardhii*, their occurrence as epiphytic or even planctonic forms threatened the Eastern Harbor and may have a drastic effects on biota. These species are potentially harmful and can flourish at suitable environmental conditions and secrete their toxins that can cause fish mortality (Ismael, 2012). In the present study, correlation coefficient was conducted between the three frequent harmful species (*Oscillatoria limosa*, *Oscillatoria tenuis* and *Planktothrix aghardhii*) and the physico-chemical parameters to determine the limiting factors for their flourishing in the Harbor. *Oscillatoria limosa* and *Planktothrix aghardhii* was only correlated with oxygen ($r = -0.98$, $p \leq 0.05$), *Oscillatoria tenuis* was positively correlated with temperature and nitrate ($r = 0.99$, 0.96) at $p \leq 0.05$, respectively.

However, the results of statistics of the present study revealed insignificant seasonal variations in the epiphytic abundance and very weak correlations between the epiphytic microalgae and the measured physico-chemical parameters on the groups and species level. Moreover, almost insignificant correlation resulted between the total epiphytic count on each algal host and these parameters, suggesting that there are other factors, which can be the limiting ones rather than water quality such as irradiance, desiccation, wave exposure and water motion and substratum (Molina-Montenegro *et al.*, 2005). In this trend Michelutti *et al.* (2003) found that the impact of substrate type on species assemblages is more effective than water chemistry.

Marine macroalgae harbor abundant and diverse assemblages of epiphytic zooplankton. Patterns of distribution and abundance of epiphytic zooplankton, which are often variable in space and time, differ markedly among macroalgae species (Viejo, 1999). Epiphytic zooplankton densities were relatively low on *U. fascicata*; the smoothly surface host and *G. doryphora*; the slimy surface one compared to the branched thallus hosts whose harbored higher densities. Our results was

supported by the significant correlation between total count of epiphytic microalgae and morphotypes of the hosts (two-way ANOVA), $p \leq 0.05$, giving the order of preference first to the branched thalli, followed by smooth surface and then the mucilaginous one, with the order of preference among the branched thalli as follows: *P. capillacea* > *C. officinalis* > *C. mediterranea* > *H. musciformis* > *Gelidium sp.* A possible explanation for the increase in epiphytic zooplankton densities may be that the leaf surface area becomes progressively more attractive for epiphytic zooplankton.

In general, the composition of epiphytic zooplankton assemblages differed between habitats in terms of abundance rather than composition of species. None of the epiphytic zooplankton was exclusively found in the different habitats, apart from the nematodes, which was associated with all hosts and numerically dominated in most of them with different percentages. Moreover, some species showed specificity to few hosts. Although the epiphytic zooplankton assemblages differed between habitats, there were no clear host-plant specialists. However, the differences in the distribution of abundances of epiphytic zooplankton between the habitats suggest the presence of some mechanisms of host selection. This assumption has to be made with caution; however, further experimental work would be necessary to test hypotheses related to preferences, specificity and choice of habitats (Olabarria *et al.*, 2002). Several studies have reported that low specificity of epifauna to the host plant is quite common in marine systems dominated by macroalgae, presumably because few marine epifaunal organisms live and feed directly on host tissues (Arrontes, 1999; Wikstrom and Kautsky, 2004; Prado and Thibaut, 2008). In contrast, some studies have reported strong host specificity, likely determined by specific chemical, structural and morphological characteristics of the algal species (Hay *et al.*, 1987; Edgar and Klumpp, 2003; Schmidt and Scheibling, 2006).

Complexity has been reported as an important factor influencing the composition and structure of epifaunal assemblages associated with different macroalgae (Viejo, 1999; Buschbaum *et al.*, 2006). In fact, one mechanism by which macroalgae might influence their associated epifaunal assemblages is through the provision of complex habitats (Taylor and Cole, 1994; Buschbaum *et al.*, 2006). Species diversity has been correlated with habitat complexity in a variety of systems and increased epiphytic zooplankton densities have often been related to the presence of seaweeds in many marine seagrass meadows (Orth 1992; Parker *et al.*, 2001). In our study, diversity did not vary between the habitats,

except the branched thallus, *C. officinalis* which harbored high diversity during most seasons.

Numerical fluctuations of zooplankton did not always coincide with the same for microalgae (Rickett and Watson, 1992). However, occasionally hosts of the maximum epiphytic zooplankton abundance didn't coincide with those of the highest epiphytic microalgae concentration, as occurred during winter, 2012 on *P. capillacea*; this contrast might be due to zooplankton predation. In particular, the epiphytic zooplankton consists mainly of nematodes. At the same time, a good coupling occurred between epiphytic microalgae and zooplankton suggested by higher abundances of occurring during summer, 2012 ($r = 0.95$) and the lowest of both in spring, 2013 ($r = 0.39$) at $p \leq 0.05$ and $n = 4$. This coupling occurs also at hosts scale during autumn, 2012 ($r = 0.90$, $p \leq 0.05$ and $n = 4$) with the highest epiphytic microalgae and zooplankton occurring on *C. officinalis* and the lowest on *Gelidium sp.* during winter, 2012. Perhaps some of the zooplankton were feeding on larger suspended particulars or small nauplii or were preying on each other for some time.

The statistical relationships between the abundance of epiphytic zooplankton on each algal host and the physicochemical environment variables were analyzed. The environmental variables that best correlated with the zooplankton count were water salinity, followed by nutrients. Specifically, copepods responded positively to temperature, while protozoa and nematodes responded positively to salinity. Some species were spatially controlled by these variables. For instance, *Spirillina vivipora* responded negatively to temperature and positively to salinity ($r = -0.92$, $p < 0.05$ and $r = 0.96$, $p < 0.05$, respectively).

Conclusion

Marine macroalgae harbor abundant and diverse assemblages of epiphytic microalgae. The morphotypes of algal hosts were more effective for the abundance of microalgae epiphytes rather than water quality in the study area. Whereas, the epiphytic zooplankton were less diversified than microalgae and were affected by both, the morphotypes of the algal hosts and the water quality. On the other hand, the hosts harbored some harmful algae. Although most of them are relatively low in count, the Harbor should continuously be put under control to predict any bloom of these harmful species or other ones that may appear in the Harbor.

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Author's Contributions

All authors equally contributed in this work.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

References

- Abdallah, M.A.M., 2007. The distribution and accumulation of heavy metals in sediments of semi-enclosed basin southeastern Mediterranean sea, Egypt. *Mediterranean Marine Sci.*, 8: 31-40.
- Abdel-Halim, A.M. and H.M. Khairy, 2007. Potential impact of some abiotic parameters on a phytoplankton community in a confined bay of the Eastern Mediterranean Sea: Eastern Harbour of Alexandria, Egypt, *Medit. Marina Sci.*, 8: 49-64. DOI: 10.12681/mms.153
- Aleem, A.A., 1993. The Marine Algae of Alexandria, Egypt. 1st Edn., Alexandria, ISBN-10: 9770052817, pp: 138.
- Amsler, C.D., I.N. Okogbue, D.M. Landry, M.O. Amsler and J.B. McClintock *et al.*, 2005. Potential chemical defenses against diatom fouling in Antarctic macroalgae. *Bot. Marina* 48: 318-322. DOI: 10.1515/BOT.2005.041
- Anagnostidis, K. and J. Komárek, 1988. Modern approach to the classification system of cyanophytes. 3-Oscillatoriales. *Arch. Hydrobiol.*, 80: 327-472.
- Arrontes, J., 1999. On the evolution of interactions between marine mesoherbivores and algae. *Bot. Marina*, 42: 137-155. DOI: 10.1515/BOT.1999.017
- Braune, W., 2008. Meeresalgen: Ein Farbbildführer zu den verbreiteten benthischen Grün-, Braun- und Rotalgen der Weltmeere. 1st Edn., Gantner, A R, Germany, ISBN-10: 3906166694596, pp: 596.
- Buschbaum, C., A.S. Chapman and B. Saier, 2006. How an introduced seaweed can affect epibiota diversity in different coastal systems. *Marine Biol.*, 148: 743-754. DOI: 10.1007/S00227-005-0128-9
- Buschmann, A. and P. Gómez, 1993. Interaction mechanisms between *Gracilaria chilensis* (Rhodophyta) and epiphytes. *Hydrobiologia*, 260-261: 345-351. DOI: 10.1007/BF00049039
- Carlberg, S.R., 1972. *New Baltic Manual: With New Methods for Sampling and Analyses of Physical, Chemical and Biological Parameters.* 1st Edn., International Council for the Exploration of the Sea, Charlottenlund, pp: 145.
- Casteleyn, G., V.A. Chepurinov, F. Leliaert, D.G. Mann and S.S. Bates *et al.*, 2008. *Pseudo-nitzschia pungens* (Bacillariophyceae): A cosmopolitan diatom species? *Harmful Algae*, 7: 241-257. DOI: 10.1016/j.hal.2007.08.004
- Cupp, E.E., 1943. Marine plankton diatoms of the west coast of North America. *Bull. Scripps Inst. Oceanogr.*, 5: 1-238.
- Danilov, R.A. and N.G.A. Ekelund, 2000. The use of epiphyton and epilithon data as a base for calculating ecological indices in monitoring of eutrophication in lakes in central Sweden. *Sci. Environ.*, 248: 63-70. DOI: 10.1016/S0048-9697(00)00363-6
- David, C.P.C., Y.Y. Sta. Maria, F.P. Siringan, J.M. Reotita and P.B. Zamora *et al.*, 2009. Coastal pollution due to increasing nutrient flux in aquaculture sites. *J. Environ. Geol.*, 58: 447-454. DOI: 10.1007/s00254-008-1516-5
- Davies, O.A., 2009. Epiphytic diatoms growing on *Nypa Fructican* of Okpoka Creek, Niger Delta, Nigeria and their relationship to water quality. *Res. J. Applied Sci., Eng. Technol.*, 1: 1-9.
- Dickson, A.G., C.L. Sabine and J.R., Christian, 2007. *Guide to Best Practices for Ocean CO₂ Measurements.* 1st Edn., North Pacific Marine Science Organization, Sidney, ISBN-10: 1897176074.
- Dodge, J.D. and B. Hart-Jones, 1982. *Marine Dinoflagellates of the British Isles.* 1st Edn., Her Majesty's Stationary Office, London, pp: 303.
- Edgar, G.J. and D.W. Klumpp, 2003. Consistencies over regional scales in assemblages of mobile epifauna associated with natural and artificial plants of different shape. *Aquatic Bot.*, 75: 275-291. DOI: 10.1016/S0304-3770(02)00194-8
- EEAA., 2008. Alexandria Integrated Coastal Zone Management. Sub-program (AICZM) of the Egyptian Pollution Abatement Project (EPAP II) global environmental facility fund, Egyptian environmental affairs agency, Egypt (ID #2602). Strategic Environmental Assessment, Technical Report.
- El-Geziry, T.M. and I.A. Maiya, 2006. The hydrographic structure of Alexandria Eastern Harbour. *Egypt. J. Aquatic Res.*, 32: 60-73.
- El-Zayat, F., 2012. Macroalgae and associated harmful microalgae in different habitats along Alexandria Coast. MSc Thesis, Alexandria University.

- Enoksson, V., E. Fogelqvist and S. Fonselius, 1996. Nitrogen Speciation and nitrification potential in the Skagerrak area during the SKAGEX IV experiment. *Deep Sea Res.*, 43: 1029-1044.
DOI: 10.1016/0967-0637(96)00050-7
- Fehling, J., D.H. Green, K. Davidson, C.J. Bolch and S.S. Bates, 2004. Domoic acid production by *Pseudo-Nitzschia seriata* (bacillariophyceae) in scottish waters. *J. Phycol.*, 40: 622-630.
DOI: 10.1111/j.1529-8817.2004.03200.x
- Fontaine, T.D. and D.G. Nigh, 1983. Characteristics of epiphytic communities on natural and artificial submerged lotic plants: Substrate effects. *Arch. Hydrobiol.*, 96: 293-301.
- Frankovich, T.A. and J.W. Fourqurean, 1997. Seagrass epiphyte loads along a nutrient availability gradient, Florida Bay, USA. *Marine Ecol. Progress Series*, 159: 37-50. DOI: 10.3354/meps159037
- Frankovich, T.A., E.E. Gaiser, J.C. Ziemann and A.H. Wachnicka, 2006. Spatial and temporal distributions of epiphytic diatoms growing on *Thalassia testudinum* Banks ex König: Relationships to water quality. *Hydrobiologia*, 569: 259-271.
DOI: 10.1007/s10750-006-0136-x
- Gavio, B. and S. Fredericq, 2002. *Grateloupia turuturu* (Halymeniaceae, Rhodophyta) is the correct name of the non-native species in the Atlantic known as *Grateloupia doryphora*. *Eur. J. Phycol.*, 37: 349-359.
DOI: 10.1017/S0967026202003839
- Gestoso, I., C. Olabarria and J.S. Troncoso, 2010. Variability of epifaunal assemblages associated with native and invasive macroalgae. *Marine Freshwater Res.*, 61: 724-731.
DOI: 10.1071/MF09251
- Grasshof, G., 1975. The hydrochemistry of land locked basins. *Fjords. Chem. Oceanography*, 2: 568-574.
- Hay, M.E., J.E. Duffy, C.A. Pfister and W. Fenical, 1987. Chemical defense against different marine herbivores: Are amphipods insect equivalents? *Ecology*, 68: 1567-1580. DOI: 10.2307/1939849
- Hegazy, W.H., 2013. Taxonomic study of some potentially harmful *Oscillatoria* species in Alexandria coastal water. M.Sc. Thesis, Faculty of Science, Botany Dept., Tanta University.
- Hendey, N.I., 1964. An Introductory Account of the smaller Algae of British Coastal waters. *Fishery Investigations, Series IV, Part V: Bacillariophyceae*. Her Majesty's Stationery office, London.
- Heurk, V.H., 1962. A Treatise on the Diataneaceae. 1st Edn., Wheldon and Wesley, LTd., Verlag. G. Gramer, Berlin, pp: 558.
- Hillebrand, H., B. Worm and H.K. Lotze, 2000. Marine microbenthic community structure regulated by nitrogen loading and grazing pressure. *Marine Ecol. Progress Series*, 204: 27-38.
DOI: 10.3354/meps204027
- Ismael, A.A. and Y. Halim, 2000. Harmful Algal Blooms, 2000. In: Intergovernmental Oceanographic Commission of UNESCO, 2001. Hallegraeff, G.M., S.I. Blackburn, C.J. Bloch and R.J. Lewis (Eds).
- Ismael, A.A., E.I. Hemeda, K. Jammo and O.A. El-Rayis, 2005. Phytoplankton and environmental parameters in the Eastern Harbor of Alexandria. *Egypt. J. Aquat. Biol. Fish.*, 9: 87-110.
- Ismael, A.A., 2012. Benthic bloom of cyanobacteria associated with fish mortality in Alexandria waters. *Egypt. J. Aquatic Res.*, 38: 241-247.
DOI: 10.1016/j.ejar.2013.01.001
- Ismael, A.A., 2014. Coastal engineering and harmful algal blooms along Alexandria coast, Egypt. *Egypt. J. Aquatic Res.*, 40: 125-131.
DOI: 10.1016/j.ejar.2014.07.005
- Jacobs, R.P.W.M. and T.M.P.A. Noten, 1980. The annual pattern of the diatoms in the epiphyton of eelgrass (*Zostera marina* L.) at Roscoff, France. *Aquat. Aquatic Bot.*, 8: 355-370.
DOI: 10.1016/0304-3770(80)90065-0
- Jafari, N.G. and V.R. Gunale, 2006. Hydrobiological study of algae of an urban freshwater river. *J. Applied Sci. Environ. Mgt.*, 10: 153-158.
- Jorgensen, E., 1924. Mediterranean Tintinnidae. *Red. Dal. Oceanogr. Exped. Medierr.*, 2: 1-110.
- Kersen, P., J. Kotta, M. Bucas, N. Kolesova and Z. Dekere, 2011. Epiphytes and associated fauna on the brown alga *Fucus vesiculosus* in the Baltic and the North Seas in relation to different abiotic and biotic variables. *Marine Ecology*, 32: 87-95.
DOI: 10.1111/j.1439-0485.2010.00418.x
- Kraberg, A.C. and T.A. Norton, 2007. Effect of epiphytism on reproductive and vegetative lateral formation in the brown, intertidal seaweed *Ascophyllum nodosum* (Phaeophyceae). *J. Phycol. Res.*, 55: 17-24.
DOI: 10.1111/j.1440-1835.2006.00441.x
- Lepoint, G., F. Nyssen, S. Gobert, P. Dauby and J.M. Bouqueneau, 1999. Relative impact of a seagrass bed and its adjacent epilithic algal community in consumer diets. *Marine Biol.*, 136: 513-518.
DOI: 10.1007/s002270050711
- Lobban, C.S. and P.J. Harrison, 1994. *Seaweed Ecology and Physiology*. 1st Edn., Cambridge University Press, New York, ISBN-10: 0521408970, pp: 366.

- Lü, L. and X. YongJian, 2009. Effects of nitrogen nutrients on growth and epiphytic bacterial composition in sea world *Gracilaria lemaneiformis*. Fisheries Sci. (Dalian), 3: 130-135.
- Mabrouk, L., A. Hamza, M.B. Brahim and M.N. Bradai, 2011. Temporal and depth distribution of microepiphytes on *Posidonia oceanica* (L.) Delile leaves in a meadow off Tunisia. Marine Ecol., 32: 148-161. DOI: 10.1111/j.1439-0485.2011.00432.x
- Madkour, F.F. and G.A. El-Shoubaky, 2007. Spatial and temporal distribution of epiphytic diatoms on macroalgae inhabiting port said coast, Mediterranean Sea, Egypt. New Egyptian J. Microbiol., 17: 285-296.
DOI: 10.4314/nejmi.v17i1.40332
- Michelutti, N., A.J. Holtham, M.S.V. Douglas and J.P. Smol, 2003. Periphytic diatom assemblages from ultra- oligotrophic and UV transparent lakes and ponds on Victoria Island and comparisons with other diatom surveys in the Canadian Arctic. J. Phycol., 39: 465-480.
DOI: 10.1046/j.1529-8817.2003.02153.x
- Mizuno, T., 1990. Illustrations of the Freshwater Plankton of Japan. 9th Edn., Hokush Publishing Co., LT., Japan, pp: 353.
- Mohamed, Z.A., H.M. El-Sharouny and W.S.M. Ali, 2006. Microcystin production in benthic mats of cyanobacteria in the Nile River and irrigation canals, Egypt. Toxicon, 47: 584-590.
DOI: 10.1016/j.toxicon.2006.01.029
- Molina-Montenegro, M.A., A.A. Munoz, E.I. Badano, B.W. Morales and K.M. Fuentes *et al.*, 2005. Positive associations between macroalgal species in a rocky intertidal zone and their effects on the physiological performance of *Ulva lactuca*. Marine Ecol. Progress Series, 292: 173-180.
- Moncreiff, C.A., M.J. Sullivan and A.E. Daehnick, 1992. Primary production dynamics in seagrass beds of Mississippi sound: The contributions of seagrass, epiphytic algae, sand microflora and phytoplankton. Marine Ecol. Progress Series, 87: 161-171.
- Muñoz, J. and R. Fotedar, 2009. Epiphytism of *Gracilaria cliftonii* (Withell, Millar and Kraft) from Western Australia. J. Applied Phycol., 22: 371-379.
DOI: 10.1007/s10811-009-9469-y
- Navarro, N.J., 1987. Diatomeas epifitas de Puerto Rico. I. *Grammatophora oceanica* Ehr. Var. *oceanica*. Science-Ciencia, 14: 13-18.
- Newcombe, G., 2009. International Guidance Manual for the Management of Toxic Cyanobacteria. 1st Edn., Global Water Research Coalition, London, ISBN-10: 9077622217, pp: 93.
- Nogueira, I. and V. Vasconcelos, 2001. Toxicity of two filamentous cyanobacteria species-*Planktothrix planctonica* and *Planktothrix perornata*. Proceedings of the 5th International Conference of Toxic Cyanobacteria, (CTC'01), Noosa, Queensland, Australia.
- Olabarria, C., A. Underwood and M. Chapman, 2002. Appropriate experimental design to evaluate preferences for microhabitat: An example of preferences by species of microgastropods. Oecologia, 132: 159-166.
DOI: 10.1007/S00442-002-0940-6
- Orth, R.J., 1992. A perspective on Plant-Animal Interactions in Seagrasses: Physical and Biological Determinants Influencing Plant and Animal Abundance. In: Plant-Animal Interactions in the Marine Benthos, John, D.M., S.J. Hawkins and J.H. Price (Eds.), Clarendon Press, Oxford, ISBN-10: 0198577540, pp: 147-164.
- Owili, M.A., 2003. Assesment of impact of sewage effluents on coastal water quality in Hafnarfjordur, Iceland. Kenya Marine and Fisheries Research Institute, The United Nation University.
- Özman-Say, A.N. and N. Balkis, 2012. Phytoplankton assemblages in the coastal zone of the Gulf of Iskenderun-North Eastern Mediterranean. Pak. J. Bot., 44: 1785-1798.
- Palmer, C.M., 1969. A composite rating of algae tolerating organic pollution. J. Phycol., 5: 78-82.
DOI: 10.1111/j.1529-8817.1969.tb02581.x
- Parker, J.D., J.E. Duffy and R.J. Orth, 2001. Plant species diversity and composition: Experimental effects on marine epifaunal assemblages. Marine Ecol. Progress Series, 224: 55-67.
DOI: 10.3354/MEPS224055
- Patrick, R., J. Cairns and A. Scheier, 1968. The relative sensitivity of diatoms, snails and fish to twenty common constituents of industrial wastes. Progressive Fish-Culturist, 30: 137-140.
DOI: 10.1577/1548-8640(1968)30[137:TRSODS]2.0.CO;2
- Pearson, G.A. and L.V. Evans, 1990. Settlement and survival of *Polysiphonia lanosa* (Ceramiales) spores on *Ascophyllum nodosum* and *Fucus vesiculosus* (Fucales). J. Phycol., 26: 597-603.
DOI: 10.1111/j.0022-3646.1990.00597.x
- Peragallo, M. and M.M.H. Peragallo, 1897-1908. Diatomeés Marines de France et des Districts Maritimes Voisions. pp: 236.
- Person, J.L., 1989. Environmental Science Investigations. 1st Edn., J.M. Le Bel Enterprises, Ltd., Ronkonkoma, NY., pp: 131.

- Prado, P. and T. Thibaut, 2008. Differences between epiphytic assemblages on introduced *Caulerpa taxifolia* and coexisting eelgrass (*Zostera capricorni*) in Botany Bay (NSW, Australia). *Sci. Marina*, 72: 645-654. DOI: 10.3989/SCIMAR.2008.72N4645
- Rickett, J.D. and R.L. Watson, 1992. Phytoplankton community structure in Dardanelle Reservoir, 1981-1990, an update. *Proc. Arkansas Acad. Sci.*, 46: 53-56.
- Rindi, F. and M.D. Guiry, 2004. Composition and spatio-temporal variability of the epiphytic macroalgal assemblage of *Fucus vesiculosus* Linnaeus at Clare Island, Mayo, western Ireland. *J. Experimental Marine Biol. Ecol.*, 311: 233-252. DOI: 10.1016/j.jembe.2004.05.009
- Romagnoli, T., G. Bavestrello, E. Cucchiari, M. De Stefano and C. Di Camillo *et al.*, 2007. Microalgal communities epibiotic on the marine hydroid *Eudendrium racemosum* in the Ligurian Sea during an annual cycle. *Marine Biol.*, 151: 537-552. DOI: 10.1007/s00227-006-0487-x
- Rose, M., 1933. Copépodes Pélagiques. Faune de France 26. Edit. P. Lechevalier, Paris, pp: 374.
- Ruesink, J.L., 1998. Diatom epiphytes on *Odonthalia floccosa*: The importance of extent and timing. *J. Phycol.*, 34: 29-38. DOI: 10.1046/j.1529-8817.1998.340029.x
- Said, M.A., I.A. Maiyza, M.A. Hussain and A.A. Radwan, 2007. Characteristics of the Egyptian Mediterranean water masses during the cold and warm winters. *Acta Adriatica*, 48: 145-159.
- Satpathy, K.K., A.K. Mohanty, M.V.R. Prasad, U. Natesan and S.K. Sarkar, 2010. Seasonal variation in physicochemical properties of coastal waters of Kalpakkam, east coast of India with special emphasis on nutrients. *Environ. Monit. Assessment*, 164: 153-171. DOI: 10.1007/s10661-009-0882-0
- Schmidt, A.L. and R.E. Scheibling, 2006. A comparison of epifauna and epiphytes on native kelps (*Laminaria* species) and invasive alga (*Codium fragile* ssp. *tomentosoides*) in Nova Scotia, Canada. *Bot. Marina*, 49: 315-330. DOI: 10.1515/BOT.2006.039
- Shams El-Din, N.G., A.M. Amer and M.A. Abdallah, 2007. Study of natural components in some marine macroalgae in relation to nutrients along Alexandrial Coast, Egypt. *Egyptian J. Aquatic Res.*, 33: 87-112.
- Sivonen, K., W.W. Carmichael, A.M. Dahlem, K.L. Rinehart and J. Kiviranta *et al.*, 1989. Occurrence of the hepatotoxic microcystin homologues from the filamentous freshwater cyanobacterium *Nodularia spumigena* in the Baltic Sea and structure of the toxin. *Applied Environ. Microbiol.*, 55: 1990-1995.
- Sournia, A., 1968. Diatomées planctoniques du canal de Mozambique et de l'île Maurice. 1st Edn., Office de la recherche scientifique et technique outre-mer, Paris, pp: 120.
- Sournia, A., 1986. Atlas du Phytoplancton Marin: Introduction, Cyanophycées, Dictyochophycées, Dinophycées et Raphidophycées. 1st Edn., Editions du Centre national de la recherche scientifique, Paris, ISBN-10: 2222038235, pp: 219.
- Stachowicz, J.J. and R.B. Whitlatch, 2005. Multiple mutualists provide complementary benefits to their seaweed host. *Ecology*, 86: 2418-2427. DOI: 10.1890/04-0819
- Steffensen, D., A. Humpage, B. Nicholson, P. Baker and P. Christy *et al.*, 2001. Toxicity of the benthic Cyanobacterium *Phormidium* in South Australia. Proceedings of the 5th International Conference of Toxic Cyanobacteria, (CTC'01), Noosa, Queensland, Australia.
- Strickland, J.D.H. and T.R. Parsons, 1972. A Practical Handbook of Seawater Analysis. 2nd Edn., Fisheries Research Board of Canada, Ottawa, pp: 310.
- Sullivan, M.J., 1984. Community Structure of Epiphytic Diatoms from the Gulf Coast of Florida, USA. In: Proceedings of the Seventh International Diatom Symposium, Mann, D.G. (Ed.), Otto Koeltz-Science Publishers, Philadelphia, pp: 373-384.
- Sullivan, M.J. and C.A. Currin, 2000. Community Structure and Functional Dynamics of Benthic Microalgae in Salt Marshes. In: Concepts and Controversies in Tidal Marsh Ecology, Weinstein, M.P. and D.A. Kreeger (Eds.), Kluwer Academic Publishers, Dordrecht, ISBN-10: 978-0-306-47534-4, pp: 81-106.
- Talley, L.D., G.L. Pickard W.J. Emery and J.H. Swift, 2011. Descriptive Physical Oceanography: An Introduction. 6th Edn., Academic Press, Burlington, ISBN-10: 0080939112, pp: 560.
- Tanaka, N., K. Ohwada, M. Sugiyama, A. Asakawa and T. Iikura *et al.*, 1984. Seasonal occurrences of epiphytic micro-algae on the natural seaweeds and artificial seagrasses in Ago Bay. *Bull. Japanese Society Sci. Fisheries*, 50: 1665-1669. DOI: 10.2331/suisan.50.1665
- Taylor, R. and R.G. Cole, 1994. Mobile epifauna on subtidal brown seaweeds in northeastern New Zealand. *Marine Ecol. Progress Series*, 115: 271-282. DOI: 10.3354/MEPS115271
- Tilstone, G.H., R.L. Airs, M. Vicente, C. Widdicombe and C. Llewellyn, 2010. High concentrations of mycosporine-like amino acids and colored dissolved organic matter in the sea surface microlayer off the Iberian Peninsula. *Limnol. Oceanography*, 55: 1835-1850. DOI: 10.4319/lo.2010.55.5.1835

- Tomasko, D.A. and B.E. Lapointe, 1991. Productivity and biomass of *Thalassia testudinum* as related to water column nutrient availability and epiphyte levels: Field observations and experimental studies. *Marine Ecol. Progress Series*, 75: 9-17.
- Totti, C., M. Poulin, T. Romagnoli, C. Perrone and C. Pennesi *et al.*, 2009. Epiphytic diatom communities on intertidal seaweeds from Iceland. *Polar Biol.*, 32: 1681-1691. DOI: 10.1007/s00300-009-0668-4
- Tregouboff, G. and M. Rose, 1957. *Manuel de Planctologie Méditerranéenne*. 1st Edn., Centre National de la Recherche Scientifique, Paris, ISBN-10: 2222002931, pp: 587.
- Viejo, R.M., 1999. Mobile epifauna inhabiting the invasive *Sargassum muticum* and two local seaweeds in northern Spain. *Aquatic Bot.*, 64: 131-149. DOI: 10.1016/S0304-3770(99)00011-X
- Wahl, M. and O. Mark, 1999. The predominantly facultative nature of epibiosis: Experimental and observational evidence. *Marine Ecol. Progress Series*, 187: 59-66. DOI: 10.3354/meps187059
- Wear, D.J., M.J. Sullivan, A.D. Moore and D.F. Millie, 1999. Effects of water-column enrichment on the production dynamics of three seagrass species and their epiphytic algae. *Marine Ecol. Progress Series*, 179: 201-213. DOI: 10.3354/meps179201
- Wikstrom, S.A. and L. Kautsky, 2004. Invasion of a habitat-forming seaweed: Effects on associated biota. *Biol. Invasion*, 6: 141-150. DOI: 10.1023/B:BINV.0000022132.00398.14
- Wuchter, C., J. Marquardt and W.E. Krumbein, 2008. The epizoic diatom community on our bryozoan species from Helgoland (German Bight, North Sea). *Helgol. Marine Res.*, 57: 13-19.
- Yao, P., Z. Yu and C. Deng, 2006. Pigment signatures of some diatoms isolated from China seas. *Acta Oceanol. Sinica*, 25: 108-118.
- Zieman, J., J.W. Fourqurean and R.L. Iverson, 1989. Distribution, abundance and productivity of seagrasses and macroalgae in Florida Bay. *Bull. Marine Sci.*, 44: 292-311.