

# Temporal and Bathymetric Variation of Epiphytic Microalgae on *Posidonia oceanica* (L.) Delile Leaves in Gökçeada (North Aegean, Turkey)

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## Abstract

Epiphytic microalgae attached to *Posidonia oceanica* leaves play a significant role through primary production, nutrient cycling and trophic fluxes in benthic ecosystems. Due to their sensitivity, epiphytic microalgae respond to environmental alterations more quickly than their host. The aim of this study is therefore to evaluate the ecological quality in Gökçeada Underwater Park (North Aegean) using epiphytic microalgal composition and abundance. In this respect, *P. oceanica* shoots are collected at 6 m, 15 m and 28 m in May, July, October 2009 and January 2010 to estimate the microalgal composition and abundance. Also, *P. oceanica* descriptors and physico-chemical parameters in the water column of the meadow lower limit are measured. Leaf surface improvement through greater depths, have provided a convenient substratum for epiphytic colonization. A total of 56 taxa belonging to epiphytic microalgae are composed of Bacillariophyceae (91%), Cyanophyceae (7%) and Dinophyceae (2%). Temporal and bathymetric dynamics of the epiphytic community structure and abundance depend on the environmental parameters; such as leaf surface, nutrients and turbidity. Also, a mucilage phenomenon, resulted in a low diversity due to the dominancy of filamentous cyanobacteria. Necessary data is supplied for a less evaluated region affected by agricultural activities and urbanization in the recent years.

## Introduction

Endemic seagrass of the Mediterranean Sea, *Posidonia oceanica* (L.) Delile constitutes a shelter for various epiphytic communities colonizing on the leaf blades and rhizomes (Pasqualini *et al.*, 2006). It is considered as a functional substratum due to its long-life span and wide leaf blades; (Cinelli *et al.*, 1984; Mazzella *et al.*, 1989).

Photosynthetic epiphytes on leaf blades, take part in trophic fluxes in benthic ecosystems as a food source for herbivores and also contribute to the primary production (Mazzella *et al.*, 1992; Beleggrati *et al.*, 1999; Giovannetti *et al.*, 2010). Nevertheless, high epiphytic

coverage on leaf blades is the most important negative factor declining the photosynthesis rate of the host plant (Round, 1984; Cebrian *et al.*, 1999). Since photosynthetic epiphytes can not have the ability to obtain nutrients directly from the sediment; they colonize on leaf blades, especially close to the apex where they can utilize the sunlight energy (Trautman & Borowitzka, 1999). Moreover, during the colonization processes, they reach to high abundances constituting mono-specific or multi-layered communities on leaf blades therefore, they play an important role in the functioning of the *P. oceanica* ecosystem (Mazzella *et al.*, 1994; De Stefano *et al.*, 2000).

In the recent years, increasing nutrient levels and organic compounds in the coastal waters, affected *P. oceanica* habitats and also modified the composition of marine flora stimulating the excessive growth of opportunistic species (Ruiz *et al.*, 2001; UNEP/GPA, 2006; Giakoumi *et al.*, 2015). Epiphytic microalgal species respond to environmental abiotic and biotic factors more quickly than their hosts adjusting their composition and abundance (Frankovich & Fourqurean, 1997; Piazzini *et al.*, 2004; Terrados & Pons, 2008; Nesti *et al.*, 2009; Mabrouk *et al.*, 2011). Therefore, photosynthetic epiphytes can be regarded as bio-indicators of environmental alterations (Sand-Jensen & Borum, 1991; Trautman & Borowitzka, 1999; Balata *et al.*, 2008).

Distribution of *P. oceanica* meadows has been the aim of numerous studies (Pergent *et al.*, 1994; Dural & Pergent, 2001; Boyacıoğlu & Dural, 2009; Cirik *et al.*, 2010) in Turkey however, some ecological aspects, such as the relative contribution of microalgae to the epiphytic community has not been investigated. Therefore, this study mainly focused on the evaluation of the ecological quality in Gökçeada Underwater Park (North Aegean) using epiphytic microalgal composition and abundance on *P. oceanica* leaf blades due to their sensitivity to environmental alterations.

## Materials and Methods

### Study Area

Gökçeada (40°10'10.19"N – 25°50'13.93"E) is the largest island of Turkey (289 km<sup>2</sup>); located in the North Aegean Sea (Eastern Mediterranean), it exhibits distinct hydrological features comparing to the Western Mediterranean Sea due to the Turkish Straits Current System and the river inputs (Uçkaç, 2005). Correspondingly the region is the intersection point of the less intense and brackish Black Sea waters coming from Dardanelles Strait and the intense and saline Levantine waters flowing upwards along the eastern coasts of the Aegean Sea (Pazı, 2008; Siokou-Frangou *et al.*, 2009; Sayın & Beşiktepe, 2010). Study site is the Gökçeada Underwater Park situated in the northern coast of the island harboring hard bottom types with photophilic macroalgal communities and seagrass meadows (Figure 1).

### Sampling Design

Field study was performed in May, July, October 2009 and January 2010 by SCUBA diving in a continuous *Posidonia oceanica* seagrass bed (40°14'13.35" N – 25°54'14.05" E). Ecological status of the meadow bed is evaluated by measuring meadow density (shoot m<sup>-2</sup>) and meadow cover (%) in three replicated 60 cm × 60 cm quadrats placed randomly in the upper (6 m), intermediate (15 ± 1 m) and lower limit (28 m) depths of the meadows (Aktan *et al.*, 2011). Moreover, 10 shoots

of *P. oceanica* are collected randomly from each quadrat in order to measure the phenological parameters and the epiphytic microalgal abundance.

In the laboratory, leaves are sorted according to the protocol of Giraud (1979) to measure the phenological parameters: leaf number (leaf shoot<sup>-1</sup>), leaf surface (cm<sup>2</sup> shoot<sup>-1</sup>) and epiphytic microalgal abundance (cells 50 g<sup>-1</sup> fresh weight of *Posidonia*). After the detachment from their sheet, leaves are weighted to 50 g with a precision balance to record their wet mass (Turki, 2005; Aligizaki & Nikolaidis, 2006). Epiphytic cover is removed from the leaves by scraping gently with a scalpel (Kendrick & Lavery, 2001). The removed material is washed through a 500-µm sieve in order to separate larger particles. The final epiphytic material is collected in 50 ml distilled water and quantitatively subsampled for cell counting to estimate the epiphytic microalgal abundance. Cleaning in H<sub>2</sub>SO<sub>4</sub> acid solution, permanent slides are prepared for the identification of microalgae. The subsamples are also fixed with 4% formaldehyde solution for further taxonomic identification process. Cell counts are performed under the microscope at ×40 magnification examining the whole surface. The total number of epiphytic microalgal cells are expressed as the number of individuals per 50 g of fresh weight of *Posidonia* (fw). In terms of Cyanophyceae, the cells are estimated present in the trichomes (Findenegg, 1974). During the identification process; the terminology of Hustedt (1930; 1959; 1961-1966; 1985); Patrick and Reimer (1966-1975); Krammer and Lange-Bertalot (1986); Poulin (1986); Round *et al.* (1990); Tomas (1995); Anagnostidis and Komárek (1988) and Komárek and Anagnostidis (1986) are followed.

Physico-chemical water quality parameters (temperature, salinity, dissolved oxygen, pH) in the water column (0 m, 15 m, 28 m) are measured in situ with YSI Model Professional Plus multiparameter and the water transparency is measured three times at each site using a Secchi disc. In addition, water samples for determining nutrient concentrations are collected in 100 ml polyethylene bottles and kept in deep freeze (20 °C) until their analysis in the laboratory. Dissolved inorganic nitrogen (NO<sub>2</sub><sup>-1</sup>+NO<sub>3</sub><sup>-1</sup>+NH<sub>4</sub>) concentrations are analyzed spectrophotometrically (APHA, 1999). Total phosphorus (TP), Silicate (SiO<sub>4</sub>) analyses are carried out by the methods described by Parsons *et al.* (1984).

### Data Analysis

In order to reveal temporal and bathymetric variations of each epiphytic microalgal group abundances and *Posidonia oceanica* descriptors, multivariate analysis of variance (MANOVA) is used with the model consisted of three quadrats per combination of the factor levels: depth and month. Before the analysis, Kolmogorov–Smirnov test and Levene's test are applied on the data in order to investigate the normality of distribution and the homogeneity of

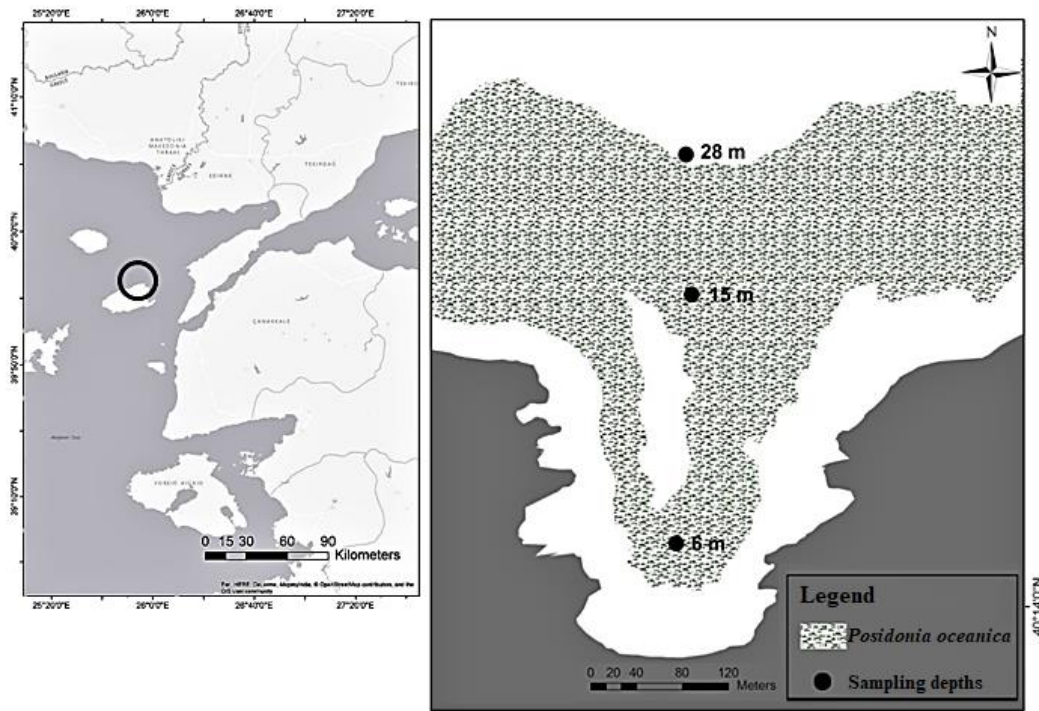


Figure 1. Study site.

variances, respectively. Significance of levels are tested at  $P < 0.05$ . In addition, the relationships between epiphytic microalgal group abundances, *P. oceanica* descriptors and water quality parameters are evaluated by using the Pearson correlation coefficient.

Hierarchical clustering of Bray – Curtis is also used to detect the similarities between epiphytic microalgal abundances among sampling months and depths. Bray – Curtis similarity coefficient (produced from  $\log(x+1)$ -transformed data) in order to balance the contributions of very abundant species and rare species) created a matrix for the Analysis of Similarity (ANOSIM) used to identify the differences in the abundances and for the Analysis of Similarity of Percentages (SIMPER) used to detect the species responsible for the dissimilarities among sampling dates (Clarke, 1993; Clarke & Warwick, 1994; 2001). Considering the algal composition; the Shannon-Weaver ( $H'$ ) diversity index is calculated. Biostatistical analyses are conducted using PRIMER 5 software.

## Results

### Ecological Status of *Posidonia oceanica*

Meadow density decreased significantly (MANOVA  $f = 4.178$ ,  $P < 0.05$ ) along depths; that the highest (mean  $207 \pm 12$  shoot  $m^{-2}$ ) at 6 m whereas; the lowest (mean  $75 \pm 16.4$  shoot  $m^{-2}$ ) at 28 m. Meadow cover showed significant decline parallelly to the meadow density (MANOVA  $f = 5.031$ ,  $P < 0.05$ ) with the highest value (mean  $89 \pm 8\%$ ) at 6 m and the lowest value (mean  $37 \pm 7\%$ ) at 28 m. On the contrary, leaf surface increased significantly along the depth gradient (MANOVA  $f = 3.945$ ,  $P < 0.05$ ); with the highest value (mean  $220$   $cm^2$

shoot $^{-1}$ ) at 28 m and the lowest value (mean  $140.6$   $cm^2$  shoot $^{-1}$ ) at 6 m. In spite of these results, total leaf number is stable at all depths (MANOVA  $f = 0.746$ ,  $P > 0.05$ ); changed temporally from July to January with the mean values of  $7.0 \pm 0.8$  leaf shoot $^{-1}$  and  $5.0 \pm 0.5$  leaf shoot $^{-1}$ , respectively.

### Water Quality Parameters

The results of the water quality parameters in the water column of the meadow lower limit are shown in the Figure 2. It can be seen that temperature dynamics are typically temporal; the lowest temperature ( $13.2$  °C) is measured in January; while the highest ( $26.4$  °C) is measured in July at surface water. Water transparency varied between 10 m and 18 m with an average of  $12.8 \pm 3.5$ . The lowest transparency (10.3 m) is measured in May however contrary to expectation, January has also low values (10.6 m) due to the massive mucilage formation.

Salinity exhibited a variation among both sampling months and depths; lowest value (27.0‰) is recorded at surface water in October, while highest value (39.0‰) is recorded in July at deeper. The mean value of pH is recorded as  $7.8 \pm 0.2$  and is similar both in the annual cycle and in the vertical profile. The lowest value (6.0) of pH is noted in July at deeper waters. Nutrient levels are recorded at their maximum at 28 m in January;  $10.3$   $\mu g$   $l^{-1}$  for dissolved inorganic nitrogen;  $0.20$   $\mu g$   $l^{-1}$  for total phosphorus and  $0.04$   $\mu g$   $l^{-1}$  for silicate. Considering the mean annual values for dissolved inorganic nitrogen, total phosphorus and silicate values ranged from  $10.3$   $\mu g$   $l^{-1}$  to  $1.2$   $\mu g$   $l^{-1}$ ,  $0.3$   $\mu g$   $l^{-1}$  to  $0.1$   $\mu g$   $l^{-1}$  and  $0.09$   $\mu g$   $l^{-1}$  to  $0.01$   $\mu g$   $l^{-1}$ , respectively during the study period.

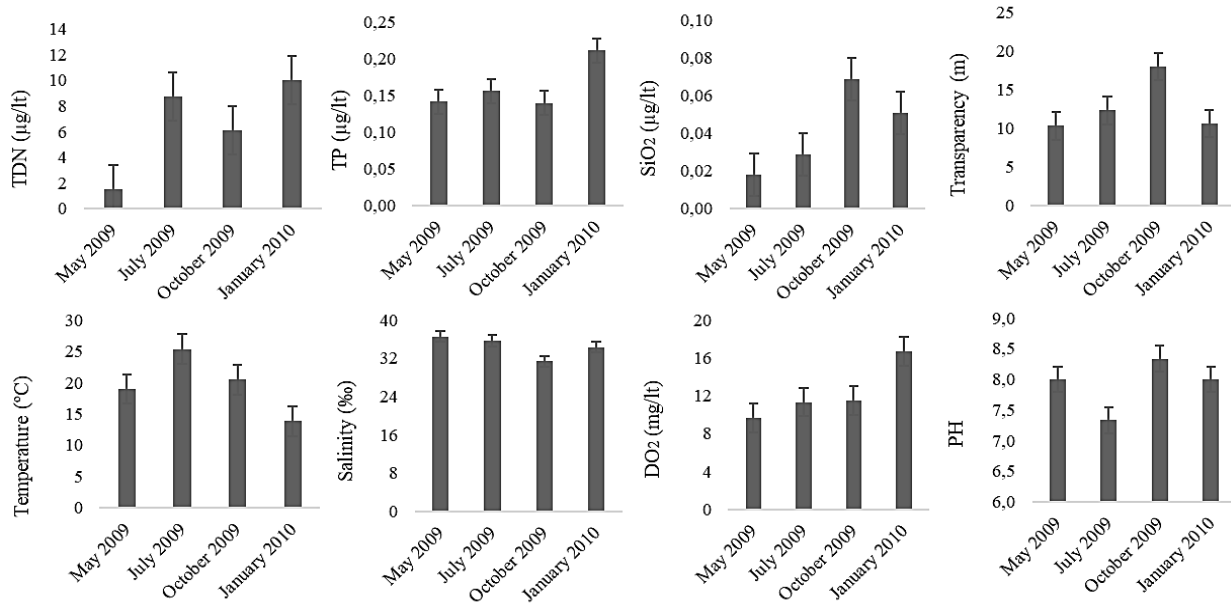


Figure 2. Mean values and standard deviations of the temporal variations of the water quality parameters.

### Epiphytic Microalgal Groups

Throughout the study period; a total of 56 taxa belonging to the epiphytic microalgal groups; Bacillariophyceae (91%), Cyanophyceae (7%) and Dinophyceae (2%) are identified on *Posidonia oceanica* leaf blades (Table 1).

Bacillariophyceae revealed significant variations temporally (MANOVA  $f = 3.491$ ,  $P < 0.05$ ); highest abundances are recorded in May (864 cells  $50 \text{ g}^{-1} \text{ fw Posidonia}$ ) and July (570 cells  $50 \text{ g}^{-1} \text{ fw Posidonia}$ ) whereas; lowest abundances (317 cells  $50 \text{ g}^{-1} \text{ fw Posidonia}$ ) are recorded in October. Followingly, in January, epiphytic community has substituted with Cyanophyceae (66517 cells  $50 \text{ g}^{-1} \text{ fw Posidonia}$ ) and Dinophyceae (262 cells  $50 \text{ g}^{-1} \text{ fw Posidonia}$ ) on the leaf blades. Cyanophyceae and Dinophyceae didn't show significant variations among sampling months (MANOVA  $f = 1.262$ ,  $P > 0.05$ ); however, reached to their highest abundances in the winter period due to the massive mucilage formation on the sea bottom. Total epiphytic abundance in October (ave. sim. 50.40) and January (ave. sim. 13.19) showed an obvious separation from May (ave. sim. 30.77) and July (ave. sim. 59.47), according to the Bray-Curtis clustering (Figure 3). SIMPER results also showed that group dissimilarities are obviously high (ave. dis. 79.33%) between May and January due to the contribution of *Lyngbya* sp. (40.29%) that showed an extreme growth in the winter period. Furthermore, *Lyngbya* sp. (35.13%) and *Cocconeis scutellum* (6.89%) are the responsible species for the high group dissimilarities (ave. dis. 72.22%) between May and October (Table 2).

In terms of the mean epiphytic microalgal species diversity ( $H'$ ) differed between sampling months; the lowest values are recorded as  $0.69 \pm 0.97$  in October and

as  $1.29 \pm 0.17$  in January whereas; the highest value is recorded as  $2.30 \pm 0.11$  in May (Figure 4).

Considering the bathymetric profile, epiphytic microalgal abundances differed between 6 m (ave. sim. 34.18) and 28 m (ave. sim. 28.23) depths; *Lyngbya* sp. (42.84%) and *Calothrix* sp. (7.1%) are the responsible species for the high dissimilarities (ave. dis. 69.80%) (Table 3). On the group basis, Bacillariophyceae, also showed significant variations bathymetrically (MANOVA,  $P < 0.05$ ); reaching high abundances through the vertical profile; the lowest (494 cells  $50 \text{ g}^{-1} \text{ fw Posidonia}$ ) and the highest (982 cells  $50 \text{ g}^{-1} \text{ fw Posidonia}$ ) abundances are detected at 6 m and 28 m, respectively.

As for the relationship between the epiphytic microalgal abundance and leaf surface area ( $r = 0.787$ ,  $P < 0.05$ ) and leaf number ( $r = 0.647$ ,  $P < 0.05$ ) is verified with the Pearson coefficient both showing the same increasing trend towards to 28 m depth. Also, there is a correlation between epiphytic microalgal abundance and total phosphorus ( $r = 0.873$ ,  $P < 0.05$ ); dissolved inorganic nitrogen ( $r = 0.550$ ,  $P < 0.05$ ) values.

### Discussion

Epiphytic microalgal composition and abundance on *Posidonia oceanica* leaf blades estimated within this study, have provided relevant information on the ecological quality in Gökçeada Underwater Park (North Aegean). Due to their sensitivity to environmental alterations, community structure and abundance of the epiphytic microalgal groups on leaf blades, showed temporal and bathymetric variation during the sampling period.

Since seagrass leaf blades are ideal habitats for benthic algal colonization (Mabrouk *et al.*, 2014), the presence of *P. oceanica* meadows around Gökçeada

**Table 1.** List of epiphytic microalgal species on *Posidonia oceanica* leaf blades

	May - 6 m	May - 15 m	May - 28 m	Jul - 6 m	Jul - 15 m	Jul - 28 m	Oct - 6 m	Oct - 15 m	Oct - 28 m	Jan - 6 m	Jan - 15 m	Jan - 28 m
<b>Bacillariophyceae</b>												
<i>Calothrix</i> sp.	+	-	-	+	+	+	-	-	+	-	-	+
<i>Lyngbya</i> sp.	+	-	-	+	+	+	+	+	+	-	+	+
<i>Phormidium</i> sp.	-	-	-	-	-	-	-	-	+	-	-	+
<i>Spirulina</i> sp.	-	-	-	-	-	+	-	-	-	-	-	+
<i>Achnanthes</i> sp.	+	-	+	+	+	+	-	-	+	-	-	+
<i>Amphiprora</i> sp.	+	+	-	-	-	-	-	+	-	-	-	-
<i>Amphora</i> sp.	-	+	-	-	-	+	-	-	-	-	-	-
<i>Amphora costata</i> W. Smith	-	-	-	-	+	-	-	+	-	-	-	-
<i>Amphora delicatissima</i> Krasske	-	-	-	-	+	+	-	+	+	-	-	-
<i>Amphora hyalina</i> Kützing	-	-	+	-	-	-	-	-	-	-	-	-
<i>Biddulphia alternans</i> (Bailey) Van Heurck	-	-	-	-	-	+	-	-	-	-	-	-
<i>Campylodiscus decorus</i> Brébisson	-	-	+	-	-	-	-	-	-	-	-	-
<i>Cocconeis</i> sp.	-	-	-	-	-	-	-	-	+	+	+	-
<i>Cocconeis pseudomarginata</i> Gregory	-	-	-	-	-	-	-	+	+	-	-	-
<i>Cocconeis placentula</i> Ehrenberg	-	+	+	+	-	+	-	-	-	-	-	-
<i>Cocconeis scutellum</i> Ehrenberg	+	+	+	+	+	+	-	+	+	+	+	+
<i>Diploneis</i> sp.	+	+	+	+	+	+	-	+	-	-	-	-
<i>Diploneis bombus</i> (Ehrenberg) Cleve	-	-	-	-	-	-	-	-	-	-	-	-
<i>Diploneis constricta</i> (Grunow) Cleve	-	-	-	-	-	+	-	-	+	-	-	-
<i>Diploneis crabro</i> Ehrenberg	-	-	-	-	+	-	-	-	-	-	-	-
<i>Diploneis didyma</i> (Ehrenberg) Cleve	-	-	-	-	-	-	-	-	+	-	-	-
<i>Diploneis incurvata</i> (Gregory) Cleve	-	-	-	-	-	-	+	-	+	-	-	+
<i>Diploneis smithii</i> (Brébisson) Cleve	-	-	+	-	-	-	-	-	-	-	-	-
<i>Grammatophora marina</i> (Lyngbye) Kützing	+	+	-	+	-	+	-	-	+	-	-	+
<i>Grammatophora angulosa</i> Ehrenberg	-	-	-	-	-	-	-	-	-	-	+	-
<i>Gyrosigma acuminatum</i> (Kützing) Rabenhorst	+	-	+	-	-	+	-	+	+	-	-	-
<i>Hemiaulus hauckii</i> Grunow ex Van Heurck	+	-	-	-	-	-	+	-	-	-	-	-
<i>Licmophora</i> sp.	+	-	-	-	-	-	-	-	-	-	-	-
<i>Licmophora ehrenbergii</i> (Kützing) Grunow	-	+	+	-	+	+	-	+	+	-	-	-
<i>Licmophora gracilis</i> (Ehrenberg) Grunow	-	-	+	-	-	+	-	+	+	-	-	-
<i>Lichmophora grandis</i> (Kützing) Grunow	-	-	-	-	+	+	-	-	-	-	-	-
<i>Lichmophora quadriplacata</i> Mereschkowsky	-	-	-	-	-	-	-	+	-	-	-	-
<i>Mastogloia acutiuscula</i> Grunow	-	+	-	-	-	-	-	-	-	-	+	-
<i>Navicula</i> sp.	+	-	+	+	+	+	-	+	+	+	-	+
<i>Navicula placenta</i> Ehrenberg	-	-	-	-	-	-	-	-	+	-	-	-
<i>Navicula rostellata</i> Kützing	-	-	-	-	-	-	-	-	+	-	-	-
<i>Nitzschia</i> sp.	+	+	-	+	-	+	-	+	+	-	+	-
<i>Nitzschia closterium</i> (Ehrenberg) Smith	-	-	-	-	+	-	-	+	+	-	-	-
<i>Nitzschia constricta</i> (Kützing) Ralfs	+	-	-	-	-	-	-	-	-	-	-	-
<i>Nitzschia frustulum</i> (Kützing) Grunow	-	-	-	-	-	-	-	+	-	-	-	-
<i>Nitzschia linearis</i> (Agardh) Smith	-	-	-	-	-	+	-	-	-	-	-	-
<i>Odontella</i> sp.	-	-	-	-	-	+	-	-	-	-	-	-
<i>Pinnularia</i> sp.	+	+	+	-	-	+	-	-	-	+	+	+
<i>Pinnularia gibba</i> var. <i>linearis</i> Hustedt	-	-	-	-	-	-	-	+	-	-	-	-
<i>Pinnularia viridis</i> (Nitzsch) Ehrenberg	-	-	-	-	-	+	-	-	-	-	-	-
<i>Plagiogramma interruptum</i> (Gregory) Ralfs	+	-	-	-	-	-	-	-	-	-	-	-
<i>Pleurosigma</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-
<i>Podocystis adriatica</i> (Kützing) Ralfs	-	-	-	-	+	-	-	-	-	-	-	-
<i>Stauroneis</i> sp.	+	-	-	+	-	-	-	-	+	-	-	-
<i>Surirella ovalis</i> Brébisson	-	-	-	+	-	-	-	-	-	-	-	-
<i>Surirella didyma</i> Kützing	+	+	-	+	-	+	-	-	+	-	-	-
<i>Synedra</i> sp.	-	-	-	-	-	-	+	-	+	-	+	+
<i>Synedra tabulata</i> (Agardh) Kützing	-	-	+	-	+	+	-	+	+	-	+	-
<i>Synedra ulna</i> (Nitzsch) Ehrenberg	-	-	-	-	-	+	-	-	-	-	-	-
<i>Tabellaria fenestrata</i> (Lyngbye) Kützing	+	-	-	+	-	-	-	-	-	-	-	-
<b>Cyanophyceae</b>												
<i>Calothrix</i> sp.	+	-	-	+	+	+	-	-	+	-	-	+
<i>Lyngbya</i> sp.	+	-	-	+	+	+	+	+	+	-	+	+
<i>Phormidium</i> sp.	-	-	-	-	-	-	-	-	+	-	-	+
<i>Spirulina</i> sp.	-	-	-	-	-	+	-	-	-	-	-	+
<b>Dinophyceae</b>												
<i>Prorocentrum lima</i> (Ehrenberg) Dodge	+	+	-	-	+	-	-	+	+	+	-	+

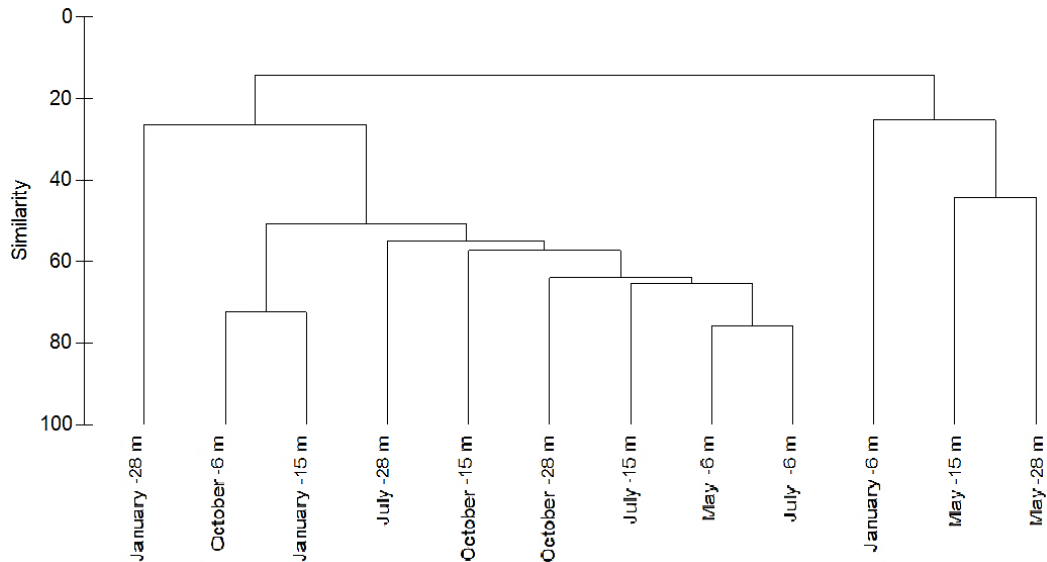


Figure 3. Bray-Curtis similarity % dendrogram of epiphytic microalgal abundance according to the sampling months and depths.

Table 2. SIMPER results among sampling months

	Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Groups May & July Average dissimilarity= 63.95	<i>Lyngbya</i> sp.	11.89	50.31	27.30	1.55	42.68	42.68
	<i>Calothrix</i> sp.	3.83	9.10	5.52	1.48	8.63	51.31
	<i>Achnanthes</i> sp.	2.76	5.14	2.79	1.33	4.36	55.67
Groups May & October Average dissimilarity = 72.22	<i>Lyngbya</i> sp.	11.89	37.48	25.37	1.37	35.13	35.13
	<i>Cocconeis scutellum</i>	7.62	4.14	4.98	1.19	6.89	42.02
	<i>Calothrix</i> sp.	3.83	2.87	3.15	0.90	4.36	46.38
Groups July & October Average dissimilarity = 44.40	<i>Lyngbya</i> sp.	50.31	37.48	8.90	0.96	20.05	20.05
	<i>Calothrix</i> sp.	9.10	2.87	4.24	1.38	9.54	29.59
	<i>Cocconeis scutellum</i>	6.14	4.14	2.88	1.42	6.50	36.08
Groups May & January Average dissimilarity = 79.33	<i>Lyngbya</i> sp.	11.89	95.17	31.96	1.25	40.29	40.29
	<i>Cocconeis scutellum</i>	7.62	2.88	6.43	0.99	8.10	48.39
	<i>Calothrix</i> sp.	3.83	14.38	5.09	1.01	6.41	54.80
Groups July & January Average dissimilarity = 69.10	<i>Lyngbya</i> sp.	50.31	95.17	31.63	1.60	45.78	45.78
	<i>Calothrix</i> sp.	9.10	14.38	7.40	2.78	10.71	56.49
	<i>Achnanthes</i> sp.	5.14	1.49	2.99	1.08	4.32	60.81
Groups October & January Average dissimilarity = 69.16	<i>Lyngbya</i> sp.	37.48	95.17	32.29	1.38	46.69	46.69
	<i>Calothrix</i> sp.	2.87	14.38	4.38	1.00	6.34	53.03
	<i>Phormidium</i> sp.	4.53	8.97	3.92	0.89	5.66	58.70

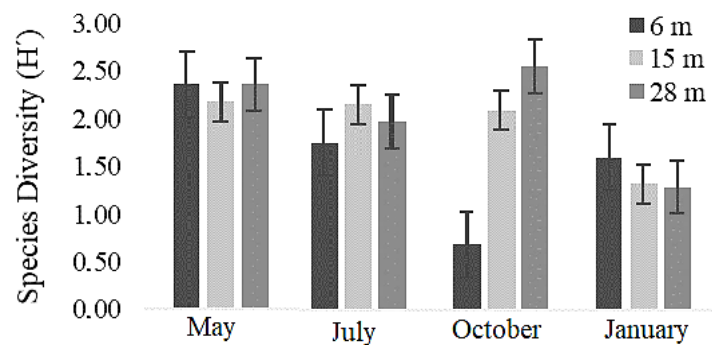


Figure 4. Shannon-Weaver species diversity ( $H'$ ) among sampling months and depths.

**Table 3.** SIMPER results among depths

	Species	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Groups 6 m & 15 m Average dissimilarity = 60.22	<i>Lyngbya</i> sp.	25.83	28.62	17.12	0.86	28.42	28.42
	<i>Cocconeis scutellum</i>	3.24	7.62	5.36	1.09	8.89	37.32
	<i>Calothrix</i> sp.	4.64	3.17	4.13	0.97	6.86	44.18
Groups 6 m & 28 m Average dissimilarity = 69.80	<i>Lyngbya</i> sp.	25.83	91.69	29.90	1.40	42.84	42.84
	<i>Calothrix</i> sp.	4.64	14.82	4.95	1.28	7.10	49.93
	<i>Phormidium</i> sp.	0.00	10.13	3.79	0.91	5.43	55.37
Groups 15 m & 28 m Average dissimilarity = 65.74	<i>Lyngbya</i> sp.	28.62	91.69	28.01	1.41	42.61	42.61
	<i>Calothrix</i> sp.	3.17	14.82	4.91	1.32	7.47	50.08

Island (North Aegean) is vital for the coastal ecological status of the region contributing to the ecosystem services. However, water turbidity affects the meadow density and meadow cover through greater depths, where the light diffusing to the leaves diminishes. Also, same results from the Mediterranean Basin are supported by Pergent *et al.* (1995); Tsirika *et al.* (2007) and Mabrouk *et al.* (2014).

On the other hand, extreme leaf movement at the sea bottom, affect the settlement of epiphytes on seagrass leaves and macroalgal thalli (Borowitzka & Lethbridge, 1989; Borowitzka *et al.*, 2006). Therefore, leaf blades have lost their functional substratum characteristics for epiphytic communities since they are exposed to strong hydrodynamism (eg. waves and currents) at shallower depths where leaf movement is greater (Aktan *et al.*, 2011). *P. oceanica* leaf surface improvement through greater depths, have provided a convenient substratum for epiphytic colonization. Relation between epiphytic microalgal abundance and leaf surface area ( $r = 0.787$ ,  $P < 0.05$ ), highlighted that leaf surface improvement support the epiphytic succession to form a diverse benthic community.

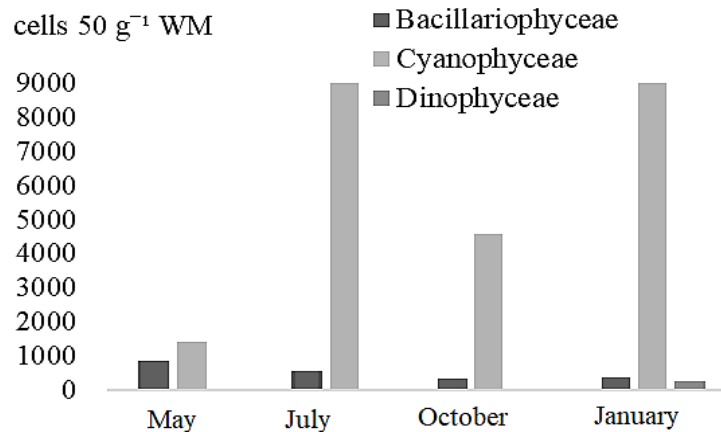
In this study, Bacillariophyceae is the principal group among epiphytic microalgal groups in terms of species composition, dominated by the pennate diatom taxa; *Navicula*, *Pinnularia*, *Achnanthes*, *Cocconeis*, *Nitzschia*, *Lichmophora* and *Synedra*. They demonstrate widespread micro-epiphytism reaching to high abundances on benthic substrates (Sullivan, 1979; Mazzella *et al.*, 1994; Mabrouk *et al.*, 2014). As stated by Patrick (1977), diatoms are the dominant group of macrophyte-associated microalgae leading other groups to proceed the colonization on leaf blades.

Totti, Poulin, Romagnoli, Perrone and Pennesi (2009) stated that diatom taxa having high adhesive strength characteristics (*Cocconeis* and *Achnanthes* species), tolerate strong hydrodynamic conditions. Due to their adaptation capability to hydrodynamic conditions, *Cocconeis* and *Achnanthes* are abundant at shallower depths where strong hydrodynamism prevailing; while erect growth forms attached to the substratum by mucilaginous stalks (*Nitzschia*, *Lichmophora*, *Grammatophora* and *Synedra*) are abundant at greater depths (15 m and 28 m) where hydrodynamism is lower. In particular, the genus *Cocconeis* Ehrenberg, family Cocconeidaceae, order

Achnanthales is frequent in all seasons firmly attached to the leaf blades through their raphe-sternum valves. The genus *Cocconeis* protect themselves from grazers and hydrodynamism by forming monospecific biofilms during their colonization process, however generally subjected to the cell exudation of the host plant (Round, 1984; Mazzella *et al.*, 1994).

During the sampling period, we noticed that temporal and bathymetric dynamics of the epiphytic microalgal composition and abundance depend on nutrient loadings in the water column. Bacillariophyceae are influenced by silicate ( $\text{SiO}_2$ ), restrictive element for the growth of diatoms (Round *et al.*, 1990) whereas; dissolved inorganic nitrogen (DIN) and total phosphorus (TP) levels have played an important role in the development of Cyanophyceae and Dinophyceae groups. Dissolved inorganic nitrogen (DIN) and total phosphorus (TP) concentrations have reached to maximum values at 28 m depth;  $10.3 \mu\text{g l}^{-1}$  and  $0.20 \mu\text{g l}^{-1}$ , respectively in January when extensive mucilaginous aggregations accumulated both on the sea bottom and on the *P. oceanica* meadows. As termed by Precali *et al.* (2005), observed aggregate type was 'blanket' forming homogenous layers of combined aggregates on the benthic habitats. This mucilage phenomenon is attributed to the excessive growth of phytoplanktonic species (Aktan & Gümüšoğlu, 2010), at the same time, Bacillariophyceae have substituted with Cyanophyceae and Dinophyceae in terms of group abundances.

Coastal zones of Gökçeada (North Aegean), have oligotrophic characteristics, however, the study site near Kaleköy Port with recreational activities, is characterized as mesotrophic or eutrophic due to nutrient inputs. In general, low nutrient levels in the spring period, are linked to algal productivity, whereas high levels of nutrients in the winter period, are attributed to algal growth limitation due to low water temperature and light intensity at deeper waters of the region (Aktan & Gümüšoğlu, 2010). In this study, high levels of nutrients and turbidity (Secchi depth; 11 m) are typical in the water column throughout the mucilage precipitation, also promoted the growth of toxin-producer epiphytic genera; *Lyngbya* and *Prorocentrum*. As known to be potential endotoxin (lyngbyatoxin-a) producers (Hamisi *et al.*, 2004); *Lyngbya* colonies dominated the surface of the substratum as filamentous mats in order to compete with other photosynthetic



**Figure 5.** Epiphytic microalgal abundance throughout the study period.

epiphytes for light energy. Meanwhile; okadaic acid and dinophysistoxin producer (Nakajima *et al.*, 1981; Marr *et al.*, 1992; Barbier *et al.*, 1999); *Prorocentrum* occurred solitarily on leaf blades. Responsible from the diarrhetic shellfish poisoning (DSP) (Prokic *et al.*, 1998); *Prorocentrum lima* reached to maximum abundance in this period when environmental conditions have been destroyed as also confirmed by other studies (Beleggratis *et al.*, 1999; Bouchouicha *et al.*, 2013; Mabrouk *et al.*, 2014). At the end of the winter period, resistance of the mucilage precipitation has influenced negatively when warmer waters diffuse to the aggregates, as also stated by Alldredge & Crocker (1995).

Throughout the study period; low diversity of the epiphytic microalgal species, is related to the dominance of filamentous cyanobacteria due to their tolerance to high nutrient levels and temperatures (Paerl & Huisman, 2009). According to the previous studies (Turley *et al.*, 2000; Ignatiades *et al.*, 2002; Balkis, 2009), the North Aegean Sea can be regarded as an oligotrophic system due to low nutrient levels. However, coastal waters of Gökçeada Island (North Aegean) are affected by increasing levels of nutrients and organic compounds as a consequence of agricultural activities and urban discharges in the recent years. Moreover, considering these outputs in terms of an early warning of changing climatic conditions; higher temperatures (>14 °C) in winter periods, might be promoted the excessive growth of cyanobacteria in such a temperate region (Figure 5).

In case of the occurrence of mucilage phenomena along the Aegean coasts and intensive colonizations of opportunistic species; biodiversity of the benthic community within the meadow habitats will be affected by the deterioration in the water quality. Taking all these facts into consideration, epiphytic microalgal assemblages responding quickly to environmental alterations, should be used as bio-indicators in the monitoring programs to distinguish and minimize the pressures on coastal ecosystems. However; the deficiency of monitoring studies through epiphytes; is linked to their disadvantageous feature; a time-

consuming process including a detailed laboratory work. Therefore, this study can be used as a necessary data for the future management plans for critical ecosystems, especially in less evaluated regions of the Eastern Mediterranean Sea.

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#### References

- Aktan, Y., El Asmi, S., Gücü, A. C., Pergent, G., & Pergent-Martini, C. (2011). Setting up the Med-Posidonia Programme in the Mediterranean Region. Proceedings of the Tenth Intern. Conf. on the Medit. Coast. Environ. Medcoast, October 2011, Rhodes, Greece.
- Aktan, Y., & Gümüšoğlu, A. (2010). Another threat on Posidonia oceanica beds: Mucilage effect in Gökçeada Island, North Aegean Sea, Turkey. Proceedings of the 4. Mediterranean Symposium on Marine Vegetation, RAC/SPA, 2-4 December 2010, Tunis, 251 p.
- Aligizaki, K., & Nikolaidis, G. (2006). The presence of the potentially toxic genera *Ostreopsis* and *Coolia* (Dinophyceae) in the North Aegean Sea, Greece. Harmful Algae, 5, 717-730. <https://doi.org/10.1016/j.hal.2006.02.005>
- Allredge, A. L., & Crocker, K. M. (1995). Why do sinking mucilage aggregates accumulate in the water column? Science of the Total Environment, 165, 15-22. [https://doi.org/10.1016/0048-9697\(95\)04539-D](https://doi.org/10.1016/0048-9697(95)04539-D)
- American Public Health Association (APHA), (1999). Standard methods for the examination of water and wastewater, 20th ed. American Public Health Association, Washington, DC.
- Anagnostidis, K. & Komárek, J. (1988). Modern approach to the classification system of the Cyanophytes 3: Oscillatoriales. Algological Studies, 50 (53), 327-472. [https://www.schweizerbart.de/papers/archiv\\_algolstud/detail/5053/65276/Modern\\_approach\\_to\\_the\\_classification\\_system\\_of\\_cyanophytes\\_3\\_Oscillatoriales](https://www.schweizerbart.de/papers/archiv_algolstud/detail/5053/65276/Modern_approach_to_the_classification_system_of_cyanophytes_3_Oscillatoriales)



- Balata, D., Bertocci, I., Piazzì, L., & Nesti, U. (2008). Comparison between epiphyte assemblages of leaves and rhizomes of the seagrass *Posidonia oceanica* subjected to different levels of anthropogenic eutrophication. *Estuarine Coastal and Shelf Science*, 79, 533-540. <https://doi.org/10.1016/j.ecss.2008.05.009>
- Balkis, N. (2009). Seasonal variations of microphytoplankton assemblages and environmental variables in the coastal zone of Bozcaada Island in the Aegean Sea (NE Mediterranean Sea). *Aquatic Ecology*, 43, 249-270. <https://doi.org/10.1007/s10452-008-9175-x>
- Barbier, M., Amzil, Z., Mondeguer, F., Bhaud, Y., Soyer-Gobillard, M. O., & Lassus, P. (1999). Okadaic acid and PP2A cellular immunolocalization in *Prorocentrum lima* (Dinophyceae). *Phycologia*, 38, 41-46. <https://www.tandfonline.com/doi/abs/10.2216/i0031-8884-38-1-41.1>
- Beleggratis, M. R., Bitis, I., Economou, A. A., & Ott, J. A. (1999). Epifitic patterns of macroalgal assemblages on *Cystoseira* species (Fucales, Phaeophyta) in the East Coast of Attica (Aegean Sea, Greece). *Hydrobiologia*, 412, 67-80.
- Borowitzka, M. A., Lavery, P., & van Keulen, M. (2006). Epiphytes of seagrasses. Larkum, A. W. D., Orth, R. J., Duarte, C. M. (Eds.), *Seagrasses: Biology, Ecology and Conservation*, (pp. 311-324). Springer, Netherlands.
- Borowitzka, M. A., & Lethbridge, R. C. (1989). Seagrass epiphytes. A.W.D. Larkum, A. J. Mc Comb and S.A. Shepherd (eds.), *Biology of seagrasses*, (pp. 458-499). Elsevier, Amsterdam.
- Bouchouicha, S., Mabrouk, H., & Hlaili, S. (2013). Driving factors of the potentially toxic and harmful species of *Prorocentrum* Ehrenberg in a semi-enclosed Mediterranean lagoon (Tunisia, SW Mediterranean), *Mediterranean Marine Science*, 14, 353-362. <http://dx.doi.org/10.12681/mms.338>
- Boudouresque, C. F., Bernard, G., Bonhomme, P., Charbonnel, E., Diviacco, G., Meinesz, A., Pergent, G., Pergent-Martini, C., Ruitton, S., & Tunesi, L. (2006). Preservation et conservation des herbiers à *Posidonia oceanica*. RaMoGe Publication, Monaco, p. 202.
- Boyacıoğlu, H., & Dural, B. (2009). The statistical investigation on *Posidonia oceanica* (L.) Delile meadows in Izmir, Turkey. *Environmental Modeling & Assessment*, 14, 769-772. <http://dx.doi.org/10.1007/s10666-008-9178-y>
- Cebrian, J., Enriquez, S., Fortesc, M., Agawin, N., Vermaat, J. E., & Duarte, C. M. (1999). Epiphyte accrual on *Posidonia oceanica* (L.) Delile leaves: Implications for light absorption. *Botanica Marina*, 42, 123-128.
- Cinelli, F., Cormaci, M., Furnari, G., & Mazzella, L. (1984). Epiphytic macroflora of *Posidonia oceanica* (L.) Delile leaves around the Island of Ischia (Gulf of Neaples). In: Boudouresque C.F., Meinesz A., Fresi E., Gravez V. (Eds), 1st International Workshop on *Posidonia oceanica* Beds. G.I.S., Posidonie: 91-99.
- Cirik, S., Meinesz, A., Akcali, B., Javel, F., Thibaut, T., & Özalp, H. B. (2010). Distribution and mapping of *Posidonia oceanica* (L.) Delile in the Dardanelles Strait and Marmara Sea. 39th CIESM Congress Proceedings, Italy, 478.
- Clarke, K. R., & Warwick, R. M. (2001). Change in marine communities: an approach to statistical analysis and interpretation. PRIMER-E Ltd. Plymouth, UK, 172 pp.
- Clarke, K. R., & Warwick, R. M. (1994). Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. Natural Environmental Research Council, UK, 144 pp.
- Clarke, K. R. (1993). Non-parametric multivariate analyses of change in community structure. *Australian Journal of Ecology*, 18, 117-143. <https://doi.org/10.1111/j.1442-9993.1993.tb00438.x>
- De Stefano, M., Marino, D., & Mazzella, L. (2000). Marine taxa of *Cocconeis* on leaves of *Posidonia oceanica*, including a new species and two new varieties. *European Journal of Phycology*, 35 (3), 225-242. <http://dx.doi.org/10.1080/09670260010001735831>
- Dural, B., & Pergent, G. (2001). Phenology of *Posidonia oceanica* along the Izmir coastline (Turkey). E. Özhan (Ed.), *Proceedings of the Fifth Intern. Conf. on the Medit. Coast. Environ. Medcoast 01*, (pp. 579-584), Hammamet, Tunisia.
- Frankovich, T. A., & Fourqurean, J. W. (1997). Seagrass epiphyte loads along a nutrient availability gradient, Florida Bay, USA. *Marine Ecology Progress Series*, 159, 37-50. [http://serc.fiu.edu/seagrass/pubs/1997\\_FrankovichAndFourqurean.pdf](http://serc.fiu.edu/seagrass/pubs/1997_FrankovichAndFourqurean.pdf)
- Findenegg, I. (1974). In Vollenweider R (ed.). *A manual of methods for measuring primary production in aquatic environments*. I.B.P. 12. Oxford: Blackwell Scientific Publications.
- Giakoumi, S., Halpern, S., Michel, L. N., Gobert, S., Sini, M., Boudouresque, F., Gambi, C., .. Possingham, P. (2015). Towards a framework for assessment and management of cumulative human impacts on marine food webs. *Conservation Biology*, 29 (4), <http://dx.doi.org/10.1111/cobi.12468>
- Giraud, G. (1979). Sur une methode de mesure et de comptage des structures foliaires de *Posidonia oceanica* (Linnaeus) Delile. *Bulletin du Museum d'Histoire Naturelle de Marseille* 39, 33-39.
- Giovannetti, E., Montefalcone, M., Morri, C., Bianchi, C. N., & Albertelli, G. (2010). Early warning response of *Posidonia oceanica* epiphyte community to environmental alterations (Ligurian Sea, NW Mediterranean). *Marine Pollution Bulletin*, 60, 1031-1039. <https://doi.org/10.1016/j.marpolbul.2010.01.024>
- Hamisi, I. M., Lyimo, T. J., & Muruke, M. H. S. (2004). Cyanobacterial occurrence and diversity in seagrass meadows in coastal Tanzania. *Western Indian Ocean Journal of Marine Science*, 3 (2), 113-122. <http://dx.doi.org/10.4314/wiojms.v3i2.28455>
- Hustedt, F. (1985). *The pennate diatoms*. Koenigstein, Germany, Koeltz Scientific Books.
- Hustedt, F. (1961-1966). *Rabenhorst's kryptogamen flora, die kieselalgen*. 3. Teil, Reprint 1977. USA: Koeltz Science Publishers.
- Hustedt, F. (1959). *Rabenhorst's kryptogamen flora, die kieselalgen*. 2. Teil, Reprint 1991. USA: Koeltz Scientific Books.
- Hustedt, F. (1930). *Rabenhorst's kryptogamen flora, die kieselalgen*. 1. Teil, Reprint 1991. USA: Koeltz Scientific Books.
- Ignatiades, L., Psarra, S., Zervakis, V., Pagou, K., & Souvermezoglou, E. (2002). Phytoplankton size-based dynamics in the Aegean Sea (Eastern Mediterranean). *Journal of Marine Systems*, 36, 11-28. [https://doi.org/10.1016/S0924-7963\(02\)00132-X](https://doi.org/10.1016/S0924-7963(02)00132-X)
- Kendrick G. A., & Lavery P. S. (2001). Assessing biomass, assemblage structure and productivity of algal epiphytes

- on seagrasses. In: Short F.T., Coles R.G. (eds), *Global Seagrass Research Methods*. Elsevier, Amsterdam. 199-222 pp.
- Komárek, J., & Anagnostidis, K. (1986). Modern approach to the classification system of the Cyanophytes 2: Chroococcales. *Algological Studies*, 43, 157-226. [https://www.schweizerbart.de/papers/algol\\_stud/detail/43/63802/Modern\\_approach\\_to\\_the\\_classification\\_system\\_of\\_cyanophytes\\_2\\_Chroococcales](https://www.schweizerbart.de/papers/algol_stud/detail/43/63802/Modern_approach_to_the_classification_system_of_cyanophytes_2_Chroococcales)
- Krammer, K., & Lange-Bertalot, H. (1986). *S.sswasserflora von Mitteleuropa, Bacillariophyceae, Band 2/3. 3. Teil*. Stuttgart: Gustav Fisher Verlag.
- Mabrouk, L., Ben Brahim, M., Hamza, A., & Mahfoudhi, M. (2014). Variability in the structure of epiphytic microalgae assemblages on the leaves of *Posidonia oceanica* in relation to human disturbance in a meadow off Tunisia. *Scientia Marina*, 78, 27-39. <https://doi.org/10.3989/scimar.03939.06A>
- Mabrouk L., Hamza A., Ben Brahim M., & Bradai M. N. (2011). Seasonal and bathymetric variations of epiphytic microorganisms on *Posidonia oceanica* (L.) Delile leaves in Mahdia (Tunisia). *Marine Ecology*, 32: 148-161.
- Marr, J. C., Jackson, A. E., & McLachlan, J. L. (1992). Occurrence of *Prorocentrum lima*, a DSP toxin-producing species from the Atlantic coast Canada. *Journal of Applied Phycology*, 4, 17-24. <https://link.springer.com/article/10.1007/BF00003956>
- Mazzella, L., Buia, M. C., & Spinoccia, L. (1994). Biodiversity of epiphytic diatom community on leaves of *Posidonia oceanica*. (Marino, D. & Montresor, M., editors), *Proceeding of the Thirteenth International Diatom Symposium*, (pp. 241-251). Biopress, Bristol.
- Mazzella, L., Buia, M., Gambi, M. C., Lorenti, M., Russo, G. F., Scipione, M. B., & Zupo, V. (1992). Plant-animal trophic relationships in the *Posidonia oceanica* ecosystem of the Mediterranean Sea: a review. John D. M., Hawkins S. J., Price J. H. (Eds), *Plant-Animal Interactions in the Marine Benthos*. (pp.165-187), Clarendon Press, Oxford.
- Mazzella, L., Scipione, M. B., & Buia, M. C. (1989). Spatio-temporal distribution of algal and animal communities in a *Posidonia oceanica* meadow. *P.S.Z.N. Marine Ecology*, 10 (2), 107-129. <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1439-0485.1989.tb00069.x>
- Meinesz, A., Cirik, S., Akcali, B., Javel, F., Migliaccio, M., Thibaout, T., Yüsek, A., & Procaccini, G. (2009). *Posidonia oceanica* in the Marmara Sea. *Aquatic Botany*, 90, 18-22. <https://doi.org/10.1016/j.aquabot.2008.04.013>
- Nakajima, I., Oshima, Y., & Yasumoto, T. (1981). Toxicity of benthic Dinoflagellates in Okinawa. *Bulletin of the Japanese Society for the Science of Fish*, 47, 1029-1033. [https://hero.epa.gov/hero/index.cfm/reference/details/reference\\_id/1579966](https://hero.epa.gov/hero/index.cfm/reference/details/reference_id/1579966)
- Nesti, U., Piazzì, L., & Balata, D. (2009). Variability in the structure of epiphytic assemblages of the Mediterranean seagrass *Posidonia oceanica* in relation to depth. *Marine Ecology*, 30: 276-287. <https://doi.org/10.1111/j.1439-0485.2008.00275.x>
- Paerl, H. W., & Huisman, J. (2009). Climate change: a catalyst for global expansion of harmful algal blooms. *Environmental Microbiology Reports*, 1 (1), 27-37. <https://doi.org/10.1111/j.1758-2229.2008.00004.x>
- Parsons, T. R., Maita, Y., & Lalli, C. M. (1984). *A Manual of Chemical and Biological Methods for Seawater Analysis*. Pergamon Press, Oxford, 173 pp.
- Pasqualini, V., Pergent-Martini, C., Clabaut, P., & Pergent, G. (1998). Mapping of *Posidonia oceanica* using aerial photographs and side scan sonar: Application off the Island of Corsica (France). *Estuarine, Coastal and Shelf Science*, 47, 359-367. <https://www.sciencedirect.com/science/article/abs/pii/S0272771498903614>
- Patrick, R. (1977). Ecology of freshwater diatoms and diatom communities. *The Biology of Diatoms*, D. Werner (Ed.). Blackwell Scientific Publications, Botanical Monographs, 13, 284-332.
- Patrick, R., & Reimer, C. W. (1966-1975). *The diatoms of the United States. Volume 1-2*. Philadelphia: The Academy of Natural Sciences of Philadelphia.
- Pazi, I. (2008). Water mass properties and chemical characteristics in the Saroz Gulf, Northeast Aegean Sea (Eastern Mediterranean). *Journal of Marine Systems*, 74, 698-710. <https://doi.org/10.1016/j.jmarsys.2008.07.002>
- Pergent, G., Pergent-Martini, C., & Boudouresque, C. F. (1995). Utilisation de l'herbier à *Posidonia oceanica* comme indicateur biologique de la qualité du milieu littoral en Méditerranée : état des connaissances. *Mésogée*, 54, 3-27.
- Pergent, G., Romero, J., Pergent-Martini, C., Mateo, M. A., & Boudouresque, C. F. (1994). Primary production, stocks and fluxes in the Mediterranean seagrass *Posidonia oceanica*. *Marine Ecology Progress Series*, 106, 139-146. <https://www.int-res.com/articles/meps/106/m106p139.pdf>
- Piazzì, L., Balata, D., & Cinelli, F. (2004). Species composition and morphological groups of macroalgal assemblages around Gorgona Island (north-western Mediterranean Sea). *Cryptogamie Algologie*, 25, 19-38. <https://eurekamag.com/research/012/573/012573871.php>
- Poulin, M., Berard-Therriault, L., & Cardinal, A. (1986). *Fragilaria* and *Synedra* (Bacillariophyceae), a morphological and ultrastructural approach. *Diatom Research*, 1, 99-112.
- Precali, R., Giani, M., Marini, M., Grilli, F., Ferrari, C. R., Pečar, O., & Paschini, E. (2005). Mucilaginous aggregates in the northern Adriatic in the period 1999-2002: typology and distribution. *Science of the Total Environment*, 353 (1), 10-23. <https://doi.org/10.1016/j.scitotenv.2005.09.066>
- Prokic, I., Brümmer, F., Brügge, T., Görtz, H. D., Gerdt, G., Schütt, C., Ellbrächter, M., & Müller, W. E. (1998). Bacteria of the genus *Roseobacter* associated with the toxic dinoflagellate *Prorocentrum lima*. *Protist*, 149, 347-357.
- Round, F. E., Crawford, R. M., & Mann, D. G. (1990). *The Diatoms; Biology & Morphology of the genera*. Cambridge University Press, 747 pp.
- Round, F. E. (1984). *The Ecology of Algae*. Cambridge University Press, 653 pp.
- Ruiz, M., Perez, M., & Romero, J. (2001). Effects of fish farm loadings on seagrass (*Posidonia oceanica*) distribution, growth and photosynthesis. *Marine Pollution Bulletin*, 42 (9), 749-760. [https://doi.org/10.1016/S0025-326X\(00\)00215-0](https://doi.org/10.1016/S0025-326X(00)00215-0)
- Sand-Jensen, K., & Borum, J. (1991). Interactions among phytoplankton, periphyton, and macrophytes in

- temperate freshwaters and estuaries. *Aquatic Botany*, 41, 137-176.
- Sayın, E., & Beşiktepe, S. T. (2010). Temporal evolution of the water mass properties during the Eastern Mediterranean Transient (EMT) in the Aegean Sea. *Journal of Geophysical Research*, 115, 1-9. <https://doi.org/10.1029/2009JC005694>
- Siokou-Frangou, I., Zervoudaki, S., Epaminondas, D. C., Zervakis, V., & Georgopoulos, D. (2009). Variability of mesozooplankton spatial distribution in the North Aegean Sea, as influenced by the Black Sea waters outflow. *Journal of Marine Systems*, 78, 557-575. <https://doi.org/10.1016/j.jmarsys.2008.12.025>
- Sullivan, M. J. (1979). Epiphytic diatoms of three seagrass species in Mississippi Sound. *Bulletin of Marine Science*, 29, 459-464. <https://www.scribd.com/document/291108689/Epiphytic-Diatoms-of-Three-Seagrass-Species-in-Mississippi-Sound-Ecologia>
- Terrados, J., & Pons, M. J. F. (2008). Epiphyte load on the seagrass *Posidonia oceanica* (L.) Delile does not indicate anthropogenic nutrient loading in Cabrera Archipelago National Park (Balearic Islands, Western Med.). *Scientia Marina*, 72 (3), 503-510. <https://doi.org/10.3989/scimar.2008.72n3503>
- Tomas, C. (1995). *Identifying marine diatoms and dinoflagellates*. London: Academic Press Inc.
- Totti, C., Poulin, M., Romagnoli, T., Perrone, C., & Pennesi, C. (2009). Epiphytic diatom communities on intertidal seaweeds from Iceland. *Polar Biology*, 32, 1681-1691. <https://doi.org/10.1007/s00300-009-0668-4>
- Trautman, D. A., & Borowitzka, M. A. (1999). Distribution of the epiphytic on *Posidonia australis* and *Posidonia sinuosa*, two seagrasses with differing leaf morphology. *Marine Ecology Progress Series*, 179, 215-229. <https://pdfs.semanticscholar.org/db55/2c52572bfa0f1bed0ecd3e954b98c734f6d1.pdf>
- Tsirika, A., Skoufas, G., & Haritonidis, S. (2007). Seasonal and bathymetric variations of epiphytic macroflora on *Posidonia oceanica* (L.) Delile leaves in the National Marine Park of Zakynthos (Greece). *Marine Ecology*, 28, 146-153. <https://doi.org/10.1111/j.1439-0485.2007.00170.x>
- Turki, S. (2005). Distribution of toxic dinoflagellates along the leaves of seagrass *Posidonia oceanica* and *Cymodocea nodosa* from the Gulf of Tunis. *Cahiers de Biologie Marine*, 46, 29-34. [https://www.researchgate.net/publication/279550325\\_Distribution\\_of\\_toxic\\_dinoflagellates\\_along\\_the\\_leaves\\_of\\_seagrass\\_Posidonia\\_oceanica\\_and\\_Cymodocea\\_nodosa\\_from\\_the\\_Gulf\\_of\\_Tunis](https://www.researchgate.net/publication/279550325_Distribution_of_toxic_dinoflagellates_along_the_leaves_of_seagrass_Posidonia_oceanica_and_Cymodocea_nodosa_from_the_Gulf_of_Tunis)
- Turley, C. M., Bianchi, M., Christaki, U., Conan, P., & Harris, J. R. W. (2000). Relationship between primary producers and bacteria in an oligotrophic sea—the Mediterranean and biochemical implications. *Marine Ecology Progress Series*, 193, 11-8. <https://doi.org/10.3354/meps193011>
- Uçkaç, S. (2005). Sea surface variability in the Aegean Sea. *E.U. Journal of Fisheries & Aquatic Sciences*, 22, 129-135. <https://doi.org/10.12714/egejfas.2005.22.1.5000156899>
- UNEP/GPA. (2006). The state of the marine environment: trends and processes. UNEP/GPA, The Hague.