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Distribution and phenology of the marine phanerogam *Posidonia oceanica* in the Pagassitikos Gulf, Greece

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Marine phanerogams are spread all over the world. Five different species exist in the Mediterranean. In Pagassitikos Gulf, a shallow semi-closed embayment in the western Aegean Sea (Greece), four species are encountered: *Posidonia oceanica* (L.) Delile, *Cymodocea nodosa* (Ucria) Ascherson, *Zostera noltii (nana)* Hornemann and *Halophila stipulacea* (Forsskål) Ascherson. The latter is a Lessepsian immigrant, which entered the eastern Mediterranean through the Suez Canal, after its opening (1864). The distribution and ecology of marine phanerogams in Pagassitikos Gulf are studied, with special emphasis to *Posidonia oceanica* primary production and epiphytes. Shoot density of *P. oceanica* meadows, number of leaves per shoot, Leaf Standing Crop, Leaf Area Index, coefficient A and epiphytic algae of *P. oceanica* are the main results that are presented below.

Key words: Marine phanerogams, *Posidonia oceanica*, epiphytes, Pagassitikos.

INTRODUCTION

The marine phanerogams contribute significantly to the balance of littoral ecosystems and are referred to as the "constructors" of ecosystems (Delépin *et al.*, 1987). They are characterized by high primary production and high oxygen generation (Mazzella *et al.*, 1992; Pergent-Martini *et al.*, 1994). They contribute to the formation of bottoms and coasts. They offer the habitat for flora and fauna, providing shelter and food to many organisms (Delépin *et al.*, 1987). Thus, they constitute a complex benthic society of the Mediterranean littoral ecosystems, whose evolution has been the subject of many studies (Mazzella *et al.*, 1986; Boudouresque *et al.*, 1989).

Globally, about 58 seagrass species belonging to two orders (Hydrocharitales and Najadales), four families (Hydrocharitaceae, Posidoniaceae, Cymodoceaceae and Zosteraceae), and 12 genera (*Enhalus*, *Thalassia*, *Halophila*, *Posidonia*, *Syringodium*, *Halodule*, *Cymodocea*, *Amphibolis*, *Thalassodendron*, *Zostera*, *Heterozostera* and *Phyllospandix)* are recognized (Kuo & McComb, 1989). Most species form extensive submarine meadows (beds, prairies, herbiers) in the sublittoral zone. *Posidonia oceanica* grows from the water surface down to at least 30 - 40 m, or down to the limit of the well-lit zone, which varies from area to area (Den Hartog, 1970).

In Pagassitikos Gulf four species of seagrasses have been found: *Posidonia oceanica* (Linnaeus) Delile, *Cymodocea nodosa* (Ucria) Ascherson, *Zostera noltii* Hornemann (= *Zostera nana* Roth) and *Halophila stipulacea* (Forsskål) Ascherson. In other Greek areas, an additional species of seagrasses, *Ruppia maritima* L., has been found in brackish waters (Malea *et al.*, 2004). The existence of *Zostera marina* in the Greek coasts is nowadays disputed (Haritonidis, 1998).

The distribution and the phenology of *P. oceanica* in Pagassitikos Gulf were investigated. The epiphytic macrophyceae found in association with *P. oceanica* have also been identified.

MATERIALS AND METHODS

Study area

Pagassitikos Gulf is a semi-closed marine area of the western Aegean Sea, covering about 627 km^2, with a maximum depth of 102 m. It communicates with the Aegean through a channel 5.9 km wide and 88 m

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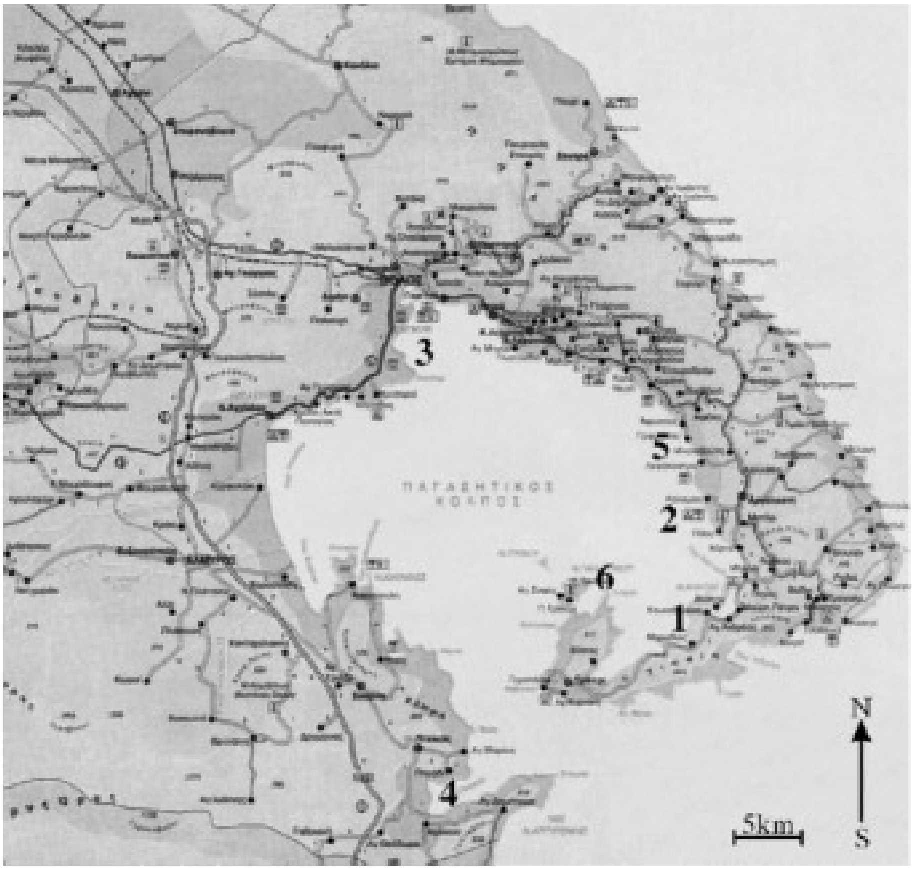

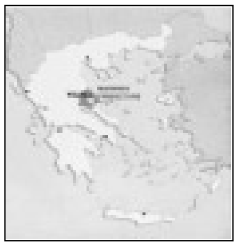

FIG. 1. Pagassitikos Gulf (Greece). The sampling areas are:
1. Baltoudi
2. Kalamos
3. Vathi
4. Lihoura
5. Razi
6. Trikeri island
(Prefecture of Magnesia).

deep (Fig. 1).

A general view of Pagassitikos Gulf was taken by means of a small vessel and a diver before the study regions were determined. Environmental criteria were taken into account for that purpose. The sampling sites were:

1. Baltoudi (Ba03 & Ba10, 3 m and 10 m deep, respectively). It is situated on the SE coasts, near the entrance of the gulf.
2. Kalamos (Ka03, 3 m deep). It is located in the middle of the eastern part of the gulf, in an area free of polluting sources.
3. Vathi (Va10, 10 m deep). It is located on the northern side of the gulf, near and west of the Volos bay. It is located near the outflow of the municipal sewage pipe of Volos - N. Ionia. The sewage is biologically purified before being cast into the sea. It is also affected by the fresh waters (polluted by fertilizers) from Eastern Thessaly, which are discharged in Volos bay, flowing into the bay through the tunnel of Karla.
4. Lihoura (Lh03 & Lh10, 3 m and 10 m deep). It is located on the S-SW coast, near the entrance of Pagassitikos Gulf. It is away from domestic wastes, but the wider region has occasionally received olive-press sewage. Nowadays, it presents mild touristic and agricultural development.

Sampling

Samplings were carried out by scuba diving. A metal quadrangle 40 × 40 cm was used for counting the number of *P. oceanica* shoots per framework (Panayotidis *et al*., 1981; Pergent-Martini *et al*., 1994). At each station the framework was placed at five different sites (one in the center and four around it) in the meadows of *P. oceanica*. This has been repeated six times. Twenty rhizomes were uprooted from each station for phenological study and 8-10 for the identification of epiphytes. The results that are presented here refer to July 2003 for the phenological measurements and to August 2003 for the epiphytes (Fig. 2).

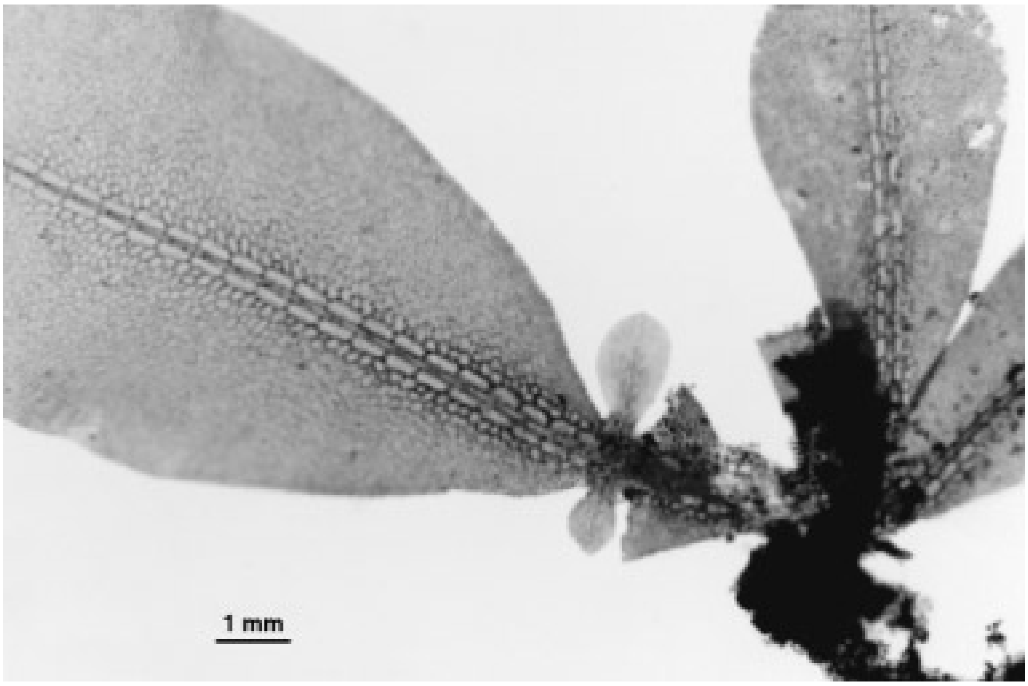

FIG. 2. *Apoglossum ruscifolium*, an epiphyte of *Posidonia oceanica* (Delesseriaceae – Ceramiales – Florideophycideae – RHODOPHYCEAE).

Material treatment

The collected rhizomes were immediately placed in vessels filled with seawater and transferred to the lab for treatment and detailed study. Samples to be preserved were kept submerged in seawater solutions with 60% ethanol.

The shoots were washed in seawater. The leaves were separated into three categories: adults, intermediates and juveniles (Giraud, 1977). The epiphytes were scratched away from the leaves and the necessary phenological measurements were carried out: leaf number, length of sheaths, blades and brown part of leaves, width of leaves. The integral and not integral leaves were recorded for the coefficient A of adult or intermediate leaves to be calculated (percentage of leaves that have lost their apex) (Giraud, 1977; Pergent *et al.*, 1995). The leaves were, then, dried at 60°C for 48 h and weighed (sheaths, adult blades, intermediate plus juvenile leaves and brown parts separately) by means of a precision balance (± 0.1 mg).

Based on the above data, the following items were measured:

1. Shoot densities (shoots/m^2)
2. Number of leaves per shoot
3. Length of adult leaves
4. Leaf area per shoot (cm^2/sh.) and per m^2 (m^2/m^2) (Leaf Area Index)
5. Photosynthetic (green) leaf area per shoot (cm^2/sh.) and per m^2 (m^2/m^2)
6. Coefficient A
7. Leaf biomass per shoot (g d.w./sh.) and per m^2 (g d.w./m^2) (Leaf Standing Crop).

Epiphytic macroalgae were identified and recorded. The identification took place according to Tsekos & Haritonidis (1977), Haritonidis (1978), Coppejans (1983), Diapoulis (1983), Delépin *et al.* (1987) and Lazaridou (1994). Statistical analysis was performed by means of the STATISTICA software (ANOVA, Duncan's multiple range test).

RESULTS

At Baltoudi bay, whose bottom in the shallows is muddy, a *C. nodosa* meadow exists (0.50-2 m deep). Further down a well-developed *P. oceanica* meadow appears (2-15 m deep) (Fig. 3).

At Kalamos, a clean bay with a relatively weak wave action, the meadow of *C. nodosa* is found at a depth of about 0.40 m. At a depth of 1 m a *P. oceanica* meadow begins, which terminates abruptly at the depth of 4 m.

FIG. 3. Morphological characteristics of *Posidonia oceanica*: 1. Rhizomes, 2. Roots, 3. Leaf bundles, 4. Scales.

At Vathi, *C. nodosa* was found to be present in the shallows. A *P. oceanica* meadow begins at a depth of about 7 m and disappears at 16 m. At that depth the bottom becomes muddy, turbitity increases, while *H. stipulacea*, accompanied by the coenocytic green alga *Caulerpa prolifera*, appears in small spots. *Halophila stipulacea* disappears beyond the depth of 17 m.

At Lihoura, in the shallows (0.3-0.6 m deep), the bottom is muddy and scattered rhizomes of *Z. noltii* are met. Further down, a *C. nodosa* meadow appears and at a depth of about 1.5 m a well-defined meadow of *P. oceanica* begins, extending down to about 18 m deep.

At Razi, from 0.6 m to 4 m deep, spots of *C. nodosa* with rare rhizomes of *Z. noltii* are found. Beyond the depth of 4 m and down to 11 m, the Lessepsian immigrant *H. stipulacea* appears, forming an unmixed bed. Its maximum density is encountered at about 6 to 7 m deep. No companion algae were found. The phenological results are presented in Table 1.

A number of 64 epiphytic taxa of macroalgae were identified in the six sites: 51 Rhodophyceae, 5 Phaeophyceae and 8 Chlorophyceae (Table 2). Two macroalgae were found as companions of seagrasses in the area under study. *Porphyra linearis* (Rhodophyceae) accompanies *P. oceanica* (station Ba10) and the coenocytic ammophile alga *C. prolifera* (Chlorophyceae) accompanies *H. stipulacea* (station Va10).

DISCUSSION – CONCLUSIONS

Pagassitikos Gulf is generally considered as oligotrophic (Friligos *et al*., 1990). It rarely exhibits eutrophic conditions except for its inner part, in the Volos bay.

Shoot density of *P. oceanica* in the study areas (Table 1) is generally lower than that measured at other sites of western Mediterranean such as Ischia (Italy), Alghero (Italy), Port-Cros (France), and even at Saronikos Gulf (Table 4). It is obvious that shoot densities at a depth of 3 m are larger than those at 10 m, while the meadows at larger depths become more homogeneous (smaller standard deviation).

The numbers of leaves per shoot at Pagassitikos coasts are approximately equal to or slightly larger than those at Saronikos coasts and Port-Cros (Table 4). The mean length of adult leaves at Pagassitikos stations, in summer, is generally larger at smaller depths (Tables 1 and 4). A similar result is found at Port-Cros (Pergent & Pergent-Martini, 1988) and at Ischia (Pergent-Martini *et al*., 1994). The leaves at Pagassitikos Gulf are smaller than those of Ischia

TABLE 1. Phenological measurements in *Posidonia oceanica* meadows in July 2003 from Pagassitikos Gulf. Each value represents the mean value ± sd of 20 shoots from each station. The shoot density was measured, on the whole, 30 times at each station

Sampling site	Shoot density	Number of leaves per shoot	Length of adult leaves (cm)	Leaf area per shoot (cm^2/sh.)	Leaf Area Index (m^2/m^2)	Green leaf area/shoot (cm^2/sh.)	Green leaf area/m^2 (m^2/m^2)	Coefficient A% of adult leaves	Leaf biomass/shoot (g.d.w./sh.)	Leaf Standing Crop (g.d.w./m^2)
Ba03	249 ± 79	5.80 ± 1.11	52.3 ± 12.1	219.6 ± 57.3	5.47 ± 1.45	178.3 ± 67.4	4.44 ± 1.71	53	1.068 ± 0.301	265.9 ± 76.2
Ba10	125 ± 45	4.75 ± 0.97	37.9 ± 14.2	114.5 ± 60.0	1.43 ± 0.73	90.7 ± 49.5	1.13 ± 0.60	40	0.631 ± 0.350	78.9 ± 42.7
Ka03	435 ± 175	4.35 ± 0.88	52.9 ± 14.3	165.2 ± 38.1	7.19 ± 1.67	154.6 ± 35.7	6.72 ± 1.57	59	0.955 ± 0.262	415.6 ± 114.8
Va10	162 ± 56	5.80 ± 1.20	36.7 ± 6.7	145.4 ± 34.4	2.36 ± 0.54	133.4 ± 33.7	2.16 ± 0.53	26	0.668 ± 0.165	108.2 ± 26.0
Lh03	330 ± 83	4.65 ± 0.88	38.3 ± 7.5	121.7 ± 46.4	4.02 ± 1.56	102.7 ± 38.3	3.39 ± 1.28	37	0.606 ± 0.236	200.1 ± 78.9
Lh10	201 ± 57	5.00 ± 1.21	40.3 ± 13.8	172.9 ± 59.5	3.47 ± 1.17	153.5 ± 60.7	3.09 ± 1.19	18	0.730 ± 0.281	146.8 ± 55.1

TABLE 2. Epiphytic macroalgae taxa associated with *P. oceanica* from Pagassitikos Gulf, in August 2003

Taxa		**Ba03**	**Ba10**	**Ka03**	**Va10**	**Lh03**	**Lh10**
Cladophora laetevirens	Cl	+	–	–	–	–	–
Cladophora pellucida	Cl	+	+	–	+	–	–
Cladophora sericeae	Cl	+	–	+	+	+	+
Cladophora sp.	Cl	–	+	–	–	–	–
Cladophora vagapunda	Cl	+	+	–	+	–	+
Udotea petiolata	Cl	–	+	–	+	–	+
Pseudochlorodesmis furcellata	Cl	+	+	–	–	–	–
Valonia urticularis	Cl	–	–	+	–	–	–
Dictyota dichotoma	Ph	+	+	–	+	+	+
Dilophus sp.	Ph	+	+	–	+	+	+
Halopteris filicina	Ph	–	–	+	–	–	+
Sphacelaria cirrosa	Ph	–	+	–	+	+	+
Sphacelaria tribuloides	Ph	+	+	+	+	–	–
Aglaothamnion tennuissimum	Rd	+	–	–	+	–	–
Alsidium corallinum	Rd	+	+		+	+	+
Anotrichium barbatum	Rd	–	+	–	+	+	+
Anotrichium furcellatum	Rd	+	+	–	+	+	+
Antithamnion cruciatum	Rd		+			+	
Antithamnion piliferum	Rd	–	–	–	–	+	–
Antithamnion tennuisimum	Rd	–	–	+	+	–	–
Apoglossum ruscifolium	Rd	–	–	+	–	–	–
Bangia fuscopurpurea	Rd	+	+		+	+	+
Botryocladia boergesenii	Rd	–	–	+	–	–	–
Calithamnion corymbosum	Rd	–	–	–	–	–	+
Calithamnion sp.	Rd	+	–	–	+	+	–
Ceramium byssoideum	Rd	+	–	–	–	–	–
Ceramium circinatum	Rd	–	–	–	+	+	+
Ceramium codii	Rd	+	+		+	+	+
Ceramium comptum	Rd		+			+	+
Ceramium diaphanum	Rd	+	+	–	+	+	+
Ceramium fastigiatum	Rd	+	–	–	–	–	–
Ceramium tenuissimum	Rd	+	+	–	+	+	–
Champia parvula	Rd	+	+	–	–	+	+
Chondria dasyphylla	Rd	+	+	–	+	–	+
Cruania attenuata	Rd	–	–	–	+	+	+
Dasya rigidula	Rd	+	+	+	–	+	–
Dasyopsis plana	Rd	+	+	–	–	–	–
Dipterosiphonia rigens	Rd	+	+	+	–	–	–
Erithrotrichia carnea	Rd	+	+	–	+	+	+
Fosliella farinosa (Melobesia f.)	Rd	–	–	–	–	+	+
Gelidium pussilum (crinale)	Rd	+	+	+	–	–	–
Griffithsia barbata	Rd	+	–	–	–	–	–
Herposiphonia secunda v.tenela	Rd	–	+	–	+	+	–
Laurencia obtusa	Rd	+	+	–	+	+	+
Lejolisia mediterrania	Rd	+	+	–	+	+	+
Lomentaria chylocladiella	Rd	+	+	–	+	–	+
Lomentaria ercegovicii (tenera)	Rd	–	+	–	+	–	+
Lophosiphonia cristata	Rd	–	+	–	+	–	–
Melobesia membranacea	Rd	+	+	+	+	+	+
Nitophyllum micropunctatum	Rd	–	+	+	–	–	–
Peyssonnelia rubra	Rd	–	+	+	+	–	–
Pneophyllum lejolisii	Rd	+	+	+	+	+	+
Polysiphonia certularioides	Rd	+	+	–	+	–	+
Polysiphonia deusta	Rd	+	+	–	+	–	+
Polysiphonia fibrillosa	Rd	+	–	–	–	–	+
Polysiphonia fruticulosa	Rd	+	+	–	–	+	+
Polysiphonia furcellata	Rd	+	–	–	–	+	+
Polysiphonia setacea	Rd	–	+	+	+	–	–
Porphyra linearis	Rd	–	+	–	–	–	–
Rhodochorton purpureum	Rd	+	+	–	+	+	+
Rhodophyllis divaricata	Rd	–	+	–	–	–	–
Spermothamnion repens	Rd	+	+	–	–	–	–
Spyridia filamentosa	Rd	+	+	–	+	+	–
Stylonema alsidii	Rd	–	+	–	+	–	–
Rhodophyceae	51	31	36	11	29	26	26
Phaeophyceae	5	3	4	2	4	3	4
Chlorophyceae	8	5	5	2	4	1	3
Total number of algae	64	39	45	15	37	30	33

TABLE 3. Comparison of means of Leaf Standing Crop (two-way ANOVA, Duncan's multiple range test, a = 0.050)

Between sites		**Ba03**	**Ba10**	**Va10**	**Lh03**	**Lh10**
	Ka03	$p = 0.0001$	$p = 0.0006$	$p = 0.0004$	$p = 0.0002$	$p = 0.0004$
		probabilities p for post-hoc tests, d.f. = 19				
Between depths			**3 m**			
		10 m	$p = 0.0001$, d.f. = 59			

and Port-Cros at similar depths (Table 4).

Leaf area per shoot in Pagassitikos Gulf is greater at 3 m deep. Compared to that of Ischia is rather similar at the depth of 3 m, but significantly lower at 10 m deep (Table 4). Leaf Area Index (LAI) in the study areas decreases with depth, due to the decrease of shoot density. The LAIs in Pagassitikos Gulf are lower than those at other areas, mainly because of the lower shoot density (Giraud *et al.*, 1979; Panayotidis & Simboura, 1989) (Table 4).

Biomass of leaves per shoot is larger at Baltoudi (3 m) and Kalamos (3 m) (Table 1). Leaf Standing Crop (g/m^2) is significantly higher ($p < 0.05$) at Kalamos in comparison to other areas (Table 3), due to the higher shoot density. The LSC at 3 m is higher ($p < 0.05$) than that at a depth of 10 m (Table 3).

TABLE 4. Phenological characteristics of *P. oceanica* from different areas

Summer results		Depth	Shoot density (sh./m^2)	Number of leaves per shoot	Length of adult leaves (cm)	Leaf area per shoot (cm^2/sh.)	Leaf Area Index (m^2/m^2)	LSC (g.d.w./m^2)
Pagassitikos Gulf, Greece,		3 m	338 ± 93	4.9 ± 0.7	48 ± 8	169 ± 49	5.56 ± 1.59	294 ± 22
July 2003		10 m	163 ± 38	5.2 ± 0.6	38 ± 2	144 ± 29	2.42 ± 1.02	111 ± 15
Other sites according to literature								
Reference	**Study area**							
Panayotidis	Saronikos Gulf	Inner	500-700	5		150	15	500
& Simboura,	(Greece)	Outer	750	4-5		150	20	1000
1989	Summer	Aegina	600-700	4-5		200	15	500-700
Gambi *et al.*,	Ischia (Italy)	3 m	325 ± 35		61 ± 4	166 ± 13		
1989	July	10 m	246 ± 34		102 ± 3	272 ± 17		
Pergent &	Port-Cros	2 m	645	4.4	68.6			
Pergent-Martini,	(France)							
1988	July	11 m	317	4.5	62.2			
Pergent-Martini	Ischia	5 m	473		73			
et al., 1994	(Italy)							
	July	10 m	351		66			
Pergent-Martini	Alghero	5 m	525					
et al., 1994	(Sardinia)							
	Italy, July	10 m	518					
Giraud	C. Aragon	2 m	950				16.32	
et al., 1979	(Ischia)							
	P. Lume	10 m	550				14.27	
	(Ischia)							

The LSCs of this study are smaller compared with those in the Saronikos Gulf (Panayotidis & Simboura, 1989) (Table 4). Coefficient A in the study area is larger at a depth of 3 m than that at 10 m deep (Table 1). This difference may imply higher hydrodynamism and/or more grazing at smaller depths (Pergent & Pergent-Martini, 1988).

The study of epiphytic flora has demonstrated a numerical dominance of Rhodophyceae over other classes (Table 2). The number of epiphytes is minimum at Ka03 (a clean sea area) and maximum at Ba10.

The meadows of marine phanerogams in Pagassitikos Gulf appear in various forms and depths. *Posidonia oceanica* is usually found beyond a depth of 1.5 m and disappears at a depth of 15-18 m. This rather small depth is probably due to the restricted transparency (18-25 m) of the water in this area (Georgopoulos & Theocharis, 1983). *Cymodocea nodosa* extends from a depth of 0.6-1 m down to 8-10 m. *Zostera noltii* is found scattered either on its one or mixed with *C. nodosa*. *Halophila stipulacea* forms homogeneous beds at Razi (4-11 m deep), rare spots together with *C. prolifera* on the borders of Volos bay (Vathi) and extensive beds at Trikeri island.

Despite the meticulous research undertaken in Pagassitikos Gulf, the species *Zostera marina* and *R. maritima* have not been found.

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