SEASONAL VARIABILITY OF WATER COLUMN BIOGEOCHEMISTRY IN THREE COASTAL AREAS IN THE IONIAN AND AEGEAN SEAS

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Abstract

The dynamics of phyto- and microzooplankton communities was investigated during July, November and April at three coastal stations in the Ionian and Aegean seas coupled with measurements of hydrographical and chemical parameters (nutrients, POC, PON). The values determined for most variables were among the lowest reported for such environments in the Mediterranean. In April nutrients, Chla, POC and PON showed maximal concentrations which resulted in an increase of the phyto- and zooplankton abundance (by a factor of 10) and species richness (by a factor of 2) in comparison to November. In April, diatoms dominated in the Ionian sites and dinoflagellates in the Aegean one, while the opposite was observed in November. The high abundance of ciliates and flagellates found at Sounion suggests the importance of the role of the microbial food web in this region.

Key-words: coastal waters, nutrients, plankton, organic matter, Eastern Mediterranean

Introduction

Coastal ecosystems contribute to the global carbon fixation an amount disproportionally higher than the area they occupy (1). In the oligotrophic Eastern Mediterranean Sea (2) this contrast between coastal and offshore ecosystems is even more pronounced and imposes the need for integrated investigation of the coastal marine ecosystems. Several studies have addressed aspects of the dynamics of phytoplankton and nutrients in eutrophic bays or polluted areas (3-7), while only limited information is available on the dynamics of undisturbed coastal ecosystems (8, 9). Three coastal areas in the Aegean and Ionian seas, were selected for the investigation of the seasonal variability in nutrient availability and the response of the phyto- and microzooplankton assemblages. Since none of these sites is influenced by urban wastes or any other evident anthropogenic activity, this study could be considered as a comparison between the Ionian and Aegean undisturbed coastal ecosystems.

Materials and methods

During three cruises in July, November 1995 and April 1996, sampling was performed from the R/V *Philia* at three coastal areas, two in the Ionian Sea (Cephalonia Bay and the eastern coast of Ithaki) and one in the Aegean Sea (Sounion). All stations were located at a distance of less than one km from the shore (at depths between 25 and 45 m) and none of them is influenced by urban waters or any other evident anthropogenic activity. Vertical profiles of salinity and temperature were measured by means of a SEABIRD-19 CTD. Current meters (AANDERAA CM-7) were deployed at the mean depth of each site. Water samples for plankton community analysis and measurements of nutrients (total inorganic N: TIN, PO_4, SiO_2), particulate organic carbon (POC), particulate organic nitrogen (PON) and chlorophyll *a* (Chl a) were taken with 5-litre Niskin bottles at depths of 1, 10, 20, 30 and 40 m. Plankton samples for microscopy were preserved with an acid Lugol solution. On board the ship, water from each sample was filtered onto Whatman GF/C filters. Both filters (for pigments and POC-PON analysis) and filtered water destined for nutrient analysis were stored at -18°C. Analyses for the concentrations of nutrient species were performed using standard chemical methods (10), chloroplastic pigments were determined fluorometrically (11) by means of a Turner 112 fluorometer, and POC-PON was analyzed with a Perkin-Elmer CHN elemental analyzer. Phyto- and microzooplankton were identified and counted with an inverted microscope (Olympus IX-70) using the Utermöhl technique (12).

One- and two-way analyses of variance as well as the Tukey test were used in order to detect significant differences among seasons and sites concerning the levels of nutrients, chlorophyll and POC-PON. Multivariate analysis on species-abundance data was performed using non-metric Multidimensional Scaling (MDS) (13). A transformation of log(x+1) as well as the Bray-Curtis similarity index were also used.

Results

A weak stratification appeared at Cephalonia during July and a more conspicuous one at Ithaki during the same period. At Sounion, the strong wind-driven currents induced a vertical mixed layer throughout the year. During November and April, the water column at all three sites appeared well mixed. In general, nitrate comprised approximately 65% of the total inorganic nitrogen, ammonia 25% and nitrite 10%. At all sites, total inorganic N (TIN) was minimal during July (Table 1). The station at Ithaki showed higher TIN concentrations in comparison to the other sites especially in April. Phosphate did not present a uniform distribution; Sounion displayed minimal phosphate concentrations in July, Ithaki during November and Cephalonia during April. All sites presented maximal concentrations of silicates during April, and minimal concentrations during July. According to a two factor (season and site) analysis of variance, significant differences were detected for silicates between April and July, for TIN between April and the two other seasons and for TIN between Ithaki and Sounion (post hoc comparisons in Table 2). One way analysis of variance for the concentrations of all nutrient species revealed no significant differences among depths ($p<0.05$) for any season or site.

Table 1. Concentrations of chlorophyll *a* ($\mu g\ l^{-1}$), nutrients ($\mu mol\ l^{-1}$) and POC, PON ($\mu g\ l^{-1}$) at the sites studied

Season	Site		TIN	PO_4	SiO_2	Chl a	POC	PON
July	Cephalonia	*av.*	0.66	0.06	0.74	0.27	218	17
		range	0.52-0.82	0.04-0.08	0.49-0.99	0.14-0.50	166-297	11-25
	Ithaki	*av.*	1.60	0.02	0.98	0.15	131	17
		range	0.50-5.35	0.01-0.04	0.36-2.72	0.10-0.24	111-142	13-19
	Sounion	*av.*	0.44	0.01	0.52	0.11	130	19
		range	0.35-0.51	0.01-0.02	0.43-0.60	0.10-0.13	94-179	13-29
October	Cephalonia	*av.*	1.39	0.07	1.39	0.38	120	22
		range	0.40-2.84	0.02-0.27	0.64-5.91	0.17-0.85	95-159	16-28
	Ithaki	*av.*	1.57	0.02	0.95	0.14	76	9
		range	0.51-3.57	0.01-0.07	0.48-1.76	0.03-0.20	56-97	7-11
	Sounion	*av.*	0.91	0.04	0.68	0.23	97	14
		range	0.15-2.26	0.03-0.09	0.45-1.04	0.19-0.28	74-136	11-19
April	Cephalonia	*av.*	0.95	0.03	1.26	0.50	277	29
		range	0.84-1.06	0.02-0.03	1.17-1.36	0.38-0.61	228-360	24-35
	Ithaki	*av.*	3.34	0.05	1.52	0.19	136	14
		range	1.58-5.91	0.02-0.11	1.09-2.15	0.12-0.23	74-208	10-18
	Sounion	*av.*	1.37	0.03	1.61	0.24	115	13
		range	0.94-2.56	0.01-0.06	1.25-1.90	0.15-0.35	83-178	8-17

Table 2. Results of two-way ANOVA for all the parameters sampled.

Variable	Source of variability	df	F	p		TUKEY post hoc test				
						July	Nov		Ceph	Ithaki
TIN	Season	2	8.95	0.000	Nov	ns		Ithaki	ns	
	Site	2	4.62	0.014	April	**	*	Sounion	ns	*
PO_4	Season	2	0.40	ns						
	Site	2	1.49	ns						
						July	Nov			
SiO2	Season	2	3.38	0.042	Nov	ns				
	Site	2	0.29	ns	April	*	ns			
Chla	Season	2	4.73	0.013		July	Nov		Ceph	Ithaki
	Site	2	14.73	0.000	Nov	ns		Ithaki	**	
					April	*	ns	Sounion	**	ns
						July	Nov		Ceph	Ithaki
POC	Season	2	27.99	0.000	Nov	**		Ithaki	**	
	Site	2	30.44	0.000	April	ns	**	Sounion	**	ns
						July	Nov		Ceph	Ithaki
PON	Season	2	4.67	0.014	Nov	ns		Ithaki	**	
	Site	2	24.29	0.000	April	ns	*èè	Sounion	**	ns

** p<0.05 ; ** p< 0.01; ns : non significant*

Chlorophyll *a* concentrations were maximal in April (Table 1) at the three sites (0.5 mg l^{-1} at Cephalonia, 0.19 mg $^{-1}$ at Ithaki, 0.24 mg l^{-1} at Sounion) and minimal during July (0.27 mg l^{-1} at Cephalonia, 0.15 mg l^{-1} at Ithaki, 0.11 mg l^{-1} at Sounion). During all seasons higher concentrations were noted at Cephalonia than at the other two sites (Table 1). These differences were significant according to the two factor analysis of variance (Table 2). One way analysis of variance for the concentrations of Chla revealed no significant differences among depths ($p<0.05$). Particulate organic carbon (POC) as well as particulate organic nitrogen (PON) concentrations were highest in April at all sites (77-359 mg C l^{-1}) while high values were also recorded in July. Among all sites, values were maximal at Cephalonia; these values