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Phytoplankton composition and biomass of the northern Adriatic lagoon of Stella Maris, Croatia

NEDA FANUKO[1*], MARKO VALČIĆ[2]

[1] Faculty of Arts and Sciences, 51000 Rijeka, Omladinska 14, Croatia

[2] Faculty of Maritime Studies, 51000 Rijeka, Studentska 2, Croatia

This study provides information on the seasonality of phytoplankton abundance, biomass expressed as cell volume and cell carbon, as well as species composition, in the small, shallow, brackish northern-Adriatic lagoon of Stella Maris near Umag (Croatia). The lagoon is permanently connected with the adjacent sea. Wide seasonal temperature and salinity excursions regulate phytoplankton assemblages. Unlike other Adriatic lagoons, the lagoon of Stella Maris showed moderate phytoplankton abundance, cell volume and carbon content and a high number of species. The specific diatom volumes from the Stella Maris lagoon were higher than those found in other Adriatic lagoons, whereas the specific volumes of dinoflagellates were in the same range. Diatoms represented 55% of all the species found, but there was a considerable contribution of nanoplankton and dinoflagellates in the annual outbursts.

Keywords: phytoplankton, taxonomy, cell volume, cell carbon, coastal lagoon, Adriatic Sea

Introduction

The lagoons of the northern Adriatic Sea are characterized by shallowness, strong influence from the adjacent land and considerable fluctuations in hydrographic conditions. The lagoons of the northwest Adriatic coast have been studied with much attention for over two centuries (NARDO 1847, NINNI 1906, BABIĆ 1911, KIESSELBACH,1936, BRUNETTI et al.1983, OREL et al. 2001, COVELLI et al. 2005), particularly with respect to lagoon phytoplankton (VATOVA 1940, 1961; MARCHESONI 1954; TOLOMIO 1982; TOLOMIO and BULLO 2001; FACCA et al. 2002, 2003; SOCAL et al. 2006). However, on the eastern coast the few lagoons have been investigated only sporadically (ZANON 1941; MALEJ et al.1979; FANUKO 1979, 1984; DE MENECH 2005; FANUKO et al. 2008).

This paper provides information on phytoplankton assemblages, their species composition, abundance, cell volume and carbon in the small, shallow brackish lagoon of Stella Maris near Umag (Croatia).

* Corresponding author, e-mail: fanukon@ffri.hr

Materials and methods

Study area

The study area is a small, natural macro-tidal northern Adriatic lagoon (45°27'06.35''N, 13°30'59.80''E), only 15,000 square meters large and 2 m deep in most parts, permanently connected with the adjacent sea by a narrow channel, 6m wide and 40 m long (Fig. 1). The climate of the region is sub-Mediterranean with an average annual air temperature of 16.4 °C and a rainfall up to 1,000 mm per year, distributed mostly over autumn and winter. In the lagoon there are several submarine springs, active mostly during late autumn and winter. The level and water exchange inside the lagoon is influenced generally by the tidal range of up to 2.04 m, while the prevailing weak winds from west and southwest probably represent an additional forcing factor. The euphotic zone comprises the whole water column. The water temperature varies in a wide range, from 4.2 °C in January to 30.2 °C in July and the salinity, ranging from 29 to 37, is directly influenced by daily events: rainfall and subsurface spring activities, with the highest values, above 33, observed in summer. The lagoon is located in the middle of a tourist resort, where bungalows are inhabited only during spring and summer. In 1979 the lagoon and the channel were deepened, a pier and lateral quays were erected, transforming the lagoon into a small marina, equipped with water and electricity supply, accessible to vehicles, with one hundred moorings for smaller boats anchoring between April and October, reaching the maximum number in August. During the cold part of the year the lagoon is entirely abandoned and the only human activity inside is sporadic fishing.

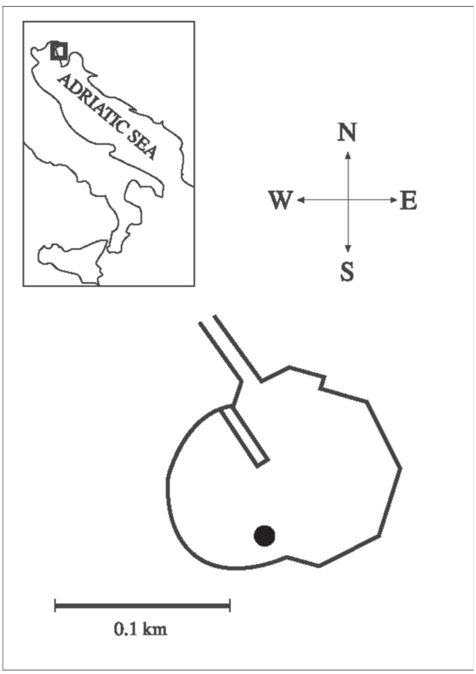

Fig. 1. Location of Stella Maris lagoon with sampling site

The sandy to muddy sediments are populated by eelgrass *Cymodocea nodosa* which dominates the macroalgae *Chaetomorpha sp*. and *Cystoseira sp*. in winter and spring and *Padina pavonica* in summer. In autumn and winter, when anthropogenic influence is sparse, the lagoon becomes a habitat for 3 species of water birds: *Tachybaptus ruficollis*, *Aythya fuligula* and *Larus genei*. Occasionally from May to September a mucilage phenomenon extending from surface to bottom is observed, in the same days but to a greater extent than in the outside sea.

Phytoplankton

From September 2004 to September 2005, with the exception of October, January and February, the sampling was carried out once or twice a month at the 1 m deep station. The phytoplankton samples for microscopic analysis were preserved with buffered formaldehyde (1.5% final concentration) and the subsamples (50 mL) were settled overnight in sedimentation chambers. The entire bottom chamber plate area was counted at 250× magnification for cells larger than 10 µm, whereas for smaller cells (< 10 µm) one transect of the chamber bottom was scanned at 500× magnification. The species were identified and classified according to STREBLE and KRAUTER (1984) for cyanobacteria, THRONDSEN (1997) for naked flagellates, HEIMDAL (1997) for coccolithophorids, PERAGALLO and PERAGALLO (1908), HUSTEDT (1930), HENDEY (1964) and HASLE and SYVERTSEN (1997) for diatoms, STEIDINGER and TANGEN (1997) for dinoflagellates. Cells of approximately 2 µm in size that were hard to identify were reported as minute nanoplankton.

During each count, linear measurements of cell size, made by ocular micrometer, were made for 3 to 5 specimens of perennial species and every specimen of rare species. These values were converted to specific average biovolume using the geometric formula of either a sphere, a parallelepiped, a cylinder, a cone or truncated cone, an ellipsoid or two composite geometric bodies. The average cell volume was converted to cell carbon using the conversion factor of 0.13 pg C μm^{-3} for armoured dinoflagellates and 0.11 pg C μm^{-3} for other phytoplankton groups (ANDERSSON and RUDEHÄLL 1993).

Results

Species composition and phytoplankton successions

The phytoplankton assemblage of the Stella Maris lagoon was composed of 151 taxa (Tab. 1). Diatoms were the dominant group (55% of all the species found), followed by dinoflagellates (28%) and prymnesiophytes (7%). The shallow lagoon assemblage was characterized by 21 genera of pennate diatoms that appeared throughout the year in low but steady number and were obviously well adapted to the fluctuating abiotic variables. The microscopic observations revealed that the winter specimens of these pennate diatoms had larger chloroplasts, which were more abundant and more intense in colour than those observed in the cells of the same species that appeared in summer.

The outbursts of abundance, cell volume or phytoplankton carbon were caused by other groups. In March 2005, when the sea temperature was 12 °C and the salinity 34.4, the coccolithophorid *Acanthoica aculeata* reached its maximum of 1.52×10^5 cells L^{-1}, while in May, when water temperature and salinity rose over 20 °C and 33 respectively, dinofla-

Tab. 1. List of the phytoplankton species found in the Stella Maris lagoon, their average cell volume and carbon content

Taxon	cell volume (µm³)	cell carbon content (pgC)
CYANOBACTERIA		
Aphanizomenon gracile Lemmermann	25	3
Dactylococcopsis acicularis Lemmermann	157	17
Oscillatoria sp.	19	2
Phormidium faveolarum Montagne ex Gomont	6	1
Synechococcus aeruginosus Nägeli	462	51
CRYPTOPHYCEAE		
Hillea fusiformis Schiller	14	2
CHRYSOPHYCEAE		
Dictyocha fibula Ehrenberg	2094	230
Meringosphaera tenerrima Lohmann	268	29
Mesocena polymorpha Lemmermann	3534	389
Uroglena volvox Ehrenberg	28	3
PRYMNESIOPHYCEAE		
Acanthoica aculeata Kamptner	133	15
Calyptrosphaera oblonga Lohmann	1047	115
Calciosolenia murrayi Gran	209	23
Emiliania huxleyi (Lohmann) Hay et Mohler	268	29
Michaelsarsia adriatica (Schiller) Manton, Bremer et Oates	335	37
Ophiaster formosum Gran	34	4
Ophiaster hydroideus (Lohmann) Lohmann	26	3
Prymnesium parvum Carter	56	6
Rhabdosphaera stylifera Lohmann	524	58
Syracosphaera pulchra Lohmann	717	79
BACILLARIOPHYCEAE		
Centrales		
Biddulphia biddulphiana (Smith) Boyer	395640	43520
Biddulphia titiana Grunow	339120	37303
Cerataulina pelagica (Cleve) Hendey	44179	4860
Chaetoceros affinis Lauder	15708	1728
Chaetoceros brevis Schütt	3402	374
Chaetoceros compressus Lauder	2650	291
Chaetoceros curvisetus Cleve	2011	221
Chaetoceros decipiens Cleve	282743	31102
Chaetoceros peruvianus Brightwell	261979	28818
Chaetoceros simplex Ostenfeld	34	4
Chaetoceros tetrastichon Cleve	942	104
Chaetoceros tortissimus Gran	877	96
Chaetoceros wighami Brightwell	1356	149
Coscinodiscus excentricus Ehrenberg	9770	1075

Tab. 1. – continued

T a x o n	cell volume (µm³)	cell carbon content (pgC)
Coscinodiscus perforatus Ehrenberg	1286	141
Guinardia flaccida Castracane (Peragallo)	1781283	195941
Hemiaulus hauckii Grunow	80592	8865
Leptocylindrus danicus Cleve	7853	864
Leptocylindrus minimus Gran	125	14
Melosira nummuloides Agardh	785	86
Melosira sulcata (Ehrenberg) Kützing	1155	127
Odontella mobiliensis (Bailey) Grunow	196250	21587
Proboscia alata (Brightwell) Sundström	6283	691
Pseudosolenia calcar avis (Schultze) Sundström	1178097	129591
Rhizosolenia styliformis Brightwell	105029	11553
Skeletonema sp.	2356	259
Thalassiosira decipiens (Grunow) Jørgensen	17671	1944
P e n n a l e s		
Achnantes brevipes Agardh	117810	12959
Achnantes longipes Agardh	376991	41469
Amphiprora sulcata O' Meara	4385	482
Amphora crassa Gregory	2880	317
Amphora hyalina Kützing	3240	356
Amphora marina (W Smith) Van Heurck	78540	8639
Amphora ostrearia Brébisson	165360	18190
Amphora ovalis Kützing	180	20
Amphora sulcata (Brébisson) Cleve	5000	550
Amphora sp.	2880	317
Auricula adriatica Peragallo	19250	2117
Auricula insecta (Grunow) Cleve	24000	2640
Campylodiscus adriaticus Grunow	28260	3109
Cocconeis scutellum Ehrenberg	943	104
Cylindrotheca closterium (Ehrenberg) Reimann et Lewin	524	58
Diploneis bombus Ehrenberg	6250	687
Diploneis crabro Ehrenberg	14400	1584
Entomoneis paludosa (W. Smith) Reimer	11025	1213
Fragilaria crotonensis Kitton	707	78
Grammatophora marina (Lyngbye) Kützing	8000	880
Grammatophora oceanica Ehrenberg	16000	1760
Licmophora communis (Heiberg) Grunow	1600	176
Licmophora flabellata (Carmichael) Agardh	12087	1330
Licmophora lyngbyei (Kützing) Grunow	27500	3025
Licmophora paradoxa (Lyngbye) Agardh	6480	713
Licmophora quadriplacata Mereschkowsky	126	14
Licmophora remulus Grunow	30000	3300
Licmophora sp.	6480	713

Tab. 1. – continued

T a x o n	cell volume (µm³)	cell carbon content (pgC)
Lioloma pacificum (Cupp) Hasle	5655	622
Mastogloia asperula Grunow	6000	660
Mastogloia citrus Cleve	2400	264
Navicula cancellata Donkin	3000	330
Navicula lyra Ehrenberg	3900	429
Navicula spp.	6000	660
Nitzschia incerta Grunow	6000	660
Nitzschia longissima (Brébisson) Ralfs	3351	369
Pleurosigma angulatum (Quekett) W. Smith	255563	28112
Pleurosigma balticum Smith	180000	19800
Pleurosigma elongatum W. Smith	144000	15840
Pleurosigma formosum W. Smith	194000	21340
Podocystis adriatica Kützing	73476	8082
Pseudo-nitzschia sp. 1	147	16
Pseudo-nitzschia sp. 2	1800	198
Striatella unipunctata (Lyngbye) Agardh	252500	27775
Surirella fluminensis Grunow	15000	1650
Synedra crystallina (Agardh) Kützing	19110	2102
Synedra fasciculata (Agardh) Kützing	4500	495
Synedra hennedyana Gregory	22973	2527
Synedra tabulata (Agardh) Kützing	5655	622
Synedra toxoneides Castracane	1050	115
Synedra sp.	5655	622
Thalassionema nitzschioides (Grunow) Mereschkowsky	120	13
Thalassionema frauenfeldi (Grunow) Hallegraeff	3750	412
Toxarium undulatum Bailey	22973	2527
Tropidoneis lepidoptera (Gregory) Cleve	60000	6600
E U G L E N O P H Y C E A E		
Euglena viridis (O.F. Müller) Ehrenberg	3142	346
Eutreptia lanowii Steuer	1571	173
D I N O P H Y C E A E		
Alexandrium minutum Halim	3462	450
Ceratium furca (Ehrenberg) Claparéde et Lachmann	36559	4753
Ceratium fusus (Ehrenberg) Dujardin	9739	1266
Ceratium macroceros (Ehrenberg) Vanhöfen	39270	5105
Ceratium massiliense (Gourret) E.G. Jørgensen	188495	24504
Ceratium tripos (Müller) Nitzsche	150795	19603
Dinophysis caudata Seville-Kent	104720	13614
Dinophysis fortii Pavillard	111910	14548
Dinophysis hastata Stein	85910	11168
Dinophysis schroederi Pavillard	91630	11912
Goniodoma polyedricum (Pouchet) Jorgensen	38288	4977

Tab. 1. – continued

Taxon	cell volume (µm³)	cell carbon content (pgC)
Goniaulax polygramma Stein	22725	2954
Gymnodinium simplex (Lohmann) Kofoid et Swezy	589	65
Gymnodinium sp.	589	65
Gyrodinium fusiforme Kofoid et Swezy	21206	2333
Gyrodinium sp.	21206	2333
Oxytoxum longiceps Schiller	1571	204
Oxytoxum tesselatum (Stein) Schütt	1140	148
Oxytoxum variabile Schiller	697	91
Phalacroma rotundatum (Claparede et Lachmann) Kofoid et Michener	6936	902
Prorocentrum arcuatum Issel	29438	3827
Prorocentrum balticum (Lohmann) Loeblich	173	22
Prorocentrum compressum (Bailey) Abé ex Dodge	22808	2965
Prorocentrum dactylus (Stein) Dodge	18850	2450
Prorocentrum gracile Schütt	2566	334
Prorocentrum lima (Ehrenberg) Dodge	14158	1841
Prorocentrum micans Ehrenberg	13090	1702
Prorocentrum minimum (Pavillard) Schiller	2545	331
Prorocentrum scutellum Schröder	20944	2723
Prorocentrum triestinum Schiller	785	102
Protoperidinium crassipes (Kofoid) Balech	174411	22673
Protoperidinium depressum (Bailey) Balech	184103	23933
Protoperidinium diabolus (Cleve) Balech	150795	19603
Protoperidinium divergens (Ehrenberg) Balech	110733	14395
Protoperidinium globulus (Stein) Balech	2617	340
Protoperidinium kofoidi Fauré-Fremiet	233674	30378
Protoperidinium leonis (Pavillard) Balech	11641	1513
Protoperidinium pallidum (Ostenfeld) Balech	102108	13274
Protoperidinium solidicorne (Mangin) Diwald	43422	5645
Protoperidinium steinii (Jörgensen) Balech	63617	8270
Protoperidinium tuba (Schiller) Balech	3393	441
Protoperidinium sp.	63617	8270
Scripsiella trochoidea (Stein) Loeblich	6283	817
dinoflagellate cyst 1	8831	971
dinoflagellate cyst 2	14130	1554
CHLOROPHYCEAE		
Carteria marina Diesing	188	21
Chlamydomonas sp.	385	42
Dunaliella sp.	198	22
Tetraselmis sp.	385	42
minute nanoplankton	6	1
incertae sedis	785	86

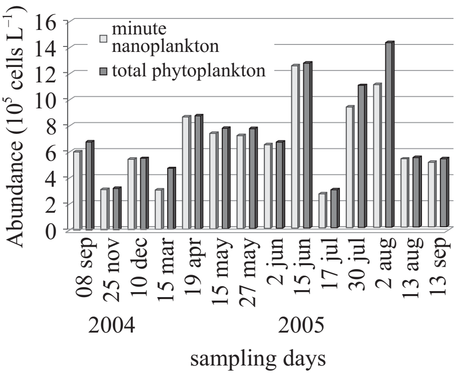

Fig. 2. Annual variation of phytoplankton abundance

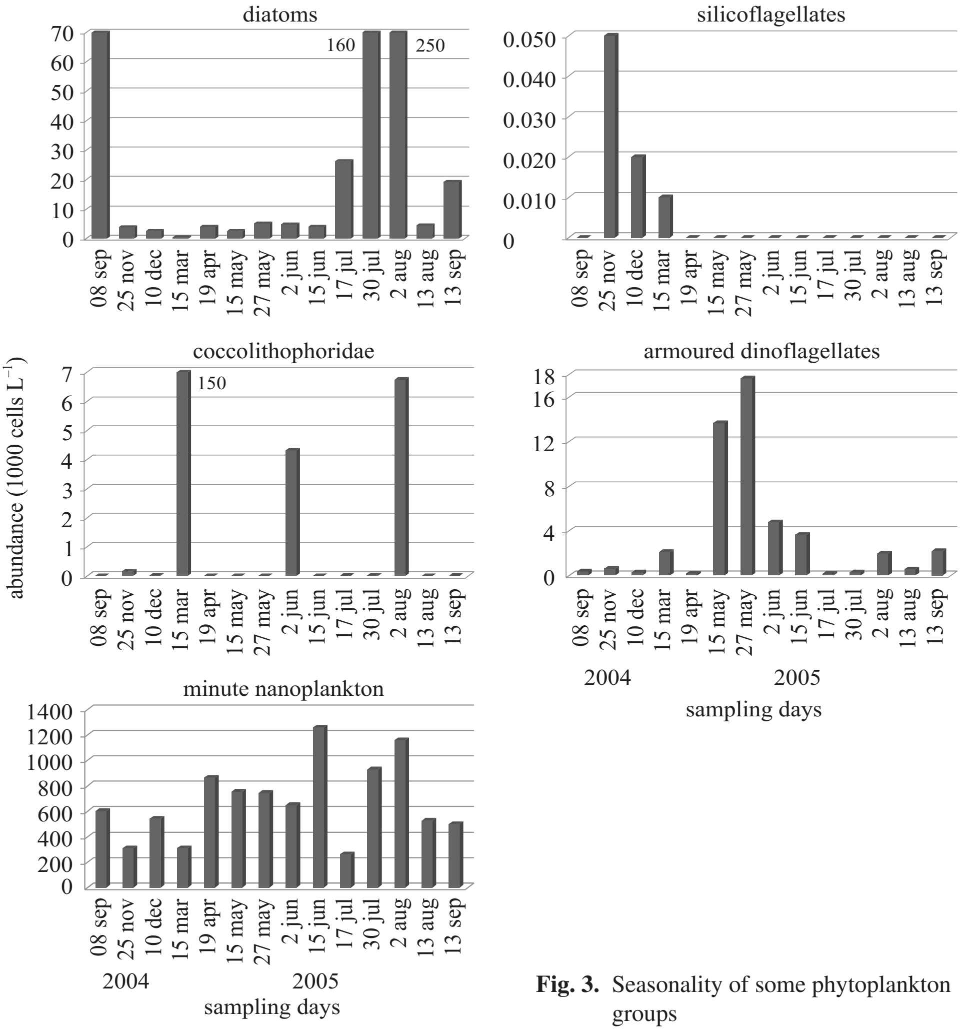

Fig. 3. Seasonality of some phytoplankton groups

gellates (*Goniaulax*, *Gymnodinium*, *Prorocentrum*, *Protoperidinium*, *Scripsiella)* became more abundant though their number never exceeded 5×10^4 cells L^{-1}. In July and August the two centric diatoms were blooming: *Skeletonema sp.* and *Chaetoceros simplex* with 1.57×10^5 cells L^{-1} and 2.33×10^5 cells L^{-1} respectively. *Skeletonema sp.* appeared when the temperature and salinity conditions were among the highest registered (30.2 °C and 36.2). In terms of abundance the minute nanoplankton cells were the most conspicuous group throughout the year (Fig. 2), contributing up to 91% of the average annual phytoplankton abundance.

Seasonality in diatoms showed bimodal annual pattern and they were most abundant in summer and autumn; the silicoflagellates appeared in modest abundances in autumn, the coccolithophorids appeared from March to August, while the armoured dinoflagellates were most abundant in May (Fig. 3).

Abundance, cell volume and carbon stock

Maximum abundances of the small nanoplankters (1.3×10^6 cells L^{-1} and 1.1×10^6 cells L^{-1}) were registered in June and August with a sharp decrease in July, which coincided with the increase of oligotrich ciliate density (results not shown) and could be explained as a

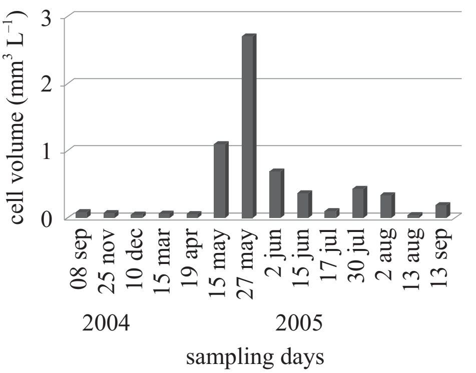

Fig. 4. Seasonal changes in phytoplankton cell volume

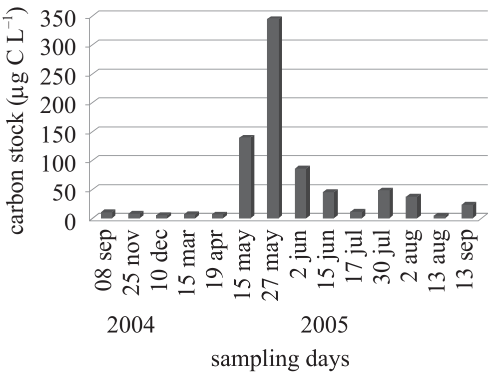

Fig. 5. Seasonal changes in phytoplankton carbon stock

consequence of the high microzooplankton grazing pressure. All the other taxonomic groups reached the maximum abundances in late spring and summer, with the exception of prymnesiophytes which had their peak in late winter.

Seasonal dynamics of phytoplankton volume and carbon showed a quite different pattern. In May, an explosive growth of large-sized dinoflagellates occurred and despite their low number (up to 5×10^4 cells L^{-1}), they provoked a marked increase in phytoplankton volume, rising up to 2.7 mm^3 L^{-1} (Fig. 4) and consequently in carbon stock, reaching its maximum of 347 µg C L^{-1} (Fig. 5). In other months the carbon content never exceeded 100 µg L^{-1}. Thus, in terms of biovolume and carbon stock, the dinoflagellates were the most prominent group, contributing up to 90% of total carbon stock in May, between 20% and 80% in other months (Fig. 6), and with an average annual contribution of 73% (Fig. 7).

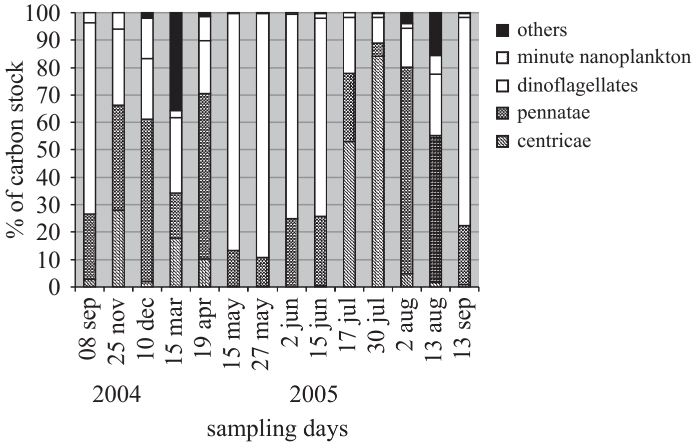

Fig. 6. Annual phytoplankton composition given as % of carbon stock

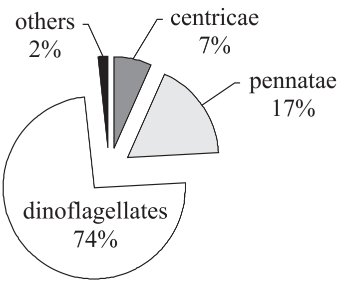

Fig. 7. Average annual contribution of different taxonomic groups to the carbon stock

Discussion

In winter season the global solar irradiance of the area is 15 KJ cm^{-2}, while in summer it reaches a fivefold value, of 80 KJ cm^{-2} (FANUKO 1986). In the phytoplankton assemblages of the adjacent open sea an inverse fivefold increase in cell chlorophyll content was observed in winter months. While in July the average monthly concentration of chlorophyll *a* per cell was 1.1 pg per cell^{-1}, in December it rose to 5.5 pg per cell^{-1} (FANUKO 1986). More numerous and larger chloroplasts in the winter pennate diatoms of the lagoon of Stella Maris could be the adaptation of this group to the reduced light conditions in winter. The same phenomenon was never observed in other taxonomic groups.

The number of phytoplankton species found in the lagoon of Stella Maris appeared to be high compared with other Mediterranean lagoons (Tab. 2). A higher number of species was found only in the southern part of the Lagoon of Venice (TOLOMIO and BULLO 2001), in a pool approximately 70 times larger than the Stella Maris lagoon and within 506 samples taken daily throughout the year.

Tab. 2. Phytoplankton diversity in several Mediterranean lagoons. [1]this study; [2]FANUKO 1980; [3]SARNO et al. 1993; [4]ANDREOLI et al. 1989; [5]TOLOMIO et al. 1990; [6]TOLOMIO and BULLO 2001; [7]ANDREOLI and TOLOMIO 1988

	Lagoon							
Taxonomic group	**Stela Maris[1]**	**Strunjan[2]**	**Strunjan exp.[2]**	**Fusaro[3]**	**Valle Pozzatini[4]**	**Varano[5]**	**Venice lagoon Chioggia area[6]**	**Venice lagoon Valle Dogà[7]**
Cyanobacteria	5	0	0	2	2	0	0	0
Cryptophyceae	1	0	0	3	0	0	0	0
Chrysophyceae	4	1	0	9	0	1	2	0
Prymnesiophyceae	10	9	6	2	2	12	6	0
Bacillariophyceae (Centrales)	27	28	16	38	10	15	35	7
Bacillariophyceae (Pennales)	55	47	43	18	37	50	148	96
Euglenophyceae	2	1	1	3	1	1	3	2
Dinophyceae	43	29	20	31	9	20	42	13
Chlorophyceae	4	0	0	4	1	1	0	1
Total number of species	**151**	**115**	**86**	**110**	**62**	**100**	**236**	**119**

Among the 198 taxa found in the adjacent open sea of the Gulf of Trieste (FANUKO 1986), 151 (76%) were also registered in the Stella Maris lagoon. In two shallow bays of the Gulf of Trieste a total of 100 species of armoured dinoflagellates were registered (FRANCE and MOZETIČ 2006) while 212 phytoplankton taxa were reported off-shore in the Gulf of Venice (BERNARDI AUBRY et al. 2006). In the more southern area off Rovinj 689 phytoplankton species were found (RELEVANTE 1986) whereas 888 species were registered for the whole Adriatic sea (VILIČIĆ et al. 2002).

In an *in situ* enrichment experiment, exhibited in the nearby lagoon of Strunjan (FANUKO 1984), the phytoplankton was significantly altered in terms of reduction of species diversity, cell density and chlorophyll biomass in the experimental lagoon which received settled municipal sewage during the period of two years. Similarly, the dystrophic status of the shallow Santa Giusta lagoon in Sardinia (SECHI et al. 2001) remained unchanged even after waste water diversion, with blooms of the toxic *Cochlodinium polykrikoides* and *Chattonella marina*, as well as the nitrophile macrobenthic alga *Ulva rigida*, whose massive proliferation in other eutrophic Mediterranean lagoons is attributed to industrial, agriculture and domestic wastes introduced in shallow lagoon waters (ACRI et al. 1995, SOCAL et al. 1999, SFRISO et al. 2003, FACCA et al. 2003). None of these algae has ever been observed in the lagoon of Stella Maris. The coccolithophorids, predominantly oceanic in distribution (HEIMDAL 1993), are completely absent in some Mediterranean lagoons (SARNO et al. 1993), but they are common in the Stella Maris lagoon. During the investigation period, 9 different species of coccolithophorids were found, among which *Acanthoica aculeata* predominated.

Tychopelagic pennate diatoms, found in the Stella Maris lagoon, are also a representative and perennial group in the Mediterranean (ANDREOLI and TOLOMIO 1988, ANDREOLI et al. 1989, SARNO et al. 1993, SOCAL et al. 2006) and some other lagoons worldwide (CONDE et al.1999, MACEDO et al. 2001) due to their capacity to support large and highly frequent changes in the physical conditions of the environment (BONILLA et al. 2005). Nevertheless, as shown in our study as well, other groups are responsible for the phytoplankton peaks: the small-sized pico- and nanoplankton cells (VAQUER et al. 1996) as primary producers in the microbial loop, centric diatoms, especially chain-forming *Chaetoceros spp*. and *Skeletonema sp.* (SOCAL et al. 1999, BEC et al. 2005, SOCAL et al. 2006) and finally dinoflagellates (CARRADA et al. 1991) which, due to their possible toxicity or other palatability issues, may be subject to relatively low grazing pressure (BADYLAK and PHLIPS 2004). In the northern Adriatic, *Skeletonema* has been recently identified as *S. marinoi* (SARNO et al. 2005).

The phytoplankton abundance of the Stella Maris lagoon was comparable to the oligotrophic Mar Chiquita lagoon in Argentina (DE MARCO et al. 2005). Compared to the western Adriatic lagoons (SOCAL et al. 1999, 2006) and the eutrophic Thau lagoon in France (VAQUER et al. 1996, BEC et al. 2005), values in the Stella Maris lagoon were lower by two or three orders of magnitude. Even when the unialgal blooms occurred (for example *Skeletonema sp.*), their abundances in the Stella Maris lagoon never resulted in brown tides, as was the case in the industrial area of the lagoon of Venice (SOCAL et al. 1999). The seasonal pattern of cell abundance is similar to that of other lagoons of the temperate zone, showing low winter values and summer peaks (FACCA and DE CASABIANCA 2003, FACCA et al. 2004).

The specific volume of diatom cells in the Stella Maris lagoon was higher than those found in the artificially fertilized fish ponds of the Po estuary (ANDREOLI et al. 1989), whereas the volumes of dinoflagellate species were in the same range (Tab. 3). Neglecting the possible inaccurate microscopy measurements (MONTAGNES et al. 1996) and great variations in cell size (VILIČIĆ 1985), cell volume may give better phytoplankton quantification than abundance. Great differences in diatom cell size could be explained by different diatom division rates in different environments. Probably the diatoms in the nutrient-rich pond multiplied more rapidly, with more frequent reduction in cell size.

As far as the total phytoplankton volumes and the estimated carbon content are concerned, both parameters were still lower in the Stella Maris lagoon than in Mediterranean (SARNO et al.1993, ANDREOLI et al. 1989) and Atlantic (BADYLAK and PHLIPS 2004, BONILLA et al. 2005) lagoons.

Tab. 3. Average cell volume (in μm^3) of some phytoplankton species in two Adriatic lagoons. [1]ANDREOLI et al. 1989; [2]this study

	Valle Pozzatini[1]	Stella Maris[2]
Diatoms		
Chaetoceros compressus	261	2650
Skeletonema sp.	142	2365
Achnantes brevipes	9075	117810
Nitzschia longissima	740	3351
Synedra affinis	1511	4500
Tropidoneis lepidoptera	15799	60000
Dinoflagellates		
Prorocentrum micans	16053	13090
Prorocentrum minimum	1379	2545
Protoperidinium globulum	4149	2617

Presuming that nutrients are not limiting in such a shallow environment and considering the high tidal dynamics, additionally enhanced by winds, low phytoplankton abundances might be the result of low residence time of the water inside the lagoon and its rapid export in the adjacent sea.

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