

Phytoplankton community composition and distribution in an eutrophic coastal area (Venice lagoon, Italy)

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We investigated the phytoplankton in the central area of the Venice lagoon in the 1990s. Water samples were collected at 46 sites in June 1993 and June 1998 and at four stations every month from November 1998 to October 1999. Collected data include community composition, cell abundance, and cell bio-volumes, estimated with an inverted light microscope. Cell abundance distribution maps display mean (6.9×10^6 and 2.5×10^6 cells dm^{-3} in June 1993 and June 1998, respectively) and peak values (151 and 16×10^6 cells dm^{-3} in June 1993 and June 1998, respectively). The reasons for differences in blooming taxa were investigated by processing environmental variables of the most abundant taxa by Canonical Correspondence Analysis. The environmental parameters that most affected the species spatial distribution were salinity and temperature in June 1993 and salinity and water transparency in June 1998. Phytoplankton temporal trends confirmed the spatial distribution: the blooming period was in June and the highest cell abundances occurred close to the mainland.

Key words: phytoplankton distribution, cell abundance, biomass, microalgae communities, Venice lagoon

INTRODUCTION

The key role of phytoplankton in the trophic chain is widely recognized. Particular attention has been paid to freshwater (HABIB *et al.*, 1997; NOGUEIRA, 2000; PIIRSOO, 2001) and pelagic (TIMMERMANS *et al.*, 1998; BOYD & HARRISON, 1999; ANDERSEN & PRIEUR, 2000) processes. Phytoplankton are also monitored in estuarine areas (GÓMEZ & BAUER, 1998; SANDERS *et al.*, 2001). However, studies on phytoplankton in protected and shallow coastal areas, such as lagoons and bays, have often been neglected because of the dominance of macrophytes. Microalgae are often estimated by means of chlorophyll *a*

concentrations and are of minor interest. Nevertheless, the abundance and distribution of microalgae can be a good indicator of ecosystem conditions, particularly when related to the impact of anthropic activities (fishing, shellfish farming, bathing, etc.).

Environmental conditions in the Venice lagoon have been strictly connected to the human presence since the fourteenth century when the Serenissima Republic of Venice began to transform the lagoon morphology and, consequently, its hydro-dynamics (diversion of main rivers, digging of channels to allow transit of commercial ships, construction of artificial dikes

and breakwaters). During the twentieth century, chemical pollution heavily affected the lagoon ecosystem, triggering noticeable changes in the flora and fauna communities. Before the 1960s, sea grasses were prevalent but, later, eutrophication increased and favored macroalgae colonization, especially in the central lagoon. During that period, phytoplankton bloomed mainly after macroalgae collapse, which usually occurred in late spring.

In the early 1990s, macroalgae started to decrease, mainly because of climatic changes that produced unfavorable growth conditions (SFRISO, 1996; SFRISO & MARCOMINI, 1996). In 1993, the total macroalgae standing crop was about 85000 tons (SFRISO *et al.*, 2003), approximately seven times less than the value estimated during the 1980s (about 550000 tons). By 1998, the macroalgae biomass had decreased to about 8700 tons (SFRISO *et al.*, 2003). While the macroalgae coverage was decreasing, the bivalve *Tapes philippinarum* Adams and Reeve, introduced to the lagoon for economic reasons, colonized the bottoms that were free of biomass (OREL *et al.*, 2000; SFRISO, 2000) and spread everywhere. The *T. philippinarum* were caught by hydraulic and mechanical dredges causing, among other damages, disruption of the upper microlayer of sediment that prevalently consists of microautotroph organisms. As a result, sediment re-suspension in the last decade increased 5-12 times, preventing the re-colonization of macrophytes, especially sea grasses (SFRISO, 2000).

Many papers describe the distribution of macrophytes and their interaction with environmental variables in the central part of Venice lagoon (SFRISO and MARCOMINI, 1999; SFRISO *et al.* 2003 and references therein). From the 1970s to the 1990s, the macroalgae biomass (especially *Ulva rigida* C. Ag.) was so high that it regulated the bio-geochemical cycles, often leading to anoxic crises that killed macrofauna and fishes. On the contrary, studies on phytoplankton are poor, scarcely comparable, and only of a systematic nature (ANDREOLI & TOLOMIO, 1988a,b; SOCAL *et al.*, 1999; TOLOMIO *et al.*, 1999). It is possible that, after the disappearance

of macroalgae, phytoplankton become the main primary producer and its abundance increases.

The present work describes the composition, abundance, and distribution of phytoplankton in the central part of the Venice lagoon, paying particular attention to environmental variables that favor or hamper microalgae primary production. The emphasis is on changes in the phytoplankton community resulting from marked environmental modifications. During the 1990s, the macroalgae biomass declined and high sediment fluxes, caused mainly by clam fishing, regulate bio-geochemical processes, especially in the central and northern areas of the lagoon.

MATERIALS AND METHODS

The study area

The Venice lagoon is a semi-enclosed water basin with a depth of about 1.2 m. It is connected to the northern Adriatic Sea by three inlets, exchanging some 60% of its entire water body at every tidal cycle (12 h). The study was conducted in the central part of the lagoon, situated between the Malamocco-Marghera canal in the south and the Burano-Torcello tidal lands in the north (Fig. 1). This area receives untreated wastewater from the Venice historical center and untreated and treated sewage from the city of Mestre, its hinterland, and the islands of Lido, Murano, and Burano. Pollutants of a different nature and cooling waters from the Porto Marghera industrial zone also flow into the lagoon. Naval traffic is rather heavy as two large deep canals (the Malamocco-Marghera and the Vittorio Emanuele; width 100-200 m; depth 12-20 m) were dug to allow transit of commercial ships. Seawater flows into this area through the Malamocco and Lido inlets.

Samples were taken at 46 stations in June 1993 to investigate the trophic conditions of the Venice lagoon. The same measurements were repeated in June 1998. Phytoplankton was monitored together with macrophyte biomass and physical variables of the water column

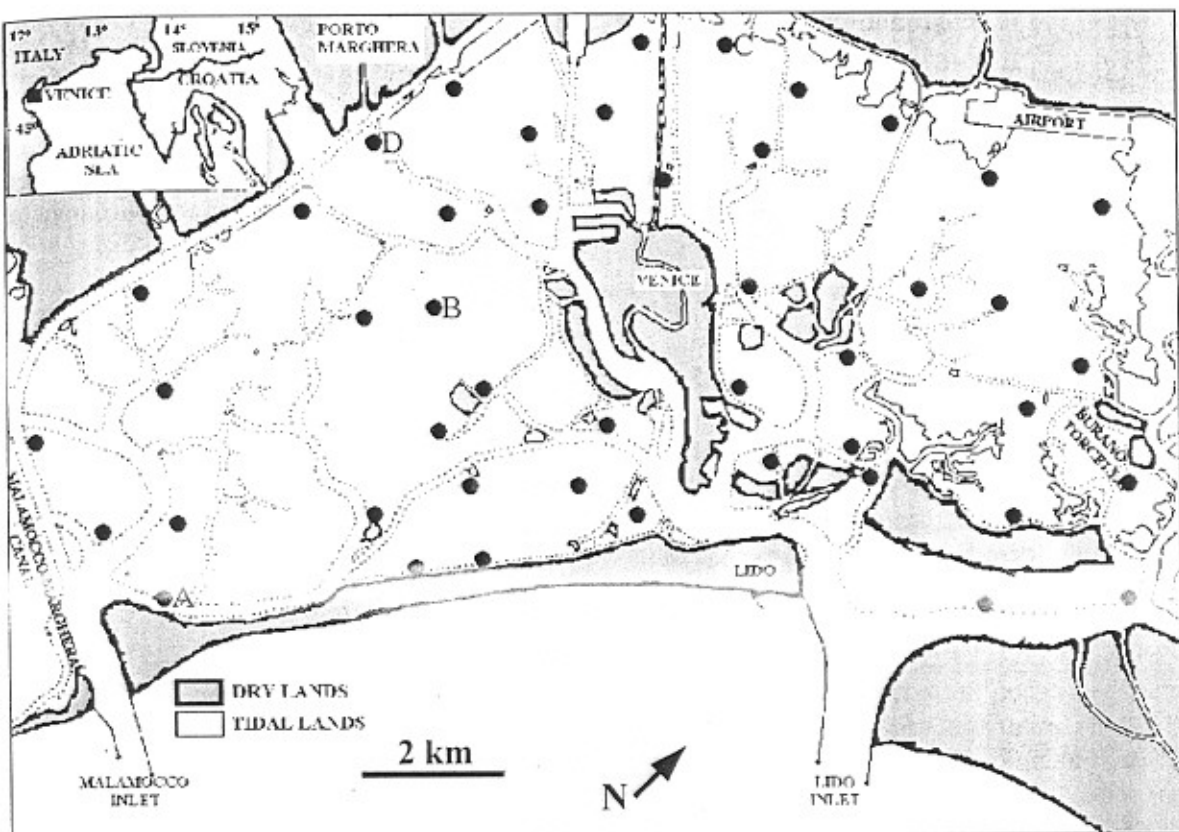


Fig. 1. Map of the central part of the Venice lagoon and sampling stations. Forty-six sites sampled in June 1993 and June 1998 are marked by circles; four sites sampled monthly from June 1998 to June 1999 are marked by letters A-D.

(temperature, chlorinity, pH, redox potential, water transparency, dissolved oxygen). In June 1998, nutrient concentrations were also determined. Four of the 46 stations were monitored monthly from November 1998 to October 1999 to assess phytoplankton peaks and composition during an entire year.

Physico-chemical parameters

Water temperature (to a precision of 0.1°C), pH, and redox potential were measured with a portable pH-meter equipped with a thermocouple sound (model HD 8705, Delta Ohm, Padua, Italy). Water transparency was measured with a SECCHI disk; values are reported as percentages with 100% indicating that the bottom was visible and 50% that the disk was not visible half-way to the bottom. Chlorinity was determined argentometrically by silver nitrate titration

according to the modified KNUDSEN method (OXNER, 1962). Dissolved oxygen was measured with an Oximeter (OXI 196, Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany) equipped with a battery stirrer (BR 190). Data were transformed into saturation percentages depending on water temperature and chlorinity.

In June 1998, water column aliquots, after filtration through GF/F WHATMAN glass fiber filters ($0.7\ \mu\text{m}$), were immediately analyzed on board for orthophosphate (RP), ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-) according to STRICKLAND & PARSONS (1972). The sum of the nitrogen compounds is expressed as dissolved inorganic nitrogen (DIN). Nutrient concentrations were spectrophotometrically determined in the laboratory on the same day.

Phytoplankton

Phytoplankton was monitored as chlorophyll *a* concentration, cell abundance, and bio-volume. Six to ten samples of the entire water column were collected with a homemade plexiglas bottle (height 150 cm, diameter 4 cm), and mixed together in a tank. Water aliquots, ranging from 100 to 1000 ml, were filtered in situ through GF/F WHATMAN glass fiber filters (0.7 μ m). Filters were stored at -20°C until pigment determination according to the spectrophotometric procedure (LORENZEN, 1967).

Unfiltered water aliquots were preserved with 4% formaldehyde neutralized with hexamethylenetetramine. Cell count and taxonomic identification were performed under an inverted light microscope provided with phase contrast optics and a 40x objective (Axiovert 10 ZEISS, Oberkochen, Germany), using settling chambers according to the method of UTHERMÖL (1958). A minimum of 200 cells was counted in each sample. Taxonomic identification was carried out using the taxonomic keys reported by PERAGALLO & PERAGALLO (1897-1908), ROUND *et al.* (1990), and TOMAS (1993, 1996). The nomenclature was updated using VAN LANDINGHAM (1967-1979). Cell size was measured under the microscope to determine the bio-volume according to EDLER (1979). Community diversity was estimated using the SHANNON Index (\log_2). The formulation of SHANNON & WEAVER (1948) was applied to the taxa identified at least to the genus level. Groups identified to the class level could have contained several different species, whose individual contributions could not be clearly isolated. Maps were drawn using the Surface Mapping System program (Surfer Version 7.02. 1993-2000. Surface Mapping System. Golden Software Inc., Golden, Colorado).

Macrophyte biomass

Macrophyte biomass, if present, was estimated according to the procedures of SFRISO *et al.* (1991) for macroalgae and of SFRISO & GHETTI (1998) for sea grasses. Six sub-samples of 0.5 and 0.05 m² for macroalgae and sea grasses, respectively, were collected using special sampling frames to allow determination of the biomass to an accuracy >95%.

Statistical analyses

A numeric matrix per year was built with all available data. Biological variables were $\log_{10}(x+1)$ transformed. Application of the PEARSON correlation matrices provided evidence of the most significant environmental variables that determined the spatial distribution of phytoplankton. Significant correlations occurred per $r \geq 0.30$ when $p < 0.05$. Principal Component Analysis (PCA) was used to describe the ecosystem variance. Significant loadings ($r \geq 0.70$, $p < 0.05$) are reported. Canonical Correspondence Analysis (CCA) allowed correlation between variation in the phytoplankton species and environmental variables. Taxa with an abundance of at least 4% per sample were used. The software CANOCO v4 (TER BRAAK & SMILAUER, 1998) was used to process data.

RESULTS

Environmental variables

Environmental parameters for June 1993 and June 1998 are given in Tables 1 and 2. In June 1993 most of the stations had good water transparency. The bottom was not visible in a restricted area near the airport. In June 1998 conditions were markedly different and water turbidity was significantly higher in the area south of Venice. The number of stations with clear water decreased progressively, confirming a trend already observed (SFRISO, 2000; FACCA *et al.*, 2002a; SFRISO *et al.*, 2003; SFRISO *et al.*, submitted to *Environ. Int.*). Nitrogen and phosphorus were highest along the lagoon boundaries, especially near the industrial district of Porto Marghera and the airport where the fresh waters of the Dese and Siloncello Rivers inflow.

In June 1993 the macroalgae biomass was about five times higher than in June 1998. However, attention should be focused on the spatial distribution of the biomass rather than on the total standing crop. In 1993, only 17 of the 46 stations were free of biomass whereas in 1998, except for the station near Lido Island, macroalgae were absent in the entire study area. The reason for the disappearance of the macroalgae has been widely investigated (SFRISO, 1996, 2000; SFRISO and MARCOMINI, 1996; SFRISO *et al.*, 2003).

Table 1. Environmental parameters measured in June 1993

	Temperat.	SECCHI	Chlorinity	Dissolved	pH	Eh	Macrophyte	Chlorophyll <i>a</i>
		Disk		Oxygen			Biomass	
	°C	%	g dm ⁻³	% saturation		mV	kg m ⁻² fwt	µg dm ⁻³
Mean	25,8	89,5	17,2	134	8,48	366	0,65	4,33
Std Dev	1,71	13,6	1,13	30,2	0,15	20,6	2,18	5,81
Max	29,6	100	19,3	226	8,90	411	12,50	32,0
Min	22,7	40,0	13,7	76,0	8,21	323	0,00	0,43
Significant Pearson correlation with phytoplankton								
Abundance	-	-0,64	-0,80	0,47	0,55	0,36	-	0,79
Diversity	-	-	-	-	-	-	-	-
Results of Principal Component Analysis								
Component 1	-	-0,76	-0,88	-	0,70	-	-	0,91
Component 2	0,74	-	-	-	-	-	0,76	-
Component 3	-	-	-	-	-	0,72	-	-

Table 2. Environmental parameters measured in June 1998

	Temp.	Secchi	Chlorinity	Dissolved	pH	Eh	Nutrient concentration					DIN	Macrophyte	Chlorophyll <i>a</i>
		Disk		Oxygen			RP	NO ₃	NO ₂	NH ₄	DIN	/RP	Biomass	
	°C	%	g dm ⁻³	% saturation		mV		µmol dm ⁻³				kg m ⁻² fwt	µg dm ⁻³	
Mean	24,6	74,5	16,3	112	8,01	296	0,45	10,7	1,01	10,1	21,9	60,4	0,12	3,55
Std Dev	2,52	23,2	1,62	23,7	0,12	27,0	0,21	7,99	0,54	5,17	10,1	43,8	0,81	4,86
Max	29,7	100	19,3	202	8,27	367	1,00	31,0	2,85	24,0	47,0	243	5,50	29,1
Min	20,7	26,0	12,3	70,0	7,65	238	0,09	1,62	0,23	1,19	5,38	9,78	0,00	0,30
Significant Pearson correlation with phytoplankton														
Abundance	-	-0,41	-0,53	0,53	-	0,31	-	-	-	-	-	-	-	0,52
Diversity	-	0,42	-	-	-	-	0,31	-	-	-	-	-	-	-
Results of Principal Component Analysis														
Comp. 1	-	-	-0,83	-	-	-	-	-	-	-	-	-	-	0,74
Comp. 2	-	-	-	-0,79	-	-	-	0,73	0,82	-	-	-	-	-
Comp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	-

As these values are not independent, they were not inserted in PCA

Phytoplankton: taxa

Fifty-one taxa were identified in June 1993 and 54 in June 1998 (Table 3). There were 29 Bacillariophyceae in June 1993 and 40 in June

1998. Dinophyceae decreased from 11 taxa in June 1993 to seven in June 1998. The remaining phytoplankton community consisted of micro- and nanoflagellates.

Table 3a. Bacillariophyceae. Maximum cell abundance values are reported ($\times 10^5$ cells dm^{-3})

Taxa	1993	1998	1998-99	Taxa	1993	1998	1998-99
<i>Amphipleura micans</i> Cleve			0,07	<i>Navicula anglica</i> Ralfs			0,11
<i>Amphipleura rutilans</i> Cleve			0,05	<i>Navicula arenaria</i> Donkin			0,11
<i>Amphiprora alata</i> Kützing	0,05			<i>Navicula arenicola</i> Grunow		0,21	
<i>Amphiprora paludosa</i> Smith	0,22			<i>Navicula cancellata</i> var. <i>retusa</i> Cleve			0,04
<i>Amphiprora</i> sp.			0,11	<i>Navicula cincta</i> Ralfs		0,05	0,11
<i>Amphora cymbelloides</i> Grunow			0,06	<i>Navicula cincta</i> var. <i>heufrei</i> Grunow			0,16
<i>Amphora exigua</i> Gregory	0,05		0,22	<i>Navicula complanata</i> Grunow	0,22		
<i>Amphora fluminensis</i> Grunow			0,11	<i>Navicula crucifera</i> Grunow			0,02
<i>Amphora laevis</i> Gregory			0,42	<i>Navicula cryptocephala</i> Kützing	0,83	2,23	13,2
<i>Amphora lineolata</i> Ehrenberg		0,05		<i>Navicula cryptocephala</i> var. <i>veneta</i> Rabenhorst	11,5		
<i>Amphora proteus</i> Gregory			0,11	<i>Navicula forcipata</i> Greville			0,02
<i>Amphora pusio</i> Cleve			0,04	<i>Navicula inflexa</i> Ralfs		0,11	0,21
<i>Amphora terroris</i> Ehrenberg		0,05	0,06	<i>Navicula lanceolata</i> Kützing		2,12	1,33
<i>Amphora turgida</i> Gregory			0,11	<i>Navicula minuscula</i> Grunow			0,05
<i>Amphora veneta</i> Kützing		0,53	0,42	<i>Navicula protracta</i> Cleve			0,04
<i>Amphora</i> sp.	0,08	0,11	0,44	<i>Navicula ramosissima</i> Cleve			0,11
<i>Asterionellopsis glacialis</i> Round			0,37	<i>Navicula salinarum</i> Grunow			0,11
<i>Bacillaria paradoxa</i> Gmelin			0,11	<i>Navicula viridula</i> Ehrenberg			0,09
<i>Bacteriastrum</i> sp.			0,11	<i>Navicula</i> sp.	1,95	2,55	11,1
<i>Chaetoceros affinis</i> Lauder			0,32	<i>Nitzschia amphibia</i> Grunow			0,42
<i>Chaetoceros anastomosans</i> Grunow			1,22	<i>Nitzschia angularis</i> Smith	0,04		
<i>Chaetoceros laciniosus</i> Schutt			2,76	<i>Nitzschia conscripta</i> Ralfs		0,11	0,11
<i>Chaetoceros muelleri</i> Lemmermann	0,05			<i>Nitzschia compressa</i> Grunow			0,11
<i>Chaetoceros rostratus</i> Lauder	0,17			<i>Nitzschia cursoria</i> Grunow			0,11
<i>Chaetoceros socialis</i> Lauder		0,11	13,1	<i>Nitzschia dissipata</i> Smith			0,11
<i>Chaetoceros</i> sp.			2,66	<i>Nitzschia dissipata</i> var. <i>media</i> Grunow		0,11	0,16
<i>Cocconeis costata</i> Gregory			0,13	<i>Nitzschia frustulum</i> Grunow			0,11
<i>Cocconeis dirupta</i> Gregory		0,11		<i>Nitzschia lanceolata</i> Smith		1,48	0,53
<i>Cocconeis molesta</i> Kützing		0,32	0,64	<i>Nitzschia longissima</i> Grunow	0,42		2,02
<i>Cocconeis quarnerensis</i> Schmidt	2,04			<i>Nitzschia microcephala</i> Grunow		0,21	0,64
<i>Cocconeis scutellum</i> Ehrenberg	1,77	1,06	0,21	<i>Nitzschia palea</i> Smith	0,10		
<i>Cocconeis</i> sp.			0,21	<i>Nitzschia recta</i> Hantzsch			0,04

Table 3a cont'd

<i>Coscinodiscus</i> sp.	0,11		<i>Nitzschia sigma</i> Smith	0,05	0,63	0,04
<i>Cyclotella</i> sp.	4,41	1,17	<i>Nitzschia sigma</i> var. <i>rigida</i> Grunow		0,11	0,11
<i>Cylindrotheca closterium</i> Reimann & Lewin	95,14	28,3	205 <i>Nitzschia subtilis</i> Grunow			0,05
<i>Cymbella</i> sp.	0,22		<i>Nitzschia tryblionella</i> Hantzsch	0,05		
<i>Dactyliosolen fragilissimus</i> Hasle	0,08		<i>Nitzschia</i> sp.	8,24	1,69	3,72
<i>Diploneis hyalina</i> Cleve	0,05	0,02	<i>Paralia sulcata</i> Cleve		0,11	0,02
<i>Diploneis</i> sp.		0,11	<i>Phaeodactylum tricornutum</i> Bohlin	11,7		
<i>Fragilaria hyalina</i> Grunow		0,28	<i>Pleurosigma australe</i> Grunow		0,11	
<i>Fragilaria</i> sp.		3,82	<i>Pleurosigma naviculaceum</i> Brébisson			0,11
<i>Gomphonema olivaceum</i> Kützing		0,22	<i>Pleurosigma pulchrum</i> Grunow			0,02
<i>Gomphonema parvulum</i> Kützing	0,08		<i>Pleurosigma rigidum</i> Smith			0,02
<i>Grammatophora oceanica</i> Ehrenberg		0,11	<i>Pleurosigma</i> sp.			0,09
<i>Guinardia striata</i> Stol. Hasle		0,37	<i>Podosira</i> sp.			0,78
<i>Gyrosigma balticum</i> Rabenhorst		0,11	<i>Proboscia alata</i> Sundström			0,11
<i>Gyrosigma distortum</i> Griffith & Henfrey		0,22	<i>Psammodictyon panduriforme</i> Mann	0,22	0,42	0,11
<i>Gyrosigma fasciola</i> Griffith & Henfrey	0,10	0,78	<i>Skeletonema costatum</i> Cleve		0,42	15,7
<i>Gyrosigma spenceri</i> Griffith & Henfrey		0,11	<i>Surirella fluminensis</i> Grunow			0,02
<i>Hantzschia amphioxys</i> Grunow	1,91	0,11	<i>Surirella ovata</i> Kützing		0,63	0,42
<i>Hantzschia hyalina</i> Grunow		0,11	<i>Surirella</i> sp.		0,11	0,11
<i>Hemiaulus hauckii</i> Grunow	0,05		<i>Synedra crystallina</i> Kützing			0,05
<i>Licmophora abbreviata</i> Agardh	0,11		<i>Synedra investiens</i> Smith			0,22
<i>Licmophora dalmatica</i> Grunow		0,02	<i>Synedra tabulata</i> Kützing			0,11
<i>Licmophora debilis</i> Grunow		0,02	<i>Synedra</i> sp.			0,21
<i>Licmophora gracilis</i> Grunow	0,11	0,11	<i>Thalassionema nitzschioides</i> Van Heurck		0,74	0,21
<i>Licmophora tenuis</i> Grunow		0,05	<i>Thalassiosira</i> sp.	2,75	73,9	68,9
<i>Licmophora</i> sp.	0,11	0,11	<i>Tropidoneis lepidoptera</i> Cleve			0,05
<i>Melosira nummuloides</i> Agardh		0,02	Centricae not identified	57,4	0,21	1,27
<i>Melosira</i> sp.		0,21	Pennatae not identified	32,5	2,12	1,59
<i>Navicula ammophila</i> Grunow	0,21	0,27				

Table 3b. Flagellate and Dinoflagellate taxa

Maximum cell abundance values are reported (x 10⁵ cells dm⁻³)

Taxa	1993	1998	1998-99
CHLOROPHYCEAE			
Chlorophyceae not identified	21,2	6,69	2,97
CRYPTOPHYCEAE			
Cryptophyceae not identified	98,4	16,2	15,6
CHRYSOPHYCEAE			
Pseudokefrion sp.	0,43		
Chrysophyceae not identified		1,59	3,72
CYANOPHYCEAE			
Cyanophyceae not identified		1,27	0,11
DINOFLAGELLATE			
cfr. <i>Alexandrium</i> sp.	6,24		
<i>Amphidinium carterae</i> Hulburt	0,04		
<i>Ceratium fusus</i> Dujardin	0,08		
<i>Gymnodinium</i> sp.		0,05	
<i>Gyrodinium estuariale</i> Hulburt		1,01	
<i>Gyrodinium</i> sp.		0,11	
<i>Prorocentrum balticum</i> Loeblich	0,04		
<i>Prorocentrum micans</i> Ehrenberg	0,31		
<i>Prorocentrum minimum</i> Schiller	0,31	0,05	
<i>Prorocentrum triestinum</i> Schiller	0,16	0,11	
<i>Prorocentrum</i> sp.	0,08	0,21	
cfr. <i>Protoperidinium</i> sp.	0,04	1,06	
<i>Protoperidinium diabolus</i> Cleve	0,04		
Dinoflagellate tectate not identified	0,21		
EUGLENOPHYCEAE			
<i>Eutreptiella marina</i> da Cunha	2,38		
<i>Eutreptiella pascheri</i> Pascher	0,08		
Euglenophyceae not identified	0,10	0,32	0,32
FLAGELLATE			
Flagellate not identified	3,03		
NANOFLAGELLATAE			
Nanoflagellatae not identified	1496	31,2	13,4
PRASINOPHYCEAE			
<i>Micromonas</i> sp.	11,7		
<i>Pseudoscourfieldia marina</i> Manton	23,4		
Prasinophyceae not identified	0,87		
PRYMNESIOPHYCEAE			
Chrysochromulina sp.	72,5		
Prymnesiophyceae not identified		4,67	9,24

The Bacillariophyceae, centric diatoms typical of pelagic habitats such as *Chaetoceros muelleri*, *C. rostratus*, *Cyclotella* sp., and *Dactyliosolen fragilissimus*, were abundant in June 1993 before the beginning of the bivalve spread and collecting. In contrast, in June 1998 when clam fishing was intensive, there was a high number of pennate diatoms (*Amphora veneta*, *Cocconeis molesta*, *Navicula lanceolata*, *Nitzschia lanceolata*, *Pleurosigma australe* and *Surirella ovata*) typical to benthic communities (FACCA *et al.*, 2002b).

Nanoflagellates, small ($\leq 5 \mu\text{m}$) naked spherical cells that are difficult to identify under the light microscope, were often the most abundant fraction, reaching up to 58% of the total cell abundance. The abundance of diatom taxa

increased from 10.5% in June 1993 to 39.7% in June 1998. Cryptophyceae accounted for a significant fraction of the phytoplankton communities in both years (21.2% in 1993 and 10.9% in 1998). Chlorophyceae, Dinophyceae, and Prymnesiophyceae did not change significantly and were 1.6 and 2.1%, 0.4 and 0.5%, and 2.5 and 4.5% of the total cell abundance during 1993 and 1998, respectively. Chrysophyceae and Euglenophyceae were steadily $<1\%$.

The taxa most frequently recorded in the Venice lagoon (SOCAL *et al.*, 1985, 1999; FACCA *et al.*, 2002a) and observed in all the samples were *Cocconeis scutellum*, *Cylindrotheca closterium* and *Thalassiosira* sp. Other species belonged to genera *Navicula* and *Nitzschia*. The highest cell abundance was recorded near the mainland (Fig. 2).

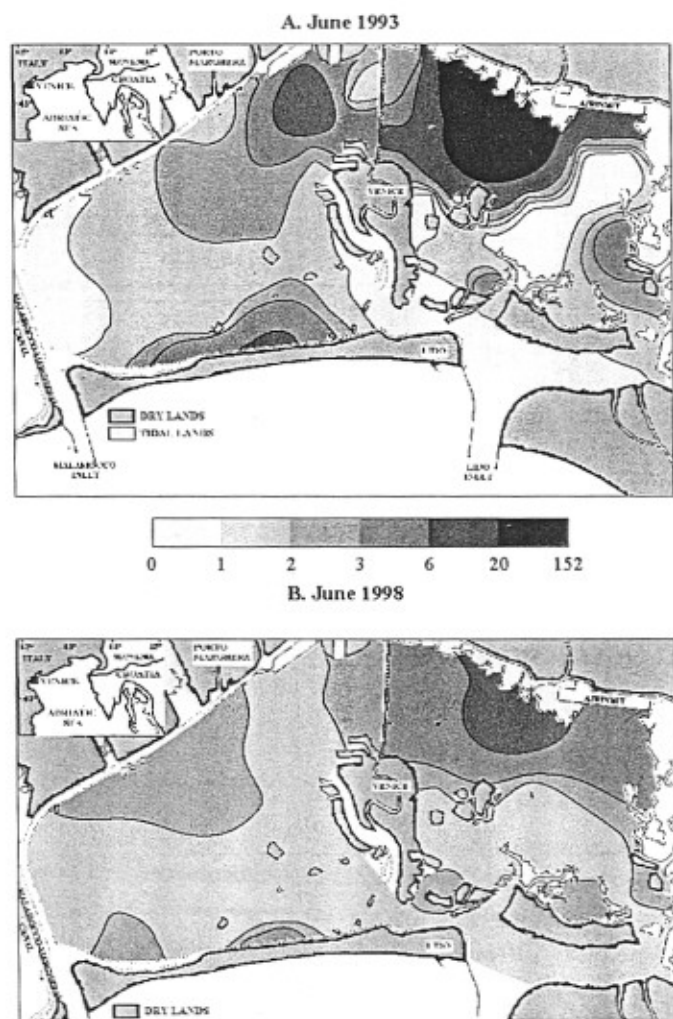


Fig. 2. Phytoplankton cell abundances in (A) June 1993 and (B) June 1998. Values are expressed as 10^6 cells dm^{-3}

In June 1993, cell abundance varied significantly from zone to zone and the highest values were recorded north of Venice where urban sewage concentrates. Significantly high cell abundances were also recorded near Lido Island and the industrial area of Porto Marghera. In June 1998, even though peak values in the central lagoon were just one order of magnitude lower than in June 1993, the phytoplankton communities appeared more homogeneously spread. About 80% of the samples were between 1 and 3×10^6 cells dm^{-3} .

In June 1993 the maximum cell bio-volume ($9.6 \text{ mm}^3 \text{ dm}^{-3}$) was recorded near the tidal lands of Burano and Torcello Islands, whereas in June 1998 the highest value ($4.9 \text{ mm}^3 \text{ dm}^{-3}$) was near the airport. Cryptophyceae accounted for 67% of the total cell bio-volume in the central part of the Venice lagoon in June 1993 and the highest value was near the Burano tidal lands. In June 1998 Cryptophyceae was significantly lower (less than 3% of the total cell volume) and the total cell bio-volume was dominated by the diatoms *Thalassiosira* sp. and *C. closterium*.

The SHANNON diversity index was rather low ($H' < 2$; Table 4) in both June 1993 and June 1998 and spatial variations were slight. Nanoflagellates were the dominant taxa throughout the study area during both years, which could explain the diversity indices. *C. closterium* was observed in both periods, but in June 1998 it represented 11% of the phytoplankton community, while in June 1993 it reached only 3%.

Chlorophyll *a* distribution is described in SFRISO *et al.* (2003). Mean values were 4.3 ± 5.8 and $3.5 \pm 4.9 \mu\text{g dm}^{-3}$ in June 1993 and June 1998, respectively. The highest chlorophyll *a* concentrations ($10\text{--}33 \mu\text{g dm}^{-3}$) were recorded northwest of Venice and the lowest near the lagoon inlets.

Phytoplankton: seasonal variations

Seasonal variations of phytoplankton were monitored monthly from November 1998 to October 1999 at stations A, B, C, and D (SFRISO, 2000; FACCA *et al.*, 2002a) in very different areas of the central lagoon. On the whole, 108 taxa were recorded. No Dinophyceae were identified, whereas 101 diatoms (Bacillariophyceae)

were counted. Diatoms represented 46%, 63%, 88%, and 80% of the total phytoplankton community at stations A, B, C, and D, respectively. However, the percentage varied depending on the month and station. Diatoms were very abundant (>80%) at all the stations in February

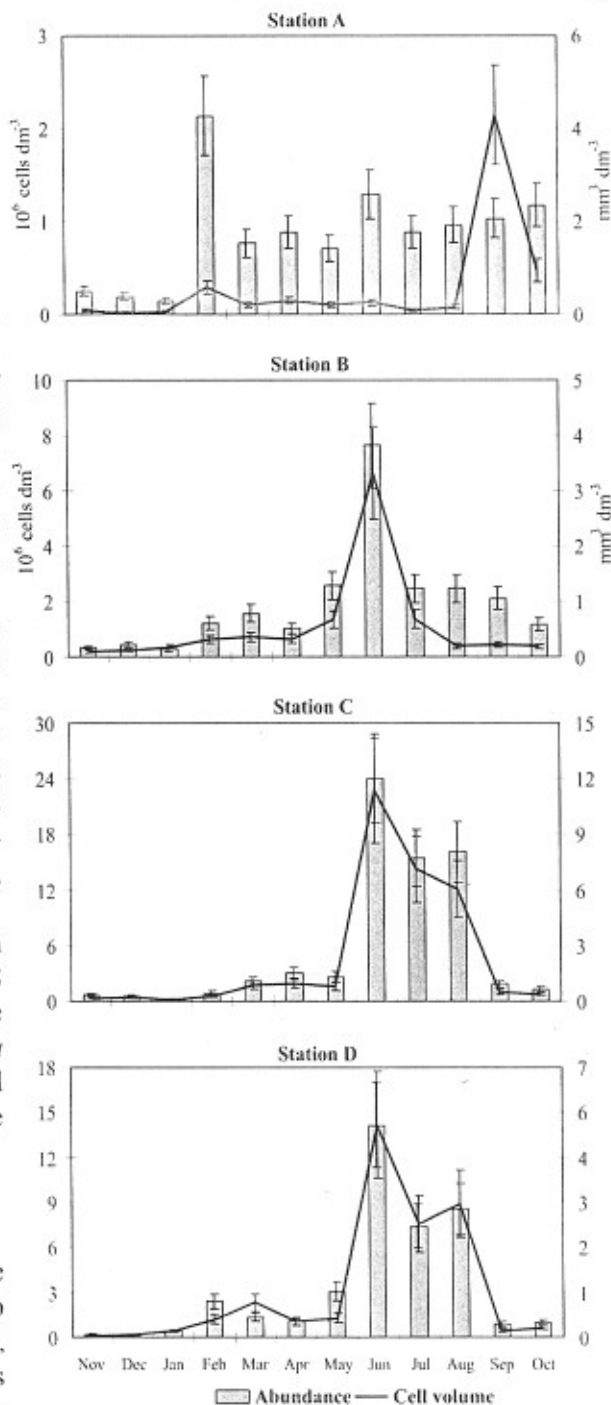


Fig. 3. Seasonal phytoplankton cell abundance and cell bio-volume from November 1998 to October 1999

because of the *Skeletonema costatum* bloom, and at stations B, C, and D in June because of the *C. closterium* bloom. Nanoflagellates and small flagellates (especially Cryptophyceae and Chlorophyceae) were abundant at station A but rare at station B in August and September. The highest cell abundance occurred at stations C and D. Peak values were observed in February at station A (especially *S. costatum*) and in June at stations B, C, and D (*C. closterium* represented 62%, 85%, and 58% of the total cell abun-

dance, respectively). The lowest values were recorded in January at stations A, B, and C and in December at station D (Fig. 3).

The seasonal variations of cell bio-volume were the same as those of cell abundance. A significant difference was recorded only at station A, in September, when large diatoms appeared. The SHANNON diversity index varied significantly among months, although the means (3.0-3.4) and peaks (4.0-4.4) of the stations were quite similar (Table 4).

Table 4. Main phytoplankton characteristics in Venice central lagoon

	Cell abundance 10^6 cells dm^{-3}	Cell volume $\text{mm}^3 \text{dm}^{-3}$	Diversity H'	Total cell volume m^3
June 1993				
Mean	6,97	1,54	1,58	244
Std. Dev.	22,6	1,99	0,70	315
Max.	151,3	9,62	3,64	-
Min.	0,07	0,05	0,00	-
June 1998				
Mean	2,55	0,54	1,62	86
Std. Dev.	2,41	0,76	0,66	120
Max.	16,1	4,91	3,03	-
Min.	0,58	0,08	0,55	-
Station A (1998-99)				
Mean	0,87	0,60	3,21	
Std. Dev.	0,55	1,19	0,69	
Max.	2,13	4,28	4,20	
Min.	0,15	0,04	1,39	
Station B (1998-99)				
Mean	1,94	0,56	2,93	
Std. Dev.	1,98	0,89	0,87	
Max.	7,65	3,33	4,28	
Min.	0,27	0,09	1,40	
Station C (1998-99)				
Mean	5,75	2,40	2,91	
Std. Dev.	8,02	3,70	1,01	
Max.	24,1	11,38	4,21	
Min.	0,24	0,07	0,73	
Station D (1998-99)				
Mean	3,39	1,17	2,76	
Std. Dev.	4,38	1,66	0,73	
Max.	14,2	5,19	3,53	
Min.	0,19	0,04	1,32	

Statistical analyses

According to the PEARSON matrices, the abundance of phytoplankton in June 1993 significantly and negatively correlated with the SECCHI disk reading (water turbidity) and chlorinity, and significantly and positively correlated with dissolved oxygen, pH, and redox potential (Table 1). Similar correlations were observed in June 1998 when nutrients were determined, but no correlations were found with phosphorous and nitrogen compounds (Table 2). In 1998, only turbidity and the reactive phosphorus concentration (RP) significantly correlated with the SHANNON diversity index.

Principal Component Analysis (PCA) shows that three components explained 63.5% (June

1993) and 65.3% (June 1998) of the total variance. In June 1993, all the variables except dissolved oxygen, showed significant loading in one of the three components (Table 1). In June 1998, chlorinity, dissolved oxygen, chlorophyll *a*, nitrate, and nitrite showed significant loading (Table 2). The loading of phytoplankton, like cell abundance and diversity, was insignificant in both 1993 and 1998.

Figs. 4 and 5 show the results of the Canonical Correspondence Analysis (CCA) as biplots: arrows represent the environmental parameters and circles the phytoplankton species. All species were well ranked along each variable gradient and it is possible to observe how each variable affected taxa distribution

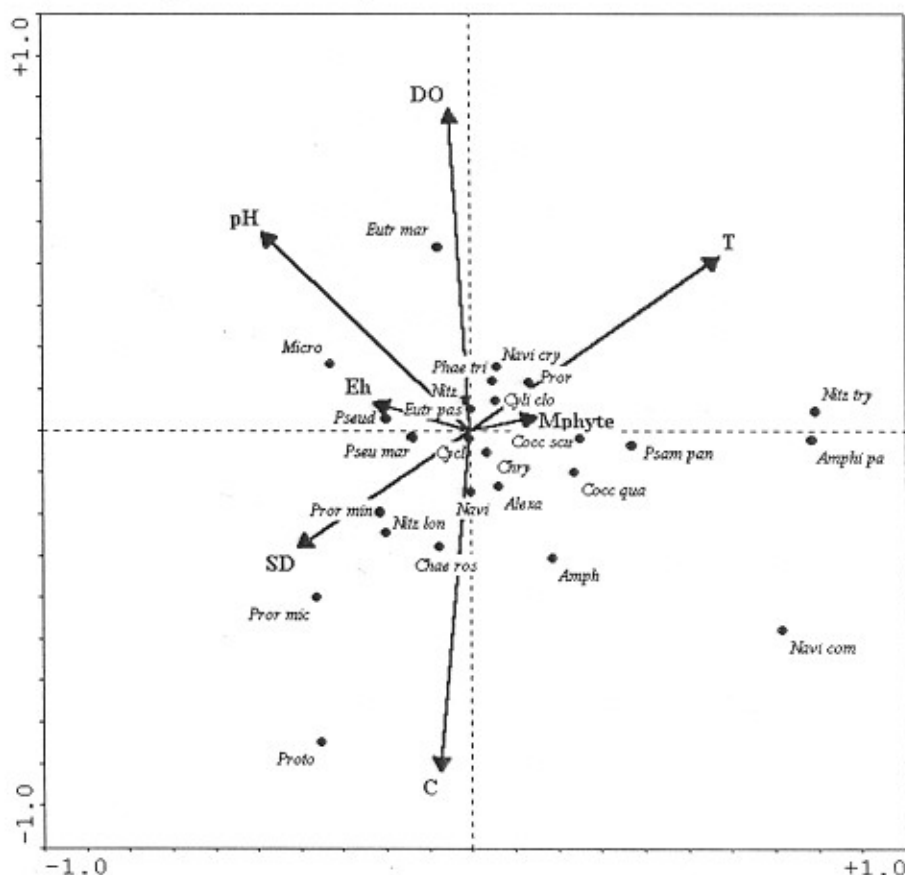


Fig. 4. Biplot of Canonical Correspondence Analysis (CCA) in June 1993. C = chlorinity, DO = dissolved oxygen (percent saturation), Eh = redox potential, Mphyte = Macrophyte biomass, SD = SECCHI disk (turbidity), T = temperature; Alexa = Alexandrium sp., Amph = Amphora sp., Amphi pa = Amphiprora paludosa, Chae ros = Chaetoceros rostratus, Chry = Chrysocromulina sp., Cocc qua = Cocconeis quarnerensis, Cocc scu = Cocconeis scutellum, Cycl = Cyclotella sp., Cyli clo = Cylindrotheca closterium, Eutr mar = Eutreptiella marina, Eutr pas = Eutreptiella pascheri, Micro = Micromonas sp., Navi = Navicula sp., Navi com = Navicula complanatae, Navi cry = Navicula cryptocephala, Nitz = Nitzschia sp., Nitz lon = Nitzschia longissima, Nitz try = Nitzschia tryblionella, Phae tri = Phaeodactylum tricorutum, Pror = Prorocentrum sp., Pror mic = Prorocentrum micans, Pror min = Prorocentrum minimum, Proto = Protoperdinium sp., Psam pan = Psammodictyon panduriforme, Pseu = Pseudokefrion sp., Pseu mar = Pseudoscourfieldia marina.

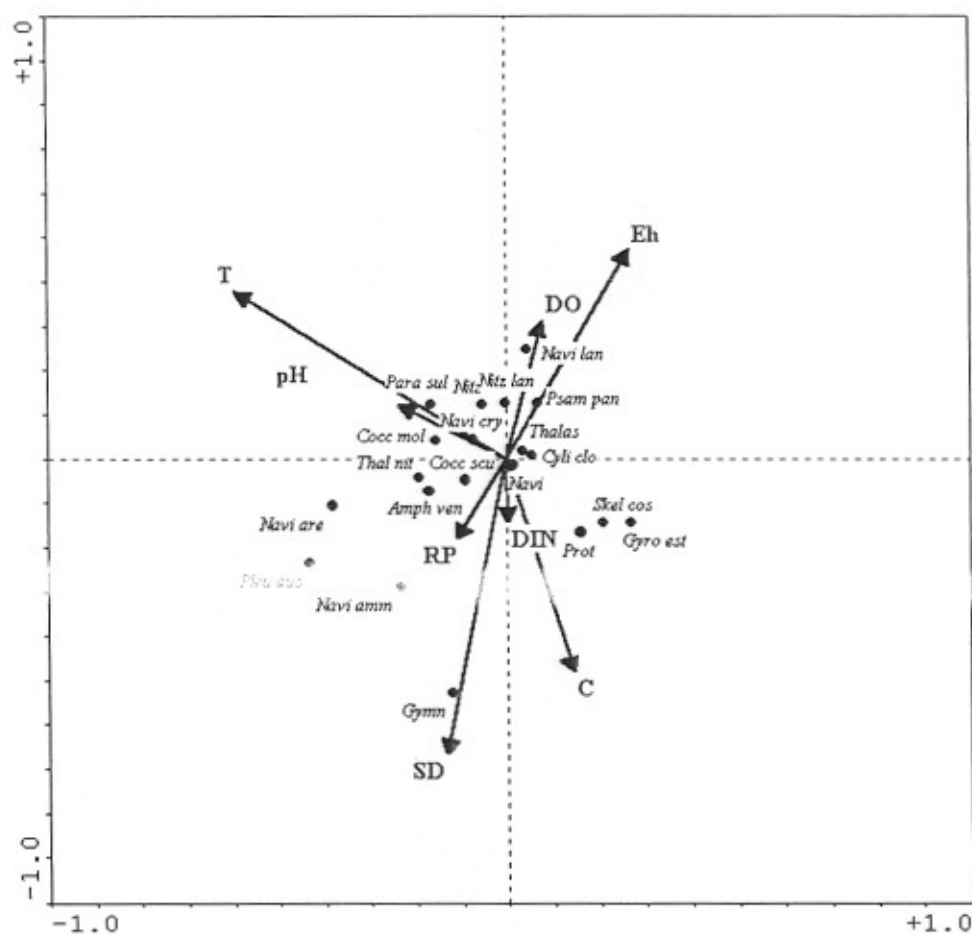


Fig. 5. Biplot of Canonical Correspondence Analysis (CCA) in June 1998. C = chlorinity, DIN = dissolved inorganic nitrogen (sum of nitrogen compounds), DO = dissolved oxygen (percent saturation), Eh = redox potential, RP = reactive phosphorus, SD = SECCHI disk (turbidity), T = temperature; Amph ven = *Amphora veneta*; Cocc mol = *Cocconeis molesta*, Cocc scu = *Cocconeis scutellum*, Cyli clo = *Cylindrotheca closterium*, Gymn = *Gymnodinium* sp., Gyro est = *Gyrodinium estuariale*, Navi = *Navicula* sp., Navi amn = *Navicula ammophila*, Navi are = *Navicula arenicola*, Navi cry = *Navicula cryptocephala*, Navi lan = *Navicula lanceolata*, Nitz = *Nitzschia* sp., Nitz lan = *Nitzschia lanceolata*, Para sul = *Paralia sulcata*, Pleu aus = *Pleurosigma australe*, Prot = *Protoperdinium* sp., Psam pan = *Psammодиctyon panduriforme*, Skel cos = *Skeletonema costatum*, Thal as = *Thalassiosira* sp., Thal nit = *Thalassionema nitzschioides*.

by projecting circles on arrows. For example, in June 1993, the variation of chlorinity (C) which, together with dissolved oxygen (DO) had the highest loading (≥ 0.70), was strongly related to the distribution of *Protoperdinium* sp., whereas *Eutreptiella marina* seemed the most euryhaline (Fig. 4). The low variation of SECCHI disk (SD) appeared well related to the presence of Dinophyceae such as *Prorocentrum micans* and *P. minimum* while other parameters had little relation to these species. In June 1998, all the environmental parameters had loadings

of ≤ 0.70 , but the highest was SECCHI disk (Fig. 5). Nutrient variations were negligible and only temperature (T) and chlorinity had important relationships to the species distribution.

DISCUSSION AND CONCLUSIONS

The Venice lagoon has always been the subject of morphological, hydraulic, and environmental studies since the development, history, and human activity of the city are strictly connected to conditions in the lagoon. The aim of

most scientific papers has been to understand the relationship between environmental dynamics and economic interests. Therefore, much literature is available, especially on fishing resources and activities. Macroalgae have also been widely studied, as they regulated the lagoon ecosystem between the 1970s and early 1990s. As primary production in the lagoon mainly depended on macrophyte cycles, little attention was paid to phytoplankton, whose contribution was negligible except during macroalgae decomposition (MARCOMINI *et al.*, 1995). Some papers describe phytoplankton dynamics in fishponds where shrimp (ANDREOLI & TOLOMIO, 1988a) and dory fry (ANDREOLI & TOLOMIO, 1988b) were cultivated. Others deal with phytoplankton distribution in the lagoon inlets (SOCAL *et al.*, 1985, 1987; TOLOMIO *et al.*, 1999) and the wetlands north of the lagoon (Palude della Rosa; SOCAL, 1981; BARILLARI *et al.*, 1984; BIANCHI *et al.*, 2000). The present paper focuses on phytoplankton in the shallow waters (approximately 1 m deep) of the central part of the lagoon. Therefore, data cannot easily be compared with earlier reports.

A comparison between June 1993 and June 1998 data does not provide exhaustive information on changes in microalgae but confirm some changes in phytoplankton as chlorophyll *a* concentrations decrease (FACCA *et al.*, 2001, 2002a; SFRISO *et al.*, 2003). The spatial sampling campaigns furnish interesting information on community composition and species distribution more than on cell abundance. Since phytoplankton can bloom in different periods, cell abundance was examined by comparing monthly data. The results confirmed both the June blooming period and the cell abundance, which did not exceed 25×10^6 cells dm^{-3} .

A marked change in lagoon environmental conditions was observed in the 1990s. Macroalgae, which had regulated the lagoon biogeochemical cycles for some twenty years, had almost disappeared allowing the colonization of bivalves. This greatly influenced clam fishing, which was most intense in the late 1990s. As a consequence, the amount of re-suspended sediment increased approximately one order of magnitude and water transparency as well as

phytoplankton abundance drastically decreased. In 1999, phytoplankton in the central lagoon accounted for an average 1-2% of the total suspended matter, peaking at 24% (FACCA *et al.*, 2002a). The annual Settling of Particulate Matter in sediment traps placed on the bottom at stations A, B, and C in 1998-99 was 7, 11, and 5 times higher than in 1989-90 (SFRISO *et al.*, 1992; SFRISO, 2000). During the 1990s, the sediment layer was continuously disrupted and re-suspended by hydraulic and mechanical devices used to catch bivalves, and microalgae typical of sea bottoms spread into the water column, affecting the composition of the phytoplankton communities. The reduction of light transmission in the water column seems to be the main cause for the general phytoplankton decrease, since nutrient availability did not appear to be a significant limiting factor as the CCA and PEARSON's correlation highlighted.

Sediment re-suspension not only reduced phytoplankton, it also affected species distribution. In both June 1993 and 1998, phytoplankton was more abundant near the mainland than elsewhere, but the abundance gradient was more marked in 1993 than in 1998. The homogenization of cell abundance and species distribution is related to the increased sediment re-suspension. Formerly, free-floating *Ulva* thalli hampered re-suspension induced by tides and winds. In the 1990s, reduction of macroalgae beds and the use of hydraulic and mechanical dredges to collect bivalves triggered the spread of fine sediments (particles $< 63 \mu\text{m}$), nutrients, and pollutants (SFRISO, 2000; FACCA *et al.*, 2002a). Pennate diatoms, typical to bottom habitats, normally use extracellular polysaccharide to aggregate on sediment particles. The surface micro-layer of extracellular polysaccharide helps reduce re-suspension (AUSTEN *et al.*, 1999; DE BROUWER *et al.*, 2000). But in cases of particularly intense perturbation, as occurs in the Venice lagoon, destruction of the micro-layer favors re-suspension of the sediment. During June 1998, there were a high number of cells of *Amphora veneta* (an epiphytic, epilithic, or epipellic pennate diatom, ROUND *et al.*, 1990), *Cocconeis scutellum* (a pennate diatom that lives on plants, rocks, etc.;

ROUND *et al.*, 1990), and *Navicula* sp., as also described in FACCA *et al.* (2002a).

All these considerations could explain the different structure of the phytoplankton community recorded in June 1998 when numerous pennate diatoms were re-suspended in the water column and Bacillariophyceae (four times higher in 1998 than in 1993) represented the most important microalgae group (BARRANGUET, 1997; WULFF *et al.*, 1997; BROTAS and PLANTE-CUNY, 1998). Nanoflagellates were the dominant taxon in both years, even though their abundance and spatial distribution differed. In June 1993 nanoflagellates were abundant near the mainland, especially near the airport, but rare or absent elsewhere. In June 1998 they were everywhere in the central lagoon, confirming the key role

played by fishing activities in spreading microalgae, particularly small cells. We can conclude that, although phytoplankton distribution was regulated mainly by chlorinity and temperature in the past (Fig. 4), it is now affected mainly by water transparency (Fig. 5).

Finally, by considering the mean cell biovolume, it is possible to estimate the total phytoplankton standing crop in the central lagoon as $244 \pm 315 \text{ m}^3$ in June 1993 and $86 \pm 120 \text{ m}^3$ in June 1998. This biomass estimation could be a first step towards calculating the contribution of phytoplankton to the primary production of the lagoon, taking into account that primary production is now measured in many areas of the lagoon.

REFERENCES

- ANDERSEN, V. & L. PRIEUR. 2000. One-month study in the open NW Mediterranean Sea (DYNAPROC experiment, May 1995): Overview of the hydrobiogeochemical structures and effects of wind event. *Deep-Sea Res. I*, 47: 397-422.
- ANDREOLI, C. & C. TOLOMIO. 1988a. Density and biomass of phytoplankton and picoplankton from fertilized fish ponds of "Valle Fosse" and "Valle Zappa" (Venice Lagoon - North Italy). *Arch. Hydrobiol. (Suppl.)*, 78 (4): 505-528 (in French with English abstract).
- ANDREOLI, C. & C. TOLOMIO. 1988b. The phytoplankton in a fishing valley (Valle Dogà) of the Venice lagoon during the period from May 1984 to April 1985. *Arch. Oceanogr. Limnol.*, 21: 95-115 (in Italian with English abstract).
- AUSTEN, I., T.J. ANDERSEN & K. EDELVANG. 1999. The influence of benthic diatoms and invertebrates on the erodibility of an intertidal mudflat, the Danish Wadden Sea. *Estuar. Coast. Shelf Sci.*, 49: 99-111.
- BARILLARI, A., F. BIANCHI, A. BOLDRIN, F. CIOCE, A. COMASCHI SCARAMUZZA, S. RABITTI & G. SOCAL. 1984. Hydrological features, suspended matter and phytoplankton biomass variations during a tidal cycle in Venice lagoon. In: Proc. 4th A.I.O.L. Conference, Livorno, Italy (in Italian with English abstract), pp. 227-234.
- BARRANGUET, C. 1997. The role of the microphytobenthic primary production in a Mediterranean mussel culture area. *Estuar. Coast. Shelf Sci.*, 44: 753-765.
- BIANCHI, F., F. ACRI, L. ALBERIGHI, M. BASTIANINI, A. BOLDRIN, B. CAVALLONI, F. CIOCE, A. COMASCHI, S. RABITTI, G. SOCAL & M.M. TURCHETTO. 2000. The lagoon of Venice: a biological variability study. A general review. *Ist. Ven. Sci., Lett. ed Arti SLV*, 3: 47-57.
- BOYD, P. & P.J. HARRISON. 1999. Phytoplankton dynamics in the NE subarctic Pacific. *Deep-Sea Res. II*, 46: 2405-2432.
- BROTAS, V. & M.R. PLANTE-CUNY. 1998. Spatial and temporal patterns of microphytobenthic taxa of estuarine tidal flats in the Tagus Estuary (Portugal) using pigment analysis by HPLC. *Mar. Ecol. Prog. Ser.*, 171: 43-57.
- DE BROUWER, J.F.C., S. BJELIC, E.M.G.T. DE DECKERE & L.J. STAL. 2000. Interplay between biology and sedimentology in a mudflat (Biezelingse Ham, Westerschelde, The Netherlands). *Cont. Shelf Res.*, 20: 1159-1177.
- EDLER, L. 1979. Recommendations for marine biological studies in the Baltic Sea. *Phyto-*

- plankton and Chlorophyll. *Baltic Marine Biologists Publ.*, 5: 1-38.
- FACCA, C., A. SFRISO & G. SOCAL. 2001. Phytoplankton spatial and temporal distribution in the central part of the Venice lagoon. XXXII^o SIBM Conference, Numana, Ancona, Italy, p. 37.
- FACCA, C., A. SFRISO & G. SOCAL. 2002a. Changes in abundance and composition of phytoplankton and microphytobenthos due to increased sediment fluxes in the Venice lagoon, Italy. *Estuar. Coast. Shelf Sci.*, 54: 773-792
- FACCA, C., A. SFRISO & G. SOCAL. 2002b. Temporal and spatial distribution of diatoms in the surface sediment of the Venice lagoon. *Bot. Mar.*, 45: 170-183
- GÓMEZ, N. & D.E. BAUER. 1998. Phytoplankton from the southern coastal fringe of the Río de la Plata (Buenos Aires, Argentina). *Hydrobiologia*, 380: 1-8.
- HABIB, O.A., R. TIPPETT & K.J. MURPHY. 1997. Seasonal changes in phytoplankton community structure in relation to physico-chemical factors in Loch Lomond, Scotland. *Hydrobiologia*, 350: 63-79.
- LORENZEN, C.J. 1967. Determination of Chlorophyll in Sea Water. UNESCO Tech. Pap. Mar. Sci., pp. 35-120.
- MARCOMINI, A., A. SFRISO, B. PAVONI & A.A. ORIO. 1995. Eutrophication of the lagoon of Venice: nutrient loads and exchanges. pp. 59-80. In: A.J. McComb (Editor). *Eutrophication in Shallow Estuaries and Lagoons*, CRC Press, Boca Raton, Florida, USA.
- NOGUEIRA, M.G. 2000. Phytoplankton composition, dominance and abundance as indicators of environmental compartmentalization in Jurumirim Reservoir (Paranapanema River), São Paulo, Brazil. *Hydrobiologia*, 431: 115-128.
- OREL, G., V. BOATTO, A. SFRISO & M. PELLIZZATO. 2000. Fishing sources management plan for the lagoons of the Venice Province. Province of Venice, Venice (in Italian).
- OXNER, M. 1962. The Determination of Chlorinity by the Knudsen Method and Hydrographical Tables. G.M. Manufacturing Co., New York.
- PERAGALLO, MM. H. & M. PERAGALLO. 1897-1908. *Diatomées Marines de France et des Districts Maritimes Voisins*. M.J. Tempère, Grez-sur-Loing, 491 pp.
- PIIRSOO, K. 2001. Phytoplankton of Estonian rivers in midsummer. *Hydrobiologia*, 444: 135-146.
- ROUND, F.E., R.M. CRAWFORD & D.G. MANN. 1990. *The Diatoms. Biology and Morphology of the Genera*. Cambridge University Press, Cambridge, 747 pp.
- SANDERS, R., T. JICKELLS & D. MILLS. 2001. Nutrients and chlorophyll at two sites in the Thames plume and southern North Sea. *J. Sea Res.*, 46: 13-28.
- SFRISO, A. 1996. Decrease of production and changes on macrophyte typology and distribution in the Venice lagoon. *Inquinamento*, 5: 80-88 (in Italian).
- SFRISO A. 2000. Eutrophication and pollution of the water and sediment in central part of the Venice lagoon. In: *Consorzio Venezia Nuova, Magistrato alle acque, Ministero dei Lavori Pubblici (Editors). Nuovi Interventi per la Salvaguardia della Laguna di Venezia, Venezia, vol. 3 (in Italian)*.
- SFRISO, A. & P.F. GHETTI. 1998. Seasonal variation in biomass, morphometric parameters and production of seagrasses in the lagoon of Venice. *Aquat. Bot.*, 61: 207-223.
- SFRISO, A. & A. MARCOMINI. 1996. Decline of *Ulva* growth in the lagoon of Venice. *Bioresour. Technol.*, 58: 299-307.
- SFRISO, A. & A. MARCOMINI. 1999. Macrophyte production in a shallow coastal lagoon. Part II: Coupling with sediment, SPM and tissue carbon, nitrogen and phosphorus concentrations. *Mar. Environ. Res.*, 47: 285-309.
- SFRISO, A., S. RACCANELLI, B. PAVONI & A. MARCOMINI. 1991. Sampling strategies for measuring macroalgal biomass in the shallow waters of the Venice lagoon. *Environ. Technol.*, 12: 263-269.
- SFRISO, A., B. PAVONI, A. MARCOMINI & A.A. ORIO. 1992. Macroalgae, nutrient cycles and pollutants in the lagoon of Venice. *Estuaries*, 15: 517-528.
- SFRISO, A., C. FACCA & P.F. GHETTI. 2003. Temporal and spatial changes of macroalgae and phy-

- toplankton in a Mediterranean coastal area: the Venice lagoon as a case study. *Mar. Environ. Res.*, 56: 617-636.
- SHANNON, C.E. & W. WEAVER. 1948. Biodiversity measurements. pp. 117-127. In: *The Mathematical Theory of Communication*. Urbana University Press, Illinois.
- SOCAL, G. 1981. Phytoplankton quantitative distribution in the northern basin of the Venice lagoon. June 1977-June 1978. *Rapporti e Studi*, 8: 105-119 (in Italian).
- SOCAL, G., L. GHETTI, A. BOLDRIN & F. BIANCHI. 1985. Phytoplankton annual cycle and diversity in Malamocco port entrance, Lagoon of Venice. *Ist. Ven. Sci., Lett. ed Arti.*, 143: 15-30 (in Italian).
- SOCAL, G., F. BIANCHI, A. COMASCHI SCARAMUZZA & F. CIOCE. 1987. Spatial distribution of plankton communities along a salinity gradient in the Venice lagoon. *Arch. Oceanogr. Limnol.*, 21: 19-43.
- SOCAL, G., F. BIANCHI & L. ALBERIGHI. 1999. Effects of thermal pollution and nutrient discharges on a spring phytoplankton bloom in the industrial area of the lagoon of Venice. *Vie Milieu*, 49: 19-31.
- STRICKLAND, J.D. & T.R. PARSONS. 1972. *A Practical Handbook of Seawater Analyses*. Fish. Res. Board Canada Bull. No. 167.
- TER BRAAK, C.J.F. & P. SMILAUER. 1998. *CANOCO* vers. 4 for Windows. Software for Canonical Community Ordination. Distributed by Scientia Publ., Budapest.
- TIMMERMANS, K.R., M. GLEDHILL, R.F. NOLTING, M.J.W. VELDHUIS, H.J.W. DE BAAR & C.M.G. VAN DEN BERG. 1998. Responses of marine phytoplankton in iron enrichment experiments in the northern North Sea and northeast Atlantic Ocean. *Mar. Chem.*, 61: 229-242.
- TOLOMIO, C., E. MOSCHIN, I. MORO & C. ANDREOLI. 1999. The phytoplankton of Venice Lagoon. I – Northern and southern basins (April 1988 – March 1989). *Vie Milieu*, 49: 33-44 (in French with English abstract).
- TOMAS, C.R. 1993. *Marine Phytoplankton. A Guide to Naked Flagellates and Coccolithophorids*. Academic Press, San Diego, 263 pp.
- TOMAS, C.R. 1996. *Identifying Marine Diatoms and Dinoflagellates*. Academic Press, San Diego, 598 pp.
- UTHERMÖL, H. 1958. Zur Vervollkommnung der quantitativen Phytoplankton-Methodik. *Mitt. Int. Verein. Limnol.*, 9: 1-38.
- VAN LANDINGHAM, S.L. 1976-1979. *Catalogue of the Fossil and Recent Genera and Species of Diatoms and their Synonyms*, Vol. 8. J. Cramer, Vaduz.
- WULFF, A., K. SUNDBACK, C. NILSSON, L. CARLSON & B. JONSSON. 1997. Effect of sediment load on the microphytobenthic community of a shallow-water sandy sediment. *Estuaries*, 20: 547-558.

Sastav i raspodjela fitoplanktonske zajednice u eutrofnom obalnom području (Venecijanska laguna, Italija)

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SAŽETAK

Istraživanja fitoplanktona središnjeg dijela Venecijanske lagune su izvršena devedesetih godina. Uzorci mora sakupljani su na 46 postaja u lipnju 1993. i u lipnju 1998. godine, a na 4 postaje jedanput mjesečno od studenog 1998. do listopada 1999. godine. Sakupljeni podaci uključuju sastav zajednice, numeričku abundanciju i stanične volumene, određene obrnutim svjetlosnim mikroskopom. Raspodjela abundancije stanica bila je u prosjeku $6,9 \times 10^6$ i $2,5 \times 10^6 \text{ dm}^{-3}$ u lipnju 1993. godine, odnosno lipnju 1998., a maksimalne vrijednosti od 151 i $16 \times 10^6 \text{ dm}^{-3}$ u lipnju 1993., odnosno lipnju 1998. Razlozi za razlike vrsta u cvatnji proučavani su u odnosu na faktore sredine ("Canonical Correspondence Analysis"). Najjači utjecaj na prostornu raspodjelu vrsta imali su slanost i temperatura mora u lipnju 1993. te slanost i prozirnost mora u lipnju 1998. S time se podudara i prostorna raspodjela fitoplanktona. Vrijeme cvatnje nastupalo je u lipnju, s najvišim vrijednostima neopredno uz obalu.

Ključne riječi: raspodjela fitoplanktona, abundancija, biomasa, zajednica mikroalga, Venecijanska laguna