Bollettino di Geofisica Teorica ed Applicata Vol. 39, n. 3, pp. 219-241; September 1998

Suspended matter in the Gulf of Trieste (northern Adriatic Sea) during the occurence of macroaggregates in 1991

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(Received October 15, 1996; accepted March, 1997)

Abstract. The composition, areal distribution, temporal variation and origin of total suspended matter (TSM) in the Gulf of Trieste (northern Adriatic Sea) in 1991, a year characterized by massive summer macroaggregate formations were studied, in terms of particulate organic and inorganic matter and particulate organic carbon (POC) and nitrogen (PN). The TSM throughout the studied period was characterized by the prevalence of the inorganic fraction except during the period of massive macroaggregates. High surface POC concentrations were observed, especially in the southern part of the Gulf. Generally, POC and PN were poorly correlated to the phytoplankton biomass (Chl. *a* concentrations) indicating that the particulate in the Gulf of Trieste is probably of a prevalent detrital nature. The principal component analysis of particulate constituents and basic hydrographic parameters (temperature, salinity) showed a net separation of all studied parameters between surface and bottom during the periods of stratified water (late spring and summer). The composition of surface suspended matter was much more variable than that of the bottom. Moreover, the areal distribution of TSM showed lower and more uniform values in the southern part than in the northern part of the gulf, since the latter was much more influenced by the inflow of the Alpine river Isonzo.

1. Introduction

The Gulf of Trieste is a shallow marine basin (max. depth 25 m) separated from the rest of the northern Adriatic Sea by a shoal between Grado and Savudrija point. It lies at the junction of the Istria platform in the south, the Karst in the east, and the Friuli Plain in the north. The Gulf of Trieste is the recipient of some important freshwater inflows, especially from the north

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(Isonzo, Timavo) and to a lesser extent from the east and south (Rosandra, Ospo, Rizana, Dragonja). The Alpine river Isonzo, with typically two flow maxima in June and November, is the most important freshwater input in this area, with a mean yearly flow of approximately 100 m^3s^{-1} (Olivotti et al., 1986), and an outflow of ~ 500 m^3s^{-1} which produces a wide spread of freshwater throughout the northern part of the Gulf of Trieste over a two day interval (Naudin et al., 1996).

The circulation system in the gulf seems to be mainly wind driven. The surface layer of thickness ~ 5 m flows clockwise when westerly winds are present, and counterclockwise when easterly winds blow. The bottom layer moves counterclockwise almost permanently with a typical transport velocity of 2-3 cms^{-1}. Tidal currents are most significant in calm weather, driving the same water mass forwards and backwards with a run of ~ 1 km (Malačič, 1991).

Existent data on the composition and variations of particulate organic matter in the northern Adriatic mostly pertain to the southern (Faganeli and Malej, 1981; Faganeli, 1983; Faganeli et al., 1988; Faganeli, 1989; Posedel and Faganeli, 1991) and central (Fonda Umani et al., 1985) parts of the Gulf of Trieste. There is however some data from the northern Adriatic between the Istria peninsula and the river Po delta (Franco et al., 1986; Faganeli et al., 1989; Franco et al., 1989; Gilmartin and Revelante, 1991; Boldrin and Rabitti, 1992).

In recent years, during the late spring algal blooms which throughout the whole of the northern Adriatic and the Gulf of Trieste, the appearence of large macroaggregates has been signaled (Brambati, 1988; Degobbis, 1989; Posedel and Faganeli, 1991). Although the occurence of mucillage in the northern Adriatic is well documented both in appearance and development, the origin of this phenomenon remains obscure (Fonda-Umani et al., 1989). Mucus aggregates are complex, probably polysaccharide formations (Faganeli et al., 1995), which may have various origins, and form a microhabitat which favours communities of bacteria, microalgae and heterotrophic flagellates (Monti et al., 1996). Diatoms such as *Nitzschia longissima* and *Nitzschia closterium* make the predominant contribution to the macroaggregate formation, as reported by Stachowitsch et al. (1990) and by Revelante and Gilmartin (1991). In the northern Adriatic Sea, Herndl (1992) proposed two main factors leading to marine snow formation; a physical one - the development of a strong pycnocline leading to a generally reduced flux to the bottom; and a biological one - high photosynthetic extracellular release during summer months. Various experiments have been carried out under controlled conditions to understand mucus formation (Monti et al., 1994; Welker and Monti, 1994). Monti et al. (1995) found that the genus *Nitzschia* seemed to be essential for the formation of mucus filaments. The study of composition, areal distribution and temporal variation of particulate organic matter, in conjunction with basic oceanographic properties, would seem important for understanding this phenomenon better.

In the summer of 1991 the quantity of mucillage in this area was remarkable, and this study represents a part of the Alpe-Adria project "Campagna scientifica di ricerca e monitoraggio sullo stato chimico, fisico e biologico delle acque dell'Alto Adriatico, in relazione al fenomeno di formazione degli ammassi gelatinosi" supported by the Friuli-Venezia Giulia and Veneto Regions, and the Republics of Slovenia and Croatia. It deals with a study of the composition, areal distribution, temporal variations and origin of suspended matter in the Gulf of Trieste during the

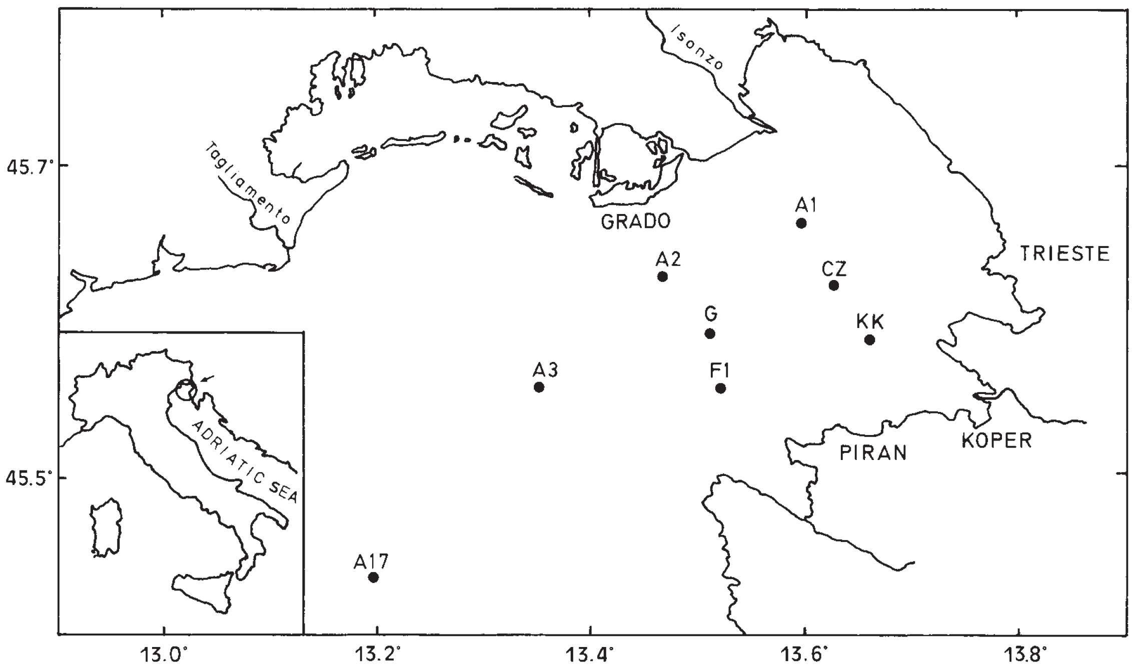

Fig. 1 - Location of the sampling stations in the Gulf of Trieste (northern Adriatic Sea).

occurrence of this phenomenon, in relation to basic oceanographic parameters.

2. Materials and methods

Seawater samples for analyses of particulate constituents were collected monthly from June to November 1991 at eight stations in the Gulf of Trieste (A1, A2, A3, A17, CZ, G, KK, F1) in the surface (0.5 m) and bottom layers (from 17 m, st. A2, to 24 m, st. CZ) of the water column, using Niskin samplers (Fig. 1).

Temperature and conductivity in the water column were determined using a CTD probe (Idronaut) with sampling frequency of 0.2 dbar. The depth, salinity and density data were calculated using UNESCO algorithms (UNESCO, 1983) and reported as mean values at a depth interval of 1 m. Some of the salinity data were also obtained titrimetrically (Strickland and Parsons, 1968).

Seawater samples (1 dm^3) were filtered through precombusted and weighed Whatman GF/F glass-fibre filters, to study the composition of the suspended matter (Banse et al., 1963; Relaxans et al., 1988). Samples (2 dm^3) for determination of chlorophyll a were filtered through Millipore HA membrane filters (Strickland and Parsons, 1968).

Total Suspended Matter (TSM), Particulate Organic Matter (POM), Inorganic Suspended Matter (ISM), Particulate Organic Carbon (POC) and Particulate Nitrogen (PN) were determined by different methods. Filters with particles were washed with distilled water and dried at 50-55 °C. TSM was determined gravimetrically. ISM concentration at the stations CZ, G, KK and F1 was determined gravimetrically after combustion at 480 °C for 3 hours. POM for these stations was calculated from the difference between TSM and ISM values, while the POM concentration in stations A1, A2, A3 and A17 was recalculated from POC data using the regression equation POM = 1.12 POC + 0.77 (n=25; r=0.434; 1%=0.487; 5%=0.381) obtained from samples analysed at stations CZ, G, KK and F1. POC and PN were determined on samples pretreated with 1M HCl (Hedges and Stern, 1984) using Perkin-Elmer (mod. 2400) and Carlo Erba (mod. 1108EA) CHN analyzers at 950-1000 °C combustion temperature. Chlorophyll *a* (Chl. *a*) concentrations were analysed fluorimetrically and spectrophotometrically in 90% acetone homogenates (Strickland and Parsons, 1968).

Statistical analyses of TSM, POM, ISM, POC, PN, C/N ratio, Chl. *a*, temperature and salinity were performed by a principal component analysis using the Matedit statistical software (Burba et al., 1992).

3. Results and discussion

3.1. Oceanographic conditions

In June 1991 the water column in the Gulf of Trieste was stratified. Surface temperatures ranged between 21.1-22.5 °C, with the highest encountered in the central part of the gulf. The bottom temperatures were in the range 12.8-13.9 °C, and the lowest were located in the residual winter nucleus in the central part of the gulf. The higher bottom temperatures observed in the southern part of the gulf (station A17) were the consequence of the central Adriatic water inflow. Surface salinities (Table 1) of over 34.0 were observed at the gulf entrance (station A3 and A17), while values under 30.0 in the central part of the gulf (station A1) were due to the high riverine inflows. Bottom water salinities (Table 2) varied between 37.4-37.8 due to the inflow of more saline waters from the central Adriatic (Mosetti, 1967; Stravisi et al., 1981).

A similar situation was also seen in July, August and September 1991 during the water column termohaline stratification. The highest surface water temperatures were observed in July and August 1991 (> 26.0 °C). In this period the bottom water temperatures ranged mainly between 15.0-16.0 °C, and the surface waters were less influenced by riverine inflows, since salinity values lower than 30.0 were not observed (Tables 1 and 2). In September 1991 the higher salinity of the surface waters (> 35.1) indicated diminuished riverine inflow. A first thermal homogenization of the surface layer was evident and was due to cooling and mechanical mixing by the ENE wind (Bora).

The autumn situation was characterized by a progressive mixing of the water column, even if in October 1991 two distinct thermohaline water layers were present. In general the water column was still characterized by the presence of summer stratification: the surface and subsurface layers contained a riverine water imprint, with temperatures between 20.4-22.0 °C and salinities around 32.0 in the northern part of the gulf (st. A1 and A2), while in the southern part the salinities reaches the value of 35.8 (A17); the bottom layers showed temperatures and salinities

Table 1 - Composition of the suspended matter in the surface layers in the Gulf of Trieste in 1991.

month	st.	POC (µg/dm³)	PON (µg/dm³)	C/N	TSM (mg/dm³)	POM (mg/dm³)	POM (%)	ISM (mg/dm³)	ISM (%)	T (°C)	S (PSU)	Chl. *a*
Jun.	**A1**	1109.8	206.2	6.3	26.82	1.24	4.6	25.58	95.4	22.03	28.66	0.80
	A2	961.1	79.2	14.2	9.85	1.08	10.9	8.77	89.1	22.49	31.64	1.00
	A3	617.5	46.6	15.5	3.86	0.69	17.9	3.17	82.1	21.20	34.60	0.40
	A17	535.2	64.2	9.7	3.09	0.60	19.4	2.49	80.6	21.12	34.74	0.70
	CZ	-	-	-	4.43	2.63	59.4	1.80	40.6	22.21	31.33	2.28
	F1	-	-	-	2.86	0.86	30.1	2.00	69.9	21.51	31.91	1.58
	G	-	-	-	2.66	1.20	45.1	1.46	54.9	21.60	30.66	1.79
	KK	-	-	-	2.86	1.04	36.4	1.82	63.6	21.26	32.56	2.07
Jul.	**A1**	512.1	131.8	4.5	14.78	0.57	3.9	14.21	96.1	24.99	32.89	0.40
	A2	443.2	95.4	5.4	8.65	0.50	5.7	8.15	94.3	26.02	33.50	0.40
	A3	265.0	22.1	14.0	9.12	0.30	3.3	8.82	96.7	25.72	33.94	0.20
	A17	889.4	120.5	8.6	16.91	1.00	5.9	15.91	94.1	26.65	34.20	0.50
	CZ	237.7	29.1	9.5	2.32	1.02	44.0	1.30	56.0	25.62	32.79	0.80
	F1	106.0	22.4	5.5	2.21	0.87	39.4	1.34	60.6	25.59	33.78	0.40
	G	131.7	15.1	10.2	1.58	0.70	44.3	0.88	55.7	25.56	32.99	0.45
	KK	191.2	28.7	7.8	1.80	0.90	50.0	0.90	50.0	25.28	33.39	0.48
Aug.	**A1**	425.6	64.6	7.7	5.62	0.48	8.5	5.14	91.5	24.96	33.68	1.60
	A2	530.8	86.9	7.1	18.43	0.60	3.2	17.83	96.8	25.54	32.13	4.00
	A3	592.7	104.9	6.6	21.63	0.66	3.1	20.97	96.9	26.62	34.90	0.40
	A17	361.6	39.7	20.6	20.47	0.41	2.0	20.06	98.0	25.98	35.22	0.30
	CZ	2363,5*	109.1	25.3	1.33	1.13	85.0	0.20	15.0	25.15	34.87	1.20
	F1	1612,3*	73.1	25.7	2.32	1.82	78.4	0.50	21.6	25.19	33.06	2.30
	G	1523,1*	113.4	15.7	3.01	1.94	64.5	1.07	35.5	25.02	34.08	3.92
	KK	3745,0*	139.3	31.4	1.86	1.86	100.0	0.00	0.0	24.83	34.33	3.68
Sep.	**A1**	420.3	34.5	14.2	2.57	0.47	18.3	2.10	81.7	22.84	35.89	0.80
	A2	388.9	91.8	4.9	1.27	0.44	34.4	0.83	65.6	24.37	35.61	0.40
	A3	393.5	38.6	11.9	2.77	0.44	15.9	2.33	84.1	24.39	35.27	0.80
	A17	184.8	32.3	6.7	0.67	0.21	31.0	0.46	69.0	24.37	35.26	0.40
	CZ	-	-	-	2.20	0.90	40.9	1.30	59.1	22.70	35.28	0.81
	F1	142.0	42.3	3.9	2.44	0.78	32.0	1.66	68.0	23.65	35.62	0.77
	G	81.2	37.6	2.5	3.18	0.98	30.8	2.20	69.2	23.48	35.07	0.87
	KK	243.4	33.9	8.4	2.46	0.98	39.8	1.48	60.2	23.35	35.82	0.67
Oct.	**A1**	330.7	33.2	11.6	2.09	0.37	17.8	1.72	82.2	20.43	32.85	0.80
	A2	494.1	151.2	3.8	2.49	0.55	22.3	1.94	77.7	21.07	32.03	0.80
	A3	488.3	62.8	9.1	2.37	0.55	23.1	1.82	76.9	21.81	35.61	1.20
	A17	286.6	31.4	20.7	0.87	0.32	37.0	0.55	63.0	21.99	35.68	0.73
	CZ	217.5	18.8	13.5	3.06	1.00	32.7	2.06	67.3	21.10	34.16	0.79
	F1	194.6	44.7	5.1	2.88	1.16	40.3	1.72	59.7	21.97	35.79	0.73
	G	675.4	22.8	34.5	2.12	0.80	37.7	1.32	62.3	21.69	34.56	0.89
	KK	102.2	19.8	6.0	2.48	0.86	34.7	1.62	65.3	21.82	35.25	0.58
Nov.	**A1**	964.7	157.1	7.2	76.88	1.08	1.4	75.80	98.6	12.90	32.55	0.80
	A2	291.6	58.1	5.9	1.34	0.33	24.4	1.01	75.6	16.14	36.75	0.40
	A3	871.8	68.0	14.9	3.55	0.98	27.5	2.57	72.5	14.82	36.32	2.40
	A17	984.7	107.3	20.7	5.19	1.10	21.3	4.09	78.7	15.46	36.97	2.70
	CZ	511.3	23.8	25.1	4.16	1.74	41.8	2.42	58.2	15.18	36.24	6.04
	F1	160.7	23.6	7.9	4.10	1.70	41.5	2.40	58.5	15.52	36.45	4.41
	G	248.2	21.0	13.8	3.69	1.70	46.1	1.99	53.9	15.43	36.17	4.64
	KK	282.0	6.6	50.0	3.38	1.32	39.1	2.06	60.9	15.97	37.19	5.41

* higher POC than TSM concentrations were probably due to the water sub-sampling.

Table 2 - Composition of the suspended matter in the bottom layers in the Gulf of Trieste in 1991.

month	st.	POC (µg/dm³)	PON (µg/dm³)	C/N	TSM (mg/dm³)	POM (mg/dm³)	POM (%)	ISM (mg/dm³)	ISM (%)	T (°C)	S (PSU)	Chl. *a*
Jun.	**A1**	1184.6	233.9	5.9	20.98	1.33	6.3	19.65	93.7	12.85	37.71	0.40
	A2	543.2	32.4	19.6	11.05	0.61	5.5	10.44	94.5	13.06	37.62	1.40
	A3	1008.1	147.5	8.0	35.78	1.13	3.2	34.65	96.8	13.43	37.73	0.80
	A17	413.8	26.1	18.5	5.12	0.46	9.1	4.66	90.9	13.94	37.76	0.66
	CZ	-	-	-	2.36	0.86	36.4	1.50	63.6	13.00	37.48	0.72
	F1	-	-	-	2.35	0.13	5.5	2.22	94.5	13.22	37.57	0.56
	G	-	-	-	3.32	0.58	25.0	1.74	75.0	12.79	37.39	0.63
	KK	-	-	-	3.22	0.14	4.3	3.08	95.7	13.83	37.36	0.56
Jul.	**A1**	1212.6	225.6	6.3	19.39	1.36	7.0	18.03	93.0	13.84	37.79	0.80
	A2	1473.5	189.4	9.1	15.31	1.65	10.8	13.66	89.2	15.24	37.56	2.20
	A3	664.4	100.4	7.7	13.93	0.74	5.3	13.19	94.7	15.69	37.78	0.40
	A17	314.0	61.3	6.0	6.62	0.35	5.3	6.27	94.7	14.49	37.80	1.50
	CZ	79.6	20.0	4.6	2.21	0.79	35.7	1.42	64.3	14.00	37.39	0.40
	F1	180.2	14.9	14.1	1.58	0.70	44.3	0.88	55.7	15.56	32.99	0.45
	G	129.8	20.1	7.5	2.04	0.70	34.3	1.34	65.7	14.50	37.21	0.78
	KK	206.0	18.3	13.1	1.56	0.78	50.0	0.78	50.0	15.88	37.10	1.29
Aug.	**A1**	403.3	77.9	6.0	23.96	0.45	1.9	23.51	98.1	15.88	37.68	0.40
	A2	829.2	135.3	7.1	25.86	0.93	3.6	24.93	96.4	18.03	37.50	0.60
	A3	308.3	111.6	3.2	20.14	0.35	1.7	19.79	98.3	17.59	37.65	0.60
	A17	493.4	64.9	8.9	25.09	0.55	2.2	24.54	97.8	15.40	37.96	1.84
	CZ	105.8	33.4	3.7	3.34	1.58	47.3	1.76	52.7	16.40	37.43	0.62
	F1	152.1	26.9	6.6	3.12	1.48	47.4	1.64	52.6	16.84	37.29	0.99
	G	123.4	41.1	3.5	6.03	2.57	42.6	3.46	57.4	16.03	37.41	0.54
	KK	57.9	23.6	2.9	4.58	2.05	44.8	2.53	55.2	17.85	37.18	0.69
Sep.	**A1**	495.8	62.3	9.3	3.37	0.56	16.5	2.81	83.5	17.81	37.66	1.20
	A2	541.2	66.9	9.4	4.60	0.61	13.2	3.99	86.8	17.89	37.66	1.20
	A3	457.6	86.2	6.2	5.77	0.51	8.9	5.26	91.1	15.45	38.00	0.40
	A17	340.2	46.2	8.6	0.98	0.38	39.0	0.60	61.0	14.28	37.91	2.94
	CZ	153.7	22.1	8.1	3.46	0.98	28.3	2.48	71.7	16.08	37.52	1.33
	F1	120.7	22.7	6.2	3.28	0.90	27.4	2.38	72.6	17.42	37.65	1.05
	G	196.3	17.1	13.4	2.60	1.06	40.8	1.54	59.2	17.54	37.18	1.91
	KK	312.5	19.2	19.0	3.10	1.16	37.4	1.94	62.6	17.81	37.00	3.71
Oct.	**A1**	2309.1	367.5	7.3	6.94	2.59	37.3	4.35	62.7	18.90	37.50	0.40
	A2	425.4	94.7	5.2	1.80	0.48	26.5	1.32	73.5	21.56	36.57	0.80
	A3	473.2	104.5	5.3	2.11	0.53	25.2	1.58	74.8	21.06	36.93	1.20
	A17	276.4	38.9	8.3	1.11	0.31	28.0	0.80	72.0	18.84	37.69	0.62
	CZ	165.0	18.2	10.6	2.20	0.81	36.8	1.39	63.2	18.00	37.25	1.29
	F1	300.4	35.2	10.0	2.61	1.25	47.9	1.36	52.1	21.70	36.00	0.90
	G	257.7	29.5	10.2	2.42	0.92	38.0	1.50	62.0	21.23	36.56	1.41
	KK	115.4	16.7	8.0	3.18	1.20	37.7	1.98	62.3	20.35	37.18	2.82
Nov.	**A1**	517.6	106.6	5.7	3.58	0.58	16.2	3.00	83.8	14.46	36.73	1.60
	A2	390.2	69.2	6.6	2.42	0.44	18.1	1.98	81.9	15.41	36.74	1.20
	A3	800.3	128.7	7.3	3.25	0.90	27.6	2.35	72.4	14.74	36.45	1.60
	A17	253.9	59.4	5.0	1.13	0.29	25.2	0.84	74.8	15.35	37.03	2.34
	CZ	193.9	21.8	10.4	2.88	1.18	41.0	1.70	59.0	16.10	36.69	6.16
	F1	124.6	22.9	6.4	3.05	1.24	40.7	1.81	59.3	15.44	36.71	2.78
	G	144.3	24.5	6.9	2.64	1.14	43.2	1.50	56.8	15.28	36.96	4.72
	KK	325.6	20.7	18.4	2.49	1.06	42.6	1.43	57.4	15.82	36.53	6.79

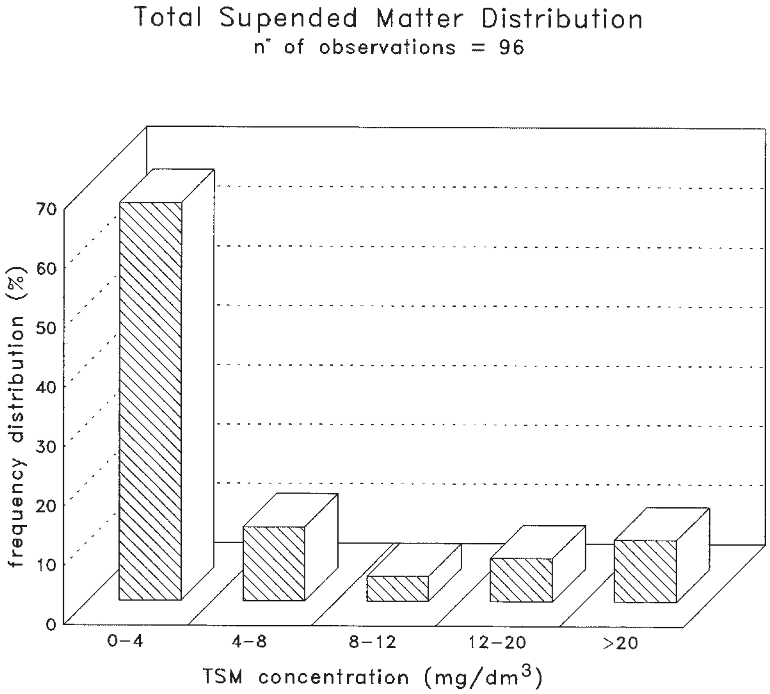

Fig. 2 - Frequency distribution of the total suspended matter (TSM) concentrations in the Gulf of Trieste.

ranging between 18.0-21.7 °C and 36.0-37.7, respectively (Tables 1 and 2).

In November 1991 convective instability was present throughout the water column. Only the surface coastal waters showed a small thermic and salinity gradient (12.9-16.1 °C, 32.5-36.7) due to the riverine inflows; their diffusion into the outer part of the gulf was limited by the initial presence of a frontal system. The offshore waters were, on the contrary, characterized by temperatures and salinities ranging between 15.2-16.0 °C and 36.2-37.2, respectively (Table 2).

3.2. Suspended Particulate Matter

The TSM concentration varied between 0.7 (September, A17 surface) and 76.9 mg/dm^3 (November, A1 surface), and the most frequent concentrations (Fig. 2) ranged between 0 and 4 mg/dm^3 (amounted to 67%). High TSM concentrations were found in surface and bottom layers at the northern stations in the summertime (June, July and August; st. A1, A2, A3 and A17). During the autumn months, TSM decreased and showed minor differences between surface and bottom at all stations. Southern stations (F1, G, Z and KK) generally showed more homogenous TSM values than the northern ones (Fig. 3). The difference between these two areas, as reported by Ogorelec et al. (1991) and Fonda-Umani et al. (1985), was probably due to the influence of riverine inflows.

The most abundant component of TSM was inorganic (ISM), representing on average 68.8 ±21.7% in the surface layer, and 74.5 ± 15.9 % in the bottom layer. Highest concentra-

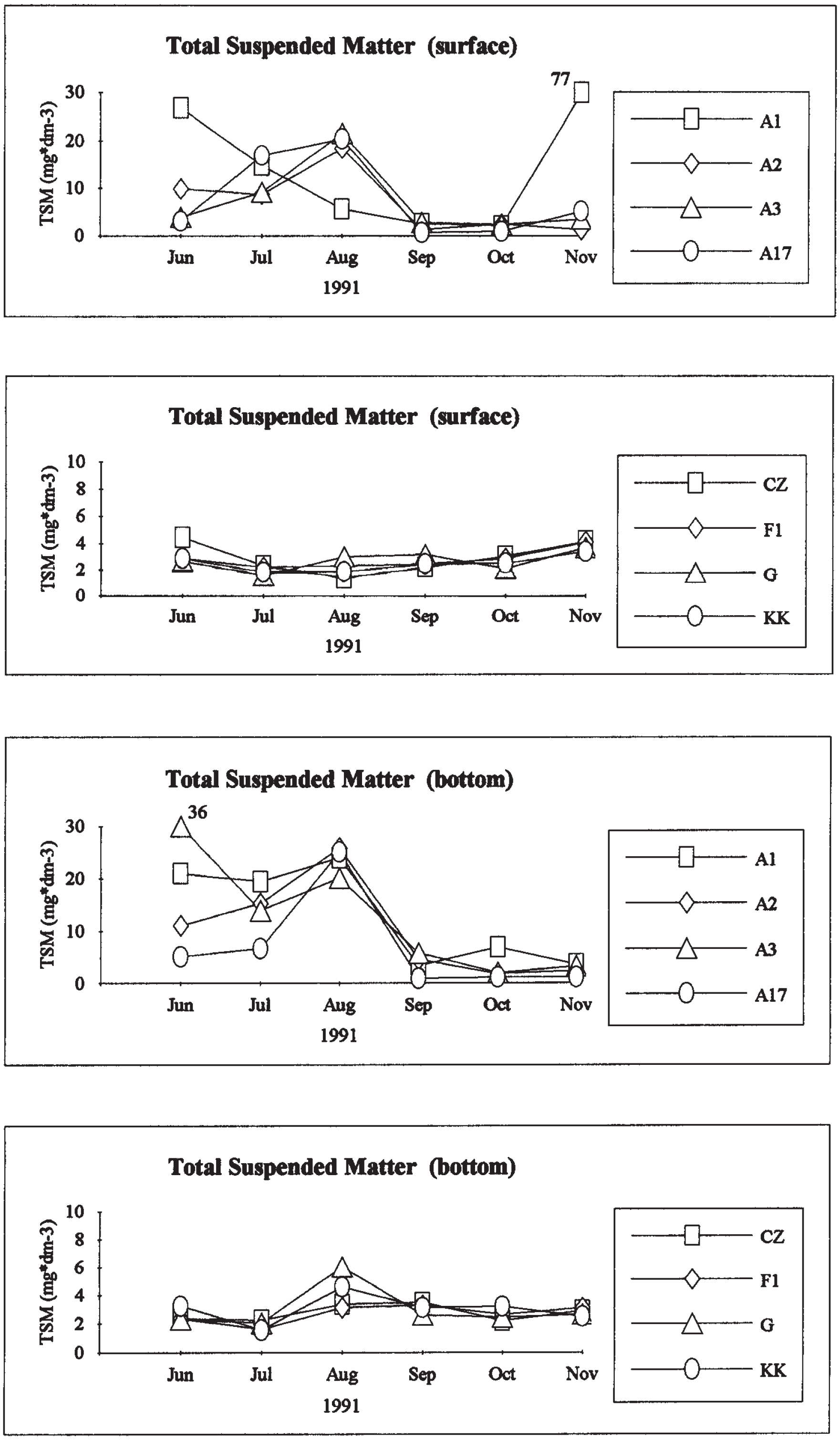

Fig. 3 - Variation of the total suspended matter (TSM) in surface and bottom layers at stations A1, A2, A3, A17, CZ, F1, G and KK in the Gulf of Trieste.

tions of ISM were observed in November (st. A1 surface, 75.8 mg/dm^3) and in June (st. A3 bottom, 34.65 mg/dm^3), and the lowest (0.16 mg/dm^3, 16.0 % of the TSM) in September (st. A17, bottom layer). From June to August a notable contribution from terrigenous imputs was evident at the northern stations (surface and bottom). During the autumn, ISM values were lower and more homogenous in most of the area. High values of ISM reported in August were probably correlated with the presence of mucous.

The organic fraction (POM) reppresented on average 31.2 ±21.9% in surface, and 25.5 ± 16.1% in the bottom layers of the TSM. Higher concentrations of POM were found in August in the southern part of the gulf. No significant variations were reported between surface and bottom values.

3.3. POC and PN

The POC concentations were extremly variable, averaging 610.9 ±655.6 $\mu g/dm^3$ in the surface layer and 444.9 ±427.8 $\mu g/dm^3$ in the bottom layer. These values were generally higher than those signaled in other northern Adriatic stations, with the exeption of those observed in the Po river delta area (Fonda Umani et al., 1985; Gilmartin and Relevante, 1991). The highest POC concentrations (from 1523.1 to 3745.0 $\mu g/dm^3$) were observed in the surface layers of the southern part of the gulf (st. CZ, KK, G, F1). Meanwhile, at the same stations, the bottom POC values were lower and homogenous. In the northern part, POC showed a decrease from July to August and an increase during the autumn, more evident in the bottom layers (Fig. 4).

The PN concentrations were also quite variable, averaging 62.7 ±46.3 $\mu g/dm^3$ in the surface and 70.6 ±71.2 $\mu g/dm^3$ in the bottom layer. The PN concentrations were rarely higher than 100 $\mu g/dm^3$. A significant relation was found between POC and PN in bottom layers, while there was no significant correlation in the surface layers (Fig. 5).

The C/N atomic ratio (Fig. 6) in surface and bottom water layers was used as an indicator of living and terrigenous fractions, as well as POC and PN contents (Kukal, 1971; Parson, 1975; Romankevich, 1984). The mean C/N ratio in the surface layer was 16.4 ±24.9, while in the bottom layer it was 8.5 ±4.1, indicating the prevalence of allochthonous riverine POC input in the surface (C/N >10) and autochthonous planktonic in the bottom layer (C/N <10).

3.4. Chlorophyll a

The Chl. *a* concentrations ranged between 0.2 (surface layer at A3 in July) and 6.79 $\mu g/dm^3$ (bottom layer at KK in November) while the majority of data were between 0.4-0.8 $\mu g/dm^3$. The highest Chl. *a* values in the Gulf of Trieste were observed in late autumn (November). The Chl. *a* distribution at the surface throughout the gulf presented higher values during June, August and November, while in bottom layers it generally increased from June to November, especially in the southern area.

A slightly positive correlation between POC and PN and Chl. *a* was noticed in the Gulf of Trieste during the summertime. Meanwhile a weak negative correlation between these parameters was observed in autumn. This behaviour is different to that of POC, PN and Chl. *a* in the northern

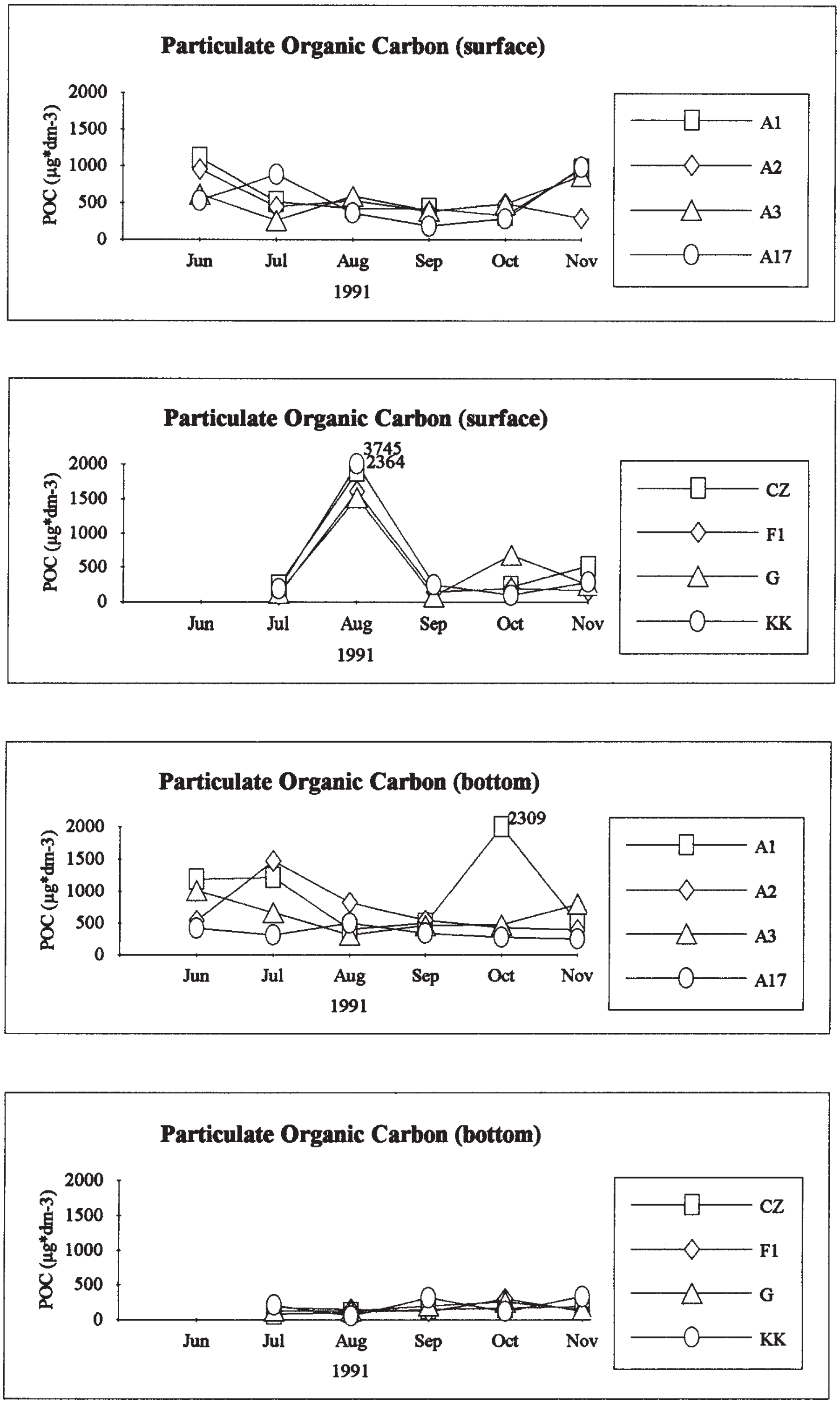

Fig. 4 - Variation of the particulate organic carbon (POC) in surface and bottom layers at stations A1, A2, A3, A17, CZ, F1, G and KK in the Gulf of Trieste.

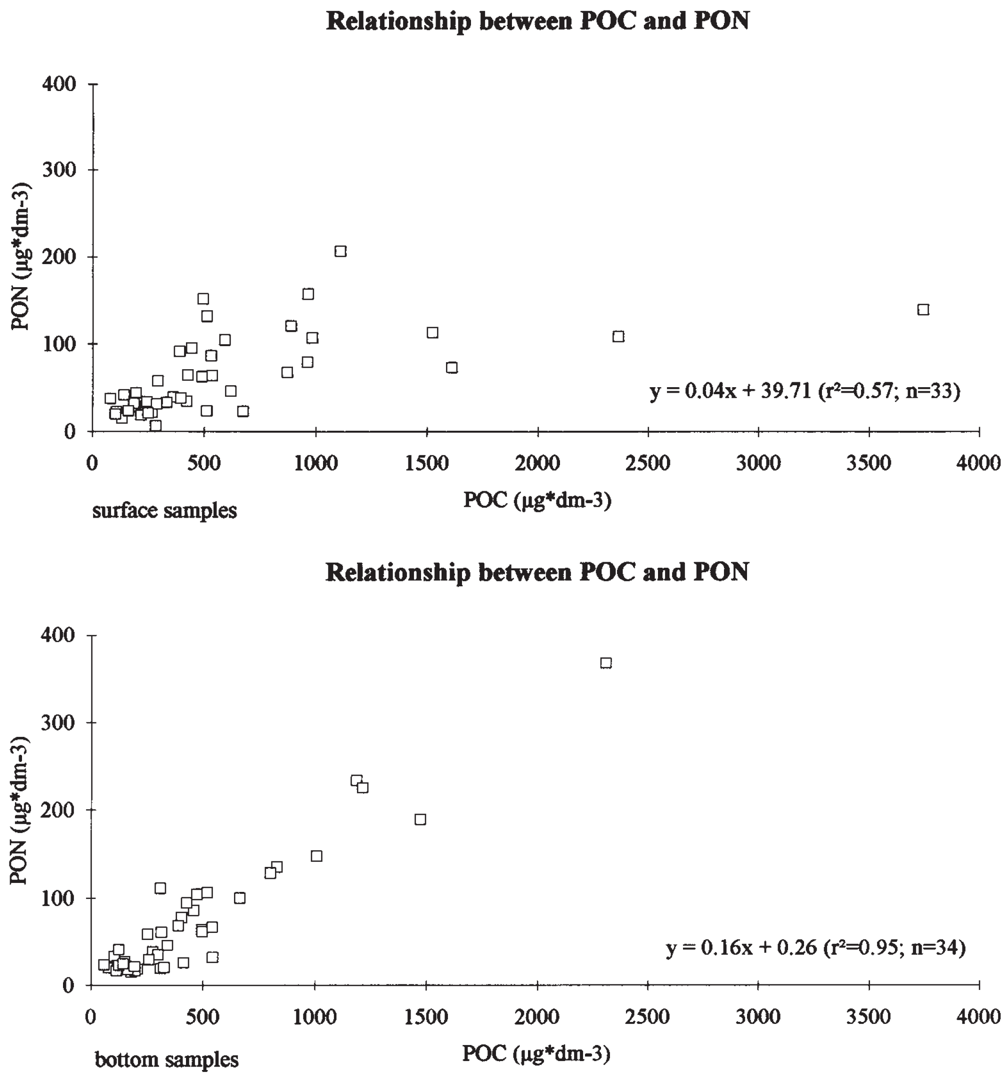

Fig. 5 - Variation of the particulate C/N atomic ratio in surface and bottom layers at stations A1, A2, A3, A17, CZ, F1, G and KK in the Gulf of Trieste.

Adriatic summer stratified waters between the Istria peninsula and the river Po delta (Gilmartin and Relevante, 1991), and this difference probably underlies the marked eutrophication effect of the river Po in this area, much larger than that of the Isonzo river in the Gulf of Trieste.

4. Temporal relationships between particulate constituents (PCA)

4.1. June 1991

The water column was stratified due to the seasonal heating of the surface layer and the

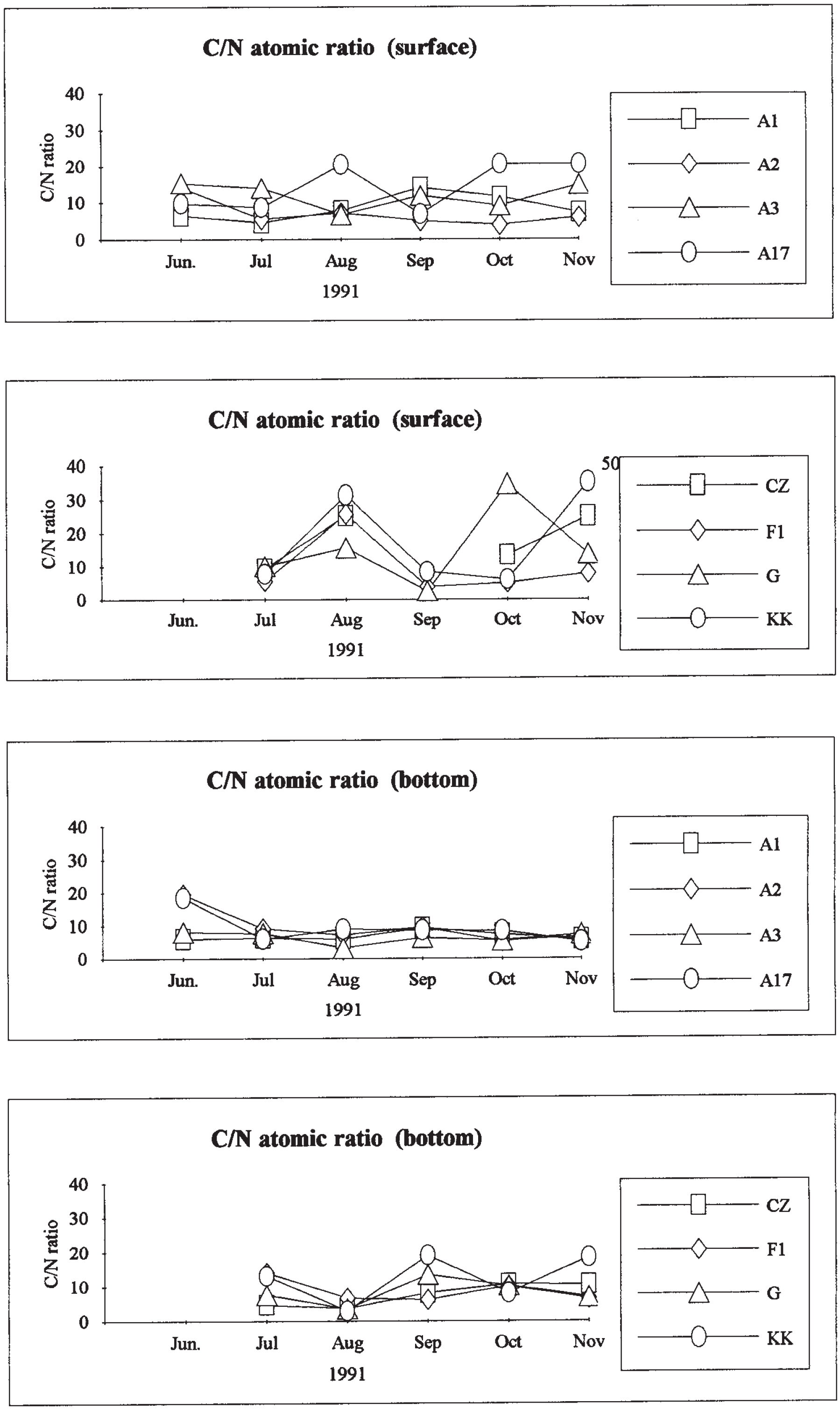

Fig. 6 - Relationship between particulate organic carbon (POC) and particulate organic nitrogen (PN) in the surface (A) and bottom (B) layers of the Gulf of Trieste.

Table 3 - Correlation matrix of surface and bottom June data. Correlation coefficient values, for 14 degrees of freedom, are 0.49 at the 5% level and 0.62 at the 1% level.

	T	S	TSM	ISM	POM	Chl. *a*
T	1.0					
S	-0.80	1.00				
TSM	-0.15	0.06	1.00			
ISM	-0.18	0.11	1.00	1.00		
POM	0.47	-0.80	0.26	0.20	1.00	
Chl. *a*	0.53	-0.70	-0.22	0.26	0.61	1.00

inflow of warmer riverine water. This caused an inverse correlation between salinity and temperature (Table 3), and was probably due to the SE-NW horizontal temperature gradient in the gulf. This phenomenon could be explained by several factors: the influence of the NE (Bora) wind, which produced a decrease in the surface temperature in the eastern part of the gulf; the higher spring temperature of northern Italian rivers compared to the surface seawater temperature; and the high concentration of TSM in the Isonzo river delta, which strongly reduced light intensity in the surface layer, leading to an increase in the surface temperature (Celio et al., 1991).

In the scatterplot (Fig. 7), the first principal component (which accounts for 50.1% of the variance) indicated an increase in temperature, Chl. *a* and POM, and a decrease in salinity, while the second principal component (which accounts for 35.2% of the variance) showed a positive

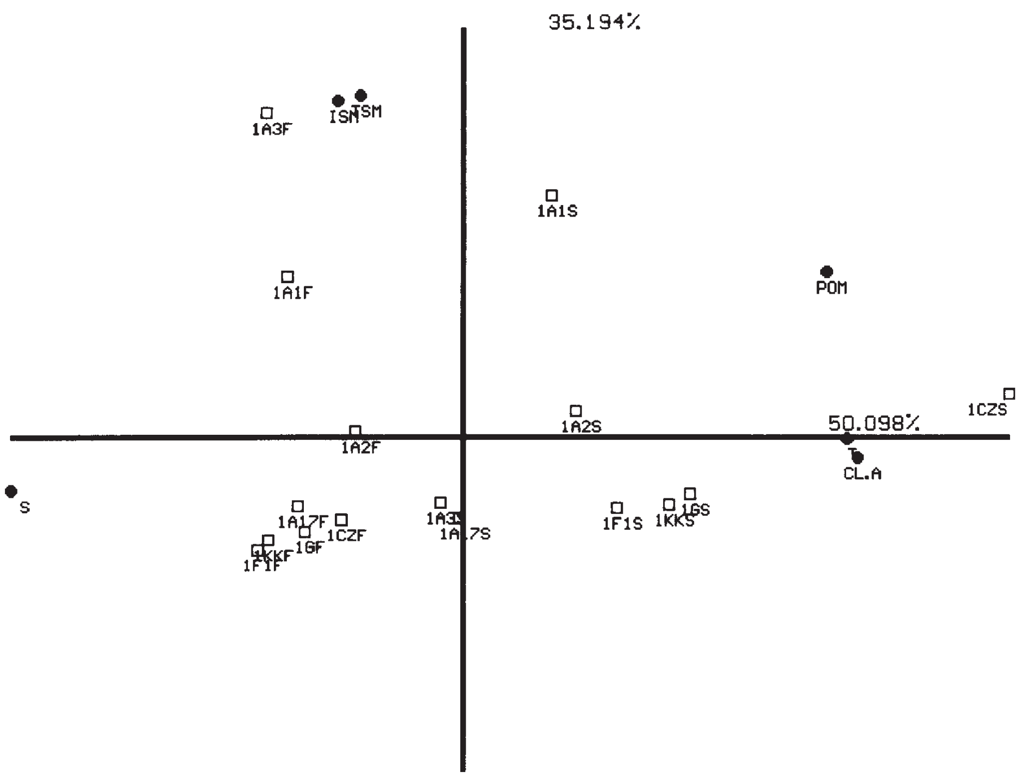

Fig. 7 - Scattergraph of the surface (S) and bottom (F) sampling stations in June 1991.

correlation between ISM and POM. According to the position of sampling stations in the scatterplot, it was possible to distinguish between surfaces with high temperature, Chl. *a* and POM and low salinity, and bottom layers with low temperature and high salinity.

The stations located in the northern part of the gulf (A1 and A3) featured higher TSM concentrations with higher inorganic contents due to the higher Isonzo river inflow, as reported in that period by Celio et al. (1992). The POC and PN concentrations decreased from the northern part of the gulf (st. A1) towards the gulf entrance (st. A17), with concomitant increase in C/N ratio, indicating the presence of partially decomposed marine organic matter and/or detrital POM in this area. The high correlation observed between TSM and ISM throughout the gulf, and the inverse correlations between salinity and POM and Chl. *a* (Table 3) could indicate the influence of the nutrient rich riverine inflows (especially the Isonzo) on the formation of late spring phytoplankton bloom, as confirmed by the massive presence of diatoms at all stations in the gulf (Cabrini, pers. comm.). Low C/N ratios observed in surface (6.3) and bottom (5.9) layers at station A1 indicated the prevalence of autochthonous living organisms.

4.2. July 1991

The seawater column was still extremely stratified due to the low salinity (32.8-34.2) and high temperature (25.0-26.6 °C) values in surface waters, the latter due to the intense heating of the surface layer. The bottom salinities and temperatures were higher (>37.1) and lower (<25.5 °C) respectively than surface values. Throughout the gulf high amounts of macroaggregates were observed in the form of stingers, nets and clouds (Stachowitsch et al., 1990; Amato, 1992; Monti et al., 1993; Faganeli et al., 1995).

The first principal component (which accounts for 50.0% of the variance) showed an inverse relation between all the parametres studied and the temperature, while the second (which accounts for 24.0% of the variance) indicated an increase in the temperature with salinity decrease (Fig. 8). A net distinction between surface and bottom layers was already observable. High concentrations of POC and PN, and C/N ratios typical of phytoplankton (6.0-7.0) were encountered, above all in the bottom layer of the northern part of the gulf, probably due to the local phytoplanktonic bloom (Cabrini, pers. comm.) within the macroaggregates. Positive correlations between almost all particulate components were found, as well as negative ones, as described above, between salinity and temperature (Table 4).

4.3. August 1991

In this period a particularly high Isonzo river outflow was observed and was reflected in high TSM concentrations in the northern part of the gulf. A net distinction between lighter and warmer surface waters and cool bottom layers with high salinity (37.2-38.0) was still evident.

The first principal component (which accounts for 45.8% of the variance) was characterized by an increase in POC, Chl. *a* and temperature, and a salinity decrease, while the second princi-

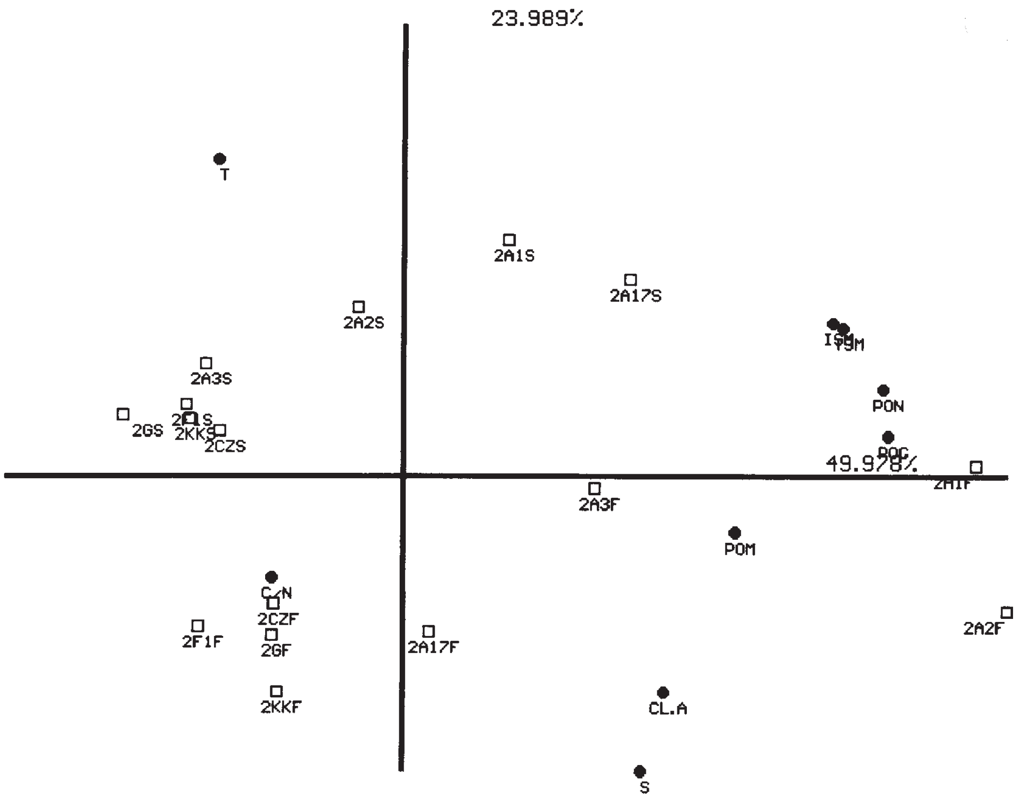

Fig. 8 - Scattergraph of the surface (S) and bottom (F) sampling stations in July 1991.

pal component (which accounts for 26.7% of the variance) was defined by an increase in TSM, ISM, PN and a POM decrease (Fig. 9). Positive correlations between TSM and ISM, temperature and C/N ratio, POC, PN and C/N ratio, as well as negative ones between temperature and salinity, salinity and Chl. *a*, confirmed the influence of this fresh water inflow on the Gulf of Trieste

Table 4 - Correlation matrix of surface and bottom July data. Correlation coefficient values, for 14 degrees of freedom, are 0.49 at the 5% level and 0.62 at the 1% level.

	T	S	TSM	ISM	POM	POC	PON	C/N	Chl. *a*
T	1.00								
S	-0.96	1.00							
TSM	-0.04	0.18	1.00						
ISM	-0.03	0.17	1.00	1.00					
POM	-0.22	0.24	0.36	0.32	1.00				
POC	-0.21	0.32	0.87	0.85	0.70	1.00			
PON	-0.18	0.26	0.92	0.90	0.59	0.94	1.00		
C/N	-0.01	-0.01	-0.25	-0.25	-0.07	-0.13	-0.35	1.00	
Chl. *a*	-0.49	0.52	0.15	0.13	0.50	0.50	0.36	0.06	1.00

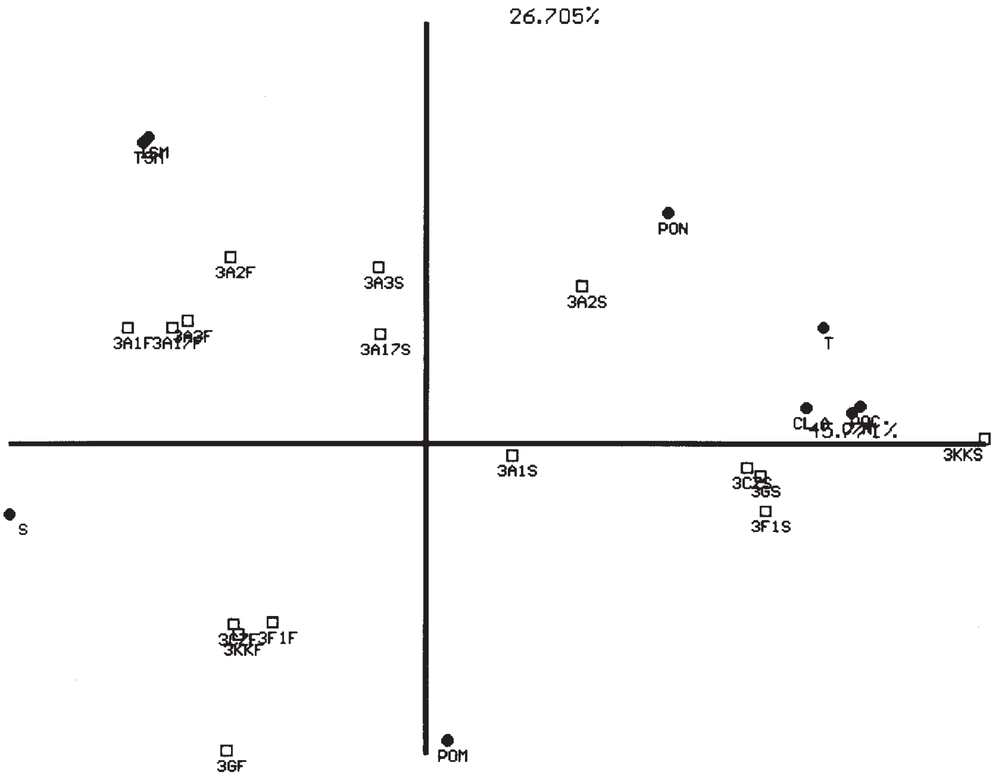

Fig. 9 - Scattergraph of the surface (S) and bottom (F) sampling stations in August 1991.

pelagic system (Table 5). High quantities of macroaggregates were found throughout the gulf, especially in the southern part, as shown by high POC concentrations.

4.4. September 1991

This period was characterized by low fresh water inflows and consequently by low TSM con-

Table 5 - Correlation matrix of surface and bottom August data. Correlation coefficient values, for 14 degrees of freedom, are 0.49 at the 5% level and 0.62 at the 1% level.

	T	S	TSM	ISM	POM	POC	PON	C/N	Chl. *a*
T	1.00								
S	-0.91	1.00							
TSM	-0.44	0.49	1.00						
ISM	-0.41	0.48	0.97	1.00					
POM	-0.21	0.14	0.30	0.08	1.00				
POC	-0.19	0.32	0.32	0.45	-0.50	1.00			
PON	0.01	0.11	0.24	0.38	-0.55	0.65	1.00		
C/N	-0.23	0.21	0.04	-0.01	0.21	0.34	-0.40	1.00	
Chl. *a*	-0.56	0.44	-0.10	-0.19	0.39	0..01	-0.40	0.64	1.00

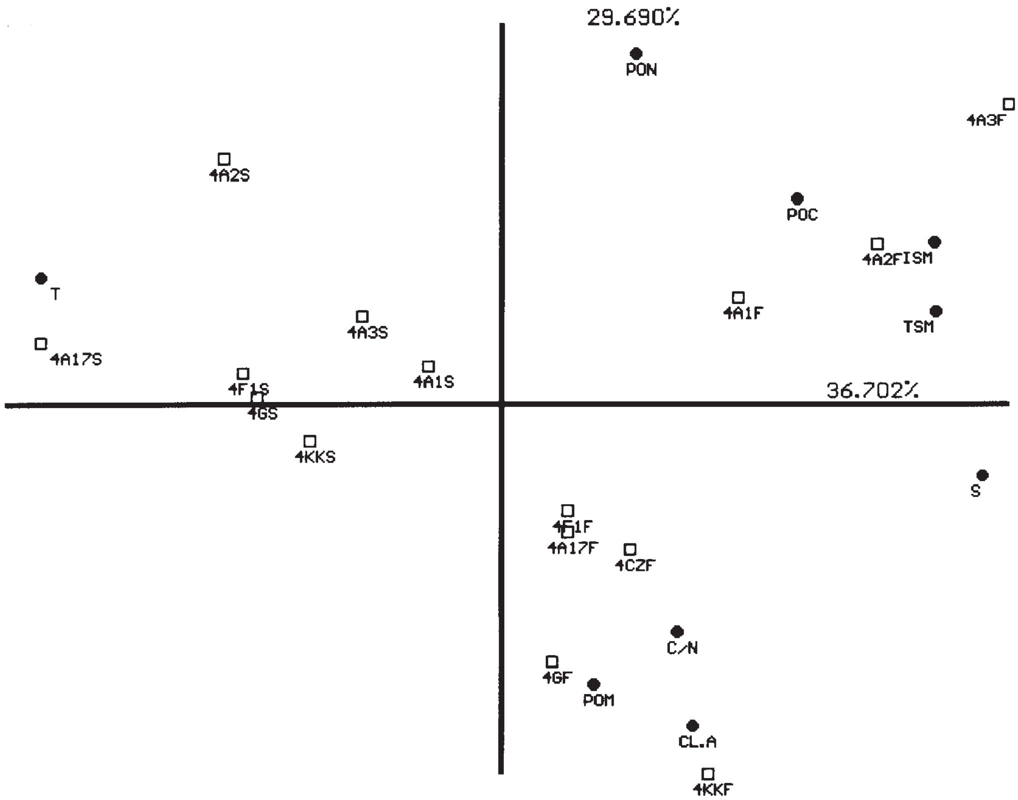

Fig. 10 - Scattergraph of the surface (S) and bottom (F) sampling stations in September 1991.

centrations in the Gulf of Trieste.

The thermohaline stratification of the water column was still present, and the bottom layer was influenced by lateral advection due to the central Adriatic current. An increase in POM concentrations in surface and bottom layers was observed between the entrance and the northern part of the gulf.

Table 6 - Correlation matrix of surface and bottom September data. Correlation coefficient values, for 14 degrees of freedom, are 0.49 at the 5% level and 0.62 at the 1% level.

	T	S	TSM	ISM	POM	POC	PON	C/N	Chl. *a*
T	1.00								
S	-0.97	1.00							
TSM	-0.44	0.49	1.00						
ISM	-0.41	0.48	0.97	1.00					
POM	-0.21	0.14	0.30	0.08	1.00				
POC	-0.19	0.32	0.32	0.45	-0.50	1.00			
PON	0.01	0.11	0.24	0.38	-0.55	0.65	1.00		
C/N	-0.23	0.21	0.04	-0.01	0.21	0.34	-0.40	1.00	
Chl. *a*	-0.56	0.44	-0.10	-0.19	0.39	0.01	-0.40	0.64	1.00

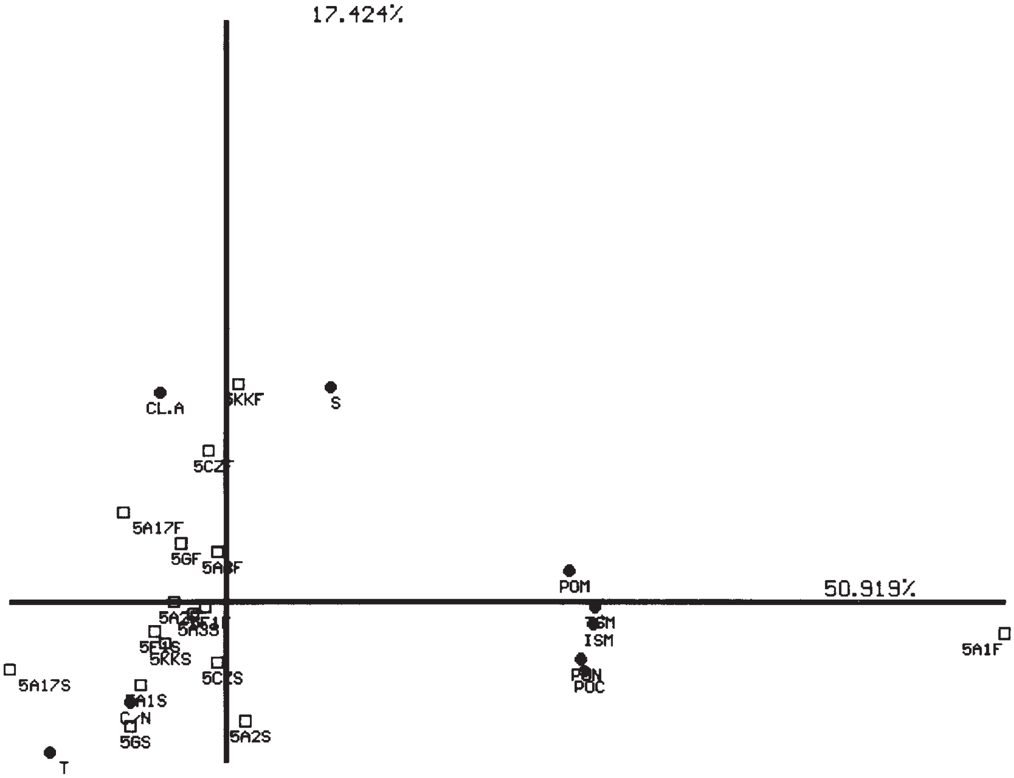

Fig. 11 - Scattergraph of the surface (S) and bottom (F) sampling stations in October 1991.

The first principal component (which accounts for 36.7% of the variance) was defined by an increase in salinity, TSM and ISM, and a temperature decrease, while the second (which accounts for 29.7% of the variance) was defined by an increase in POC and PN, and a POM and Chl. *a* decrease (Fig. 10). Positive correlations observed between TSM and ISM, POC and PN

Table 7 - Correlation matrix of surface and bottom October data. Correlation coefficient values, for 14 degrees of freedom, are 0.49 at the 5% level and 0.62 at the 1% level.

	T	S	TSM	ISM	POM	POC	PON	C/N	Chl. *a*
T	1.00								
S	-0.41	1.00							
TSM	-0.30	0.17	1.00						
ISM	-0.31	0.06	0.98	1.00					
POM	-0.36	0.30	0.89	0.82	1.00				
POC	-0.32	0.18	0.81	0.82	0.75	1.00			
PON	-0.31	0.14	0.78	0.82	0.66	0.93	1.00		
C/N	0.18	-0.18	-0.22	-0.28	-0.04	0.02	-0.29	1.00	
Chl. *a*	-0.07	0.26	-0.06	-0.08	0.04	-0.34	-0.33	-0.06	1.00

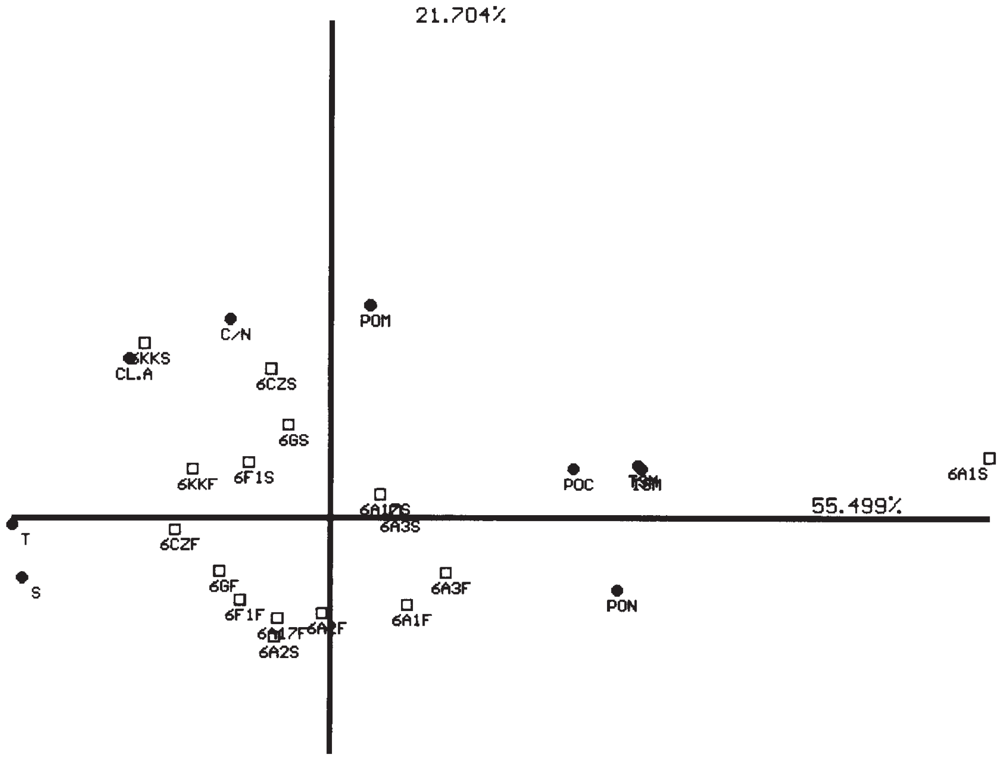

Fig. 12 - Scattergraph of the surface (S) and bottom (F) sampling stations in November 1991.

indicated the link between particulate constituents (Table 6). The C/N ratio indicated the presence of autochthonous organic matter.

4.5. October 1991

There was a progressive homogenization of the water column due to cooling of the surface

Table 8 - Correlation matrix of surface and bottom November data. Correlation coefficient values, for 14 degrees of freedom, are 0.49 at the 5% level and 0.62 at the 1% level.

	T	S	TSM	ISM	POM	POC	PON	C/N	Chl. *a*
T	1.00								
S	0.82	1.00							
TSM	-0.81	-0.97	1.00						
ISM	-0.82	-0.96	1.00	1.00					
POM	-0.15	-0.24	0.15	0.15	1.00				
POC	-0.64	-0.51	0.48	0.50	0.35	1.00			
PON	-0.76	-0.55	0.59	0.61	-0.08	0.77	1.00		
C/N	0.29	0.19	-0.12	-0.12	0.49	0.05	-0.36	1.00	
Chl. *a*	0.48	0.28	-0.32	-0.35	0.32	-0.40	-0.75	0.51	1.00

layer. This phenomenon was clearly evident from the plot of sample scores, where surface and bottom sample values were not clearly separated.

The first principal component (which accounts for 50.9% of the variance) was characterized by all particulate constituents (POM, TSM, ISM, POC and PN) being inversely correlated with T and Chl. *a*, and the second component (which accounts for 17.4% of the variance) was characterized by a temperature decrease, and an increase in salinity and Chl. *a* (Fig. 11). All particulate constituents were uniform only in the bottom layers at station A1. High TSM, POC and PN concentrations were observed. At the other stations, POC and PN were much lower than during the summer.

Positive correlations between TSM, POM, POC and PN indicated the common fluvial origin of all the particulate constituents measured (Table 7). The high C/N ratio indicated a detrital composition for the POM.

4.6. November 1991

The first principal component of the scatterplot (which accounts for 55.5% of the variance) was defined by the increase in TSM, ISM, POC and PN, and temperature and salinity decrease. The second principal component (which accounts for 21.7% of the variance) was characterized by a POM, C/N ratio and Chl. *a* increase (Fig. 12). The water column was homogenous due to vertical mixing, since the surface and bottom layer data were similar. The high inflow of the Isonzo river was clearly seen by the low salinity and high concentrations of particulate constituents at station A1.

Positive correlations between temperature and salinity demonstrated the homogenization of the water column. Positive correlations between TSM and ISM, negative ones between temperature and all particulate constituents, and between salinity and TSM indicated the prevalent allochthonous (fresh water) origin of particulate matter in the gulf in this period. Negative correlation between PN and Chl. *a*, and the very high C/N ratio at some stations probably indicated the detrital nature of POM, especially in the surface layer in the Gulf of Trieste in autumn (Table 8).

5. Conclusions

The thermohaline water column stratification lasted from June to September, while in autumn it gradually disappeared due to wind and convective mixing.

Throughout the study period we observed a strong predominance of the inorganic over organic fraction in TSM, in surface and bottom layers, except in August when there were massive quantities of macroaggregates. The higher POC concentration observed in the summer period could be attributed to the presence of macroaggregate in the water column of the gulf. In general a weak positive correlation between POC and Chl. *a* was observed, indicating a prevalence of the detrital (autochthonous and allochthonous) component of POC. A significant correlation between POC and PN was found only in the bottom samples, suggesting the autochthonous origin of bottom water POM.

In the theromohaline stratified waters of the gulf in the summertime, one may distinguish between surface and bottom samples using the principal component analysis. Surface particulate constituents exhibited much larger variations than bottom samples. From the scatterplot it was possible to differentiate between southern and northern stations, the latter being much more influenced by the fresh water inflow originating from the Alpine river Isonzo.

Acknowledgement. This work was supported by the "Osservatorio dell'Alto Adriatico" within the framework of the Alpe Adria project: "Campagna scientifica di ricerca e monitoraggio sullo stato chimico, fisico e biologico delle acque dell'Alto Adriatico, in relazione al fenomeno di formazione degli ammassi gelatinosi". Thanks are due to F. Aizza and P. Mosetic for the Chlorophyll *a* data, N. Burba for the statistical analysis, and to A. Boldrin, G. P. Fanzutti, F. Finocchiaro and S. Fonda-Umani for their critical review.

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