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Physico-chemical characterization of the benthic environment of the Golfo San Jorge, Argentina

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The benthic system of the Golfo San Jorge was characterized from physico-chemical parameters based on samplings obtained during seasonal research cruises carried out on board the INIDEP vessels from springtime 1999 through wintertime 2000. Spatial and seasonal variations of temperature, salinity, density, oxygen content and chlorophyll-*a* in bottom water and concentration of total organic matter, total organic carbon, total nitrogen, chlorophyll-*a* and phaeopigments in sediments were analysed. The origin and nutritional value of the deposited organic matter were also assessed. The behaviour of the physico-chemical characteristics of the benthic habitat, studied applying statistical techniques, defined three sectors with particular characteristics and minimum seasonal variations: sector 1, the largest and deepest one, comprises the central area of the gulf and corresponds to a depositional environment; sector 2 comprises the areas next to the extremes of the gulf and corresponds to a flow or erosive environment; sector 3 includes the coastal area and south-east part of the gulf and belongs to a transitional environment.

INTRODUCTION

The Golfo San Jorge (Figure 1) is a half-open basin located between 45°–47°S 65°30′W and the coast and covers a surface of 39,340 km^2. In its northern sector it presents a 250 km long threshold with depths ranging 80–95 m. The greatest depths (<110 m) are found in the central region where the 90 m isobath presents an elliptic contour with its largest axis in a north-east/south-west direction (Akselman, 1996).

The gulf waters are part of Platform Waters which are modified by the contribution of Coastal Waters with salinity spatially and temporarily varying between 33.0 and 33.6 psu. Coastal Waters of low salinity flow from the Magellan Strait near the coast of the Santa Cruz province where they fork their flow in two main branches: one enters the gulf at the south-east extreme and has a remarkable influence on the region throughout the year; the other moves away from the coast in a north/north-easterly direction, affecting in all its extension the threshold region (Bianchi et al., 1982). In the south-west deep area, Baldoni (1990) identified a turn in a clockwise direction with a north-east/south-west axis imposed by bathimetry. In the lowest depth extremes of the gulf the vertical mix affected by winds and tides generates frontal systems of seasonal development and permanence mainly during springtime and autumn. Coastal Waters coming from the Magellan Strait that enter the Golfo San Jorge generate an intense thermohaline front in its southern extreme (Guerrero & Piola, 1997).

The existence of spawning and breeding areas and important fishing grounds of different species turns the gulf into an important economic sector. Among the species comprised, shrimp *Pleoticus muelleri* and hake *Merluccius hubbsi* are to be highlighted (Fernández et al., 2003).

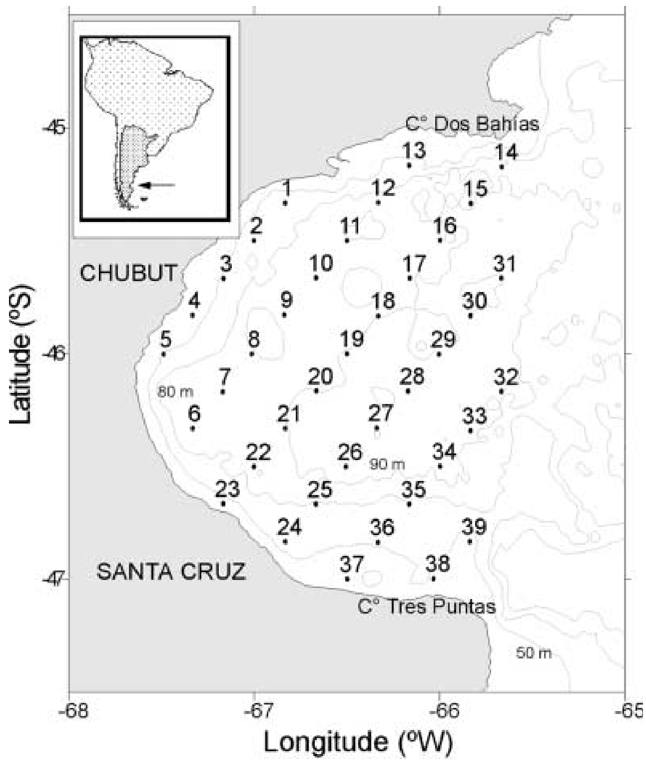

Figure 1. Geographical localization of sampling stations. Research cruises: OB-06/99 (Springtime 1999), OB-01/00 (Summertime 2000), OB-03/00 (Autumn 2000), OB-07/00 and OB-10/00 (Wintertime 2000).

The available information about the physical, chemical and nutritional factors of the Golfo San Jorge sediments and of its biological aspects is scarce (Roux et al., 1995; Fernández et al., 2003).

In this paper the spatial and seasonal results obtained from the physico-chemical characterization of surficial sediments and bottom water in the Golfo San Jorge are presented.

MATERIALS AND METHODS

Sampling design

Samplings were obtained during research cruises OB-06/99, OB-01/00, OB-03/00, OB-07/00 and OB-10/00 carried out on board the INIDEP RV 'Capitán Oca Balda' in springtime (November 1999), summertime (January 2000), autumn (May 2000) and wintertime (August and September 2000) (Figure 1). The sampling design was established based on previous studies (Roux et al., 1995) with a total of 39 sampling stations located at 12 miles distance (Table 1).

In each station samples of water and sediments were taken and physical data of the water column registered. Pressure, temperature and conductivity were measured with a CTD SBE (BE-BIRD ELECTRONIC) I MODEL XIX. A fluorometer (Seapoint Chlorophyll Fluorometer) was added to the CTD for *in situ* living phytoplankton vertical fluorescence profile determinations.

To determine dissolved oxygen (O) and chlorophyll-*a* (Chl-*a*) water samples were collected with Niskin bottles. Samples of bottom water (at 0.50 m from the bottom), of the mix layer (up the thermocline) and of the surface were taken.

Sediment samples were obtained with a Phleger gravity extractor and a Picard dredge and preserved on board at −25°C for further analysis at the laboratory. To establish total organic matter (TOM), total organic carbon (TOC), total nitrogen (TN) and origin and nutritional value of the organic matter, the first 2 cm of sample were used; for chlorophyll-*a* (Chl-*a* S) and phaeopigment (Phaeo S)

Table 1. *Station code, longitude, latitude, depth and real number of sampling stations of springtime 1999, summertime, autumn and wintertime 2000 cruises in the Golfo San Jorge.*

				Real number of sampling stations			
Station Code	Longitude (°W)	Latitude (°S)	Depth (m)	Springtime 1999	Summertime 2000	Autumn 2000	Wintertime 2000
1	66° 49.9′	45° 20.0′	68	526	—	276	—
2	67° 00.0′	45° 30.0′	74	525	—	275	—
3	67° 09.8′	45° 40.1′	63	524	—	274	—
4	67° 19.9′	45° 49.8′	37	523	—	273	—
5	67° 29.9′	45° 59.9′	59	522	—	272	—
6	67° 19.8′	46° 19.9′	83	521	68	271	522
7	67° 10.1′	46° 10.2′	86	520	69	270	553
8	67° 01.2′	46° 00.4′	88	519	80	269	554
9	66° 50.2′	45° 49.7′	86	518	84	268	555
10	66° 39.9′	45° 39.9′	86	517	—	267	556
11	66° 29.9′	45° 30.0′	87	527	90	277	557
12	66° 19.8′	45° 19.9′	86	528	—	278	558
13	66° 09.8′	45° 10.0′	69	529	91	279	559
14	65° 39.9′	45° 10.4′	83	531	—	—	—
15	64° 49.9′	45° 20.1′	87	530	92	—	—
16	65° 59.8′	45° 29.9′	90	502	—	265	560
17	66° 09.6′	45° 40.0′	91	503	89	266	561
18	66° 19.8′	45° 50.0′	92	516	—	264	562
19	66° 29.9′	46° 00.1′	92	515	85	263	563
20	66° 39.8′	46° 09.9′	89	514	79	262	564
21	66° 49.9′	46° 19.9′	87	513	70	261	565
22	67° 00.0′	46° 30.1′	83	512	67	243	523
23	66° 09.9′	46° 39.9′	31	511	64	244	524
24	66° 49.9′	46° 50.0′	66	510	65	245	525
25	66° 40.0′	46° 40.0′	80	509	66	246	526
26	66° 30.3′	46° 30.1′	92	508	71	260	566
27	66° 20.3′	46° 19.8′	93	507	78	259	567
28	66° 10.2′	46° 10.0′	95	506	86	258	568
29	66° 00.2′	46° 00.2′	95	505	—	255	569
30	65° 50.0′	45° 49.9′	92	504	88	256	570
31	65° 40.1′	45° 40.0′	89	501	—	257	571
32	65° 40.0′	46° 10.1′	93	500	—	254	—
33	65° 50.0′	46° 20.5′	91	499	87	253	—
34	65° 59.8′	46° 30.0′	89	498	77	252	—
35	66° 09.8′	46° 40.0′	75	497	72	251	529
36	66° 19.9′	46° 50.2′	58	496	73	247	528
37	66° 29.8′	47° 00.0′	21	495	74	248	527
38	66° 02.0′	46° 59.9′	53	494	75	249	531
39	65° 50.2′	46° 50.0′	36	493	76	250	530

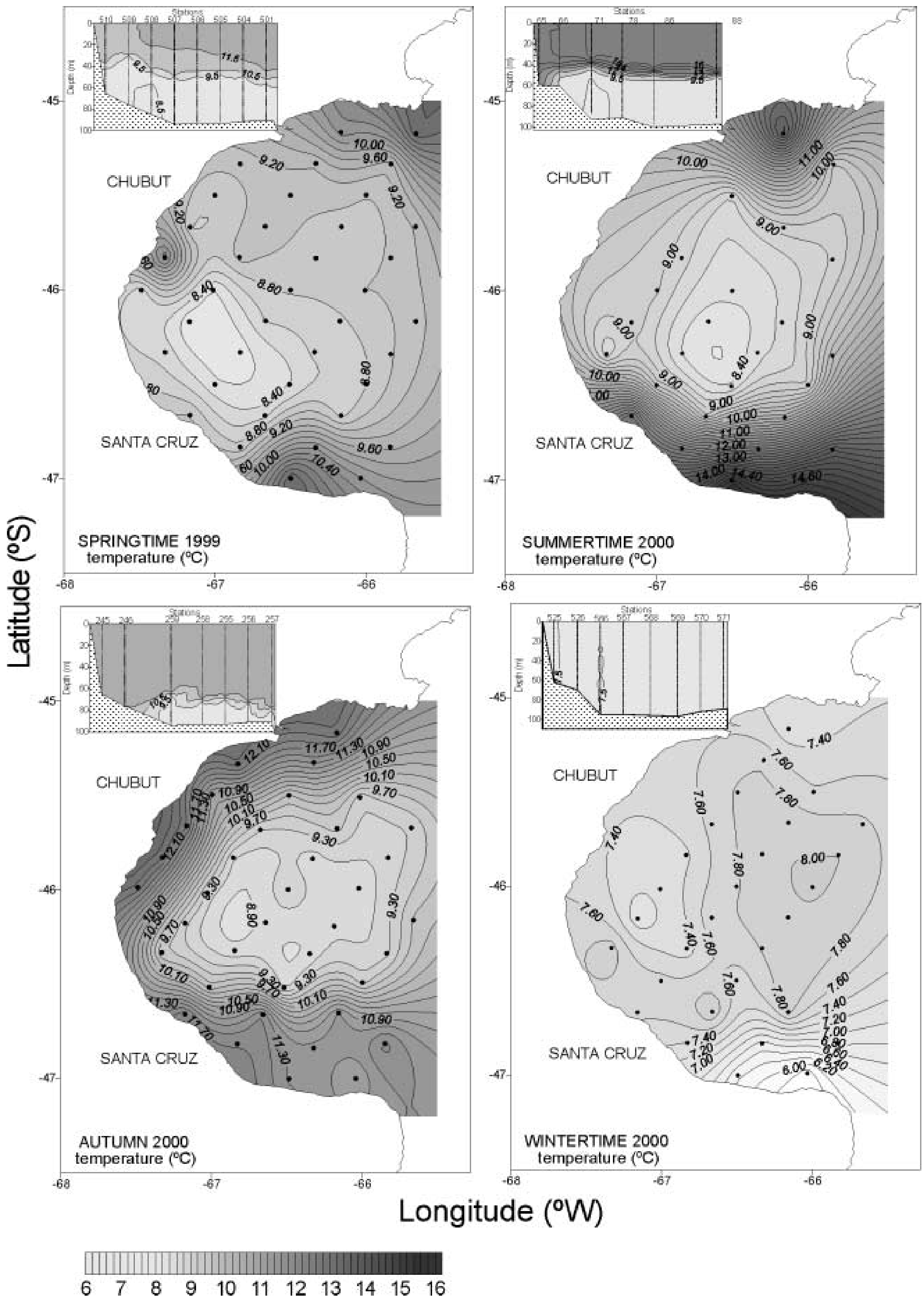

Figure 2. Temperature horizontal distribution of bottom water and water column vertical profile in the Golfo San Jorge.

determinations only the first 0.5 cm were taken (Fernández et al., 2005).

Analytical techniques

To determine dissolved oxygen and Chl-*a* in water, conventional methodologies were applied (Fernández et al., 2005). Chlorophyll-*a* information of the entire water column was incorporated (Cucchi Colleone & Carreto, 2003).

To obtain total organic matter (TOM), total organic carbon (TOC) and total nitrogen (TN) determinations and to estimate the origin and nutritional value of the organic matter (C:N), Chl-*a* S and Phaeo S, the fractioned material was homogenized manually and subsampled for further analysis.

The subsamples were dried at 100°C during 24 h. For further TOM, TOC, TN, C:N, Chl-*a* S and Phaeo S determinations, conventional techniques were applied (Fernández et al., 2005).

Table 2. *Descriptive statistics of the water and sediment variables.*

Variables	Value	Springtime 1999 'S'	Summertime 2000 'SU'	Autumn 2000 'A'	Wintertime 2000 'W'	Dunn Test
Temperature	minimum	8.04	8.31	8.94	5.66	S-SU ns S-A**
(°C)	maximum	11.43	15.37	12.35	8.02	S-W** SU-A ns
'T'	Mean	9.10	10.23	10.23	7.49	SU-W** F-W**
Bottom water	SD	0.79	2.22	1.23	0.57	
Salinity	minimum	33.26	33.30	33.13	33.07	S-SU ns S-A*
(psu)	maximum	33.69	33.64	33.75	33.80	S-W* SU-A ns
'S'	Mean	33.59	33.55	33.52	33.59	SU-W* A-W**
Bottom water	SD	0.10	0.10	0.13	0.18	
Density	minimum	25.470	24.681	25.297	26.035	S-SU ns S-A**
(kg/m^3)	maximum	26.180	26.129	26.083	26.369	S-W** SU-A*
'Den'	Mean	25.997	25.761	25.754	26.242	SU-W** A-W**
Bottom water	SD	0.16	0.48	0.24	0.09	
Oxygen	minimum	4.65	2.57	1.82	6.34	S-SU** S-A**
Concentration	maximum	6.61	6.43	6.03	6.82	S-W** SU-A ns
(ml O_2/l)	Mean	5.56	4.50	3.93	6.56	SU-W** A-W**
'O' Bottom water	SD	0.53	0.86	1.47	0.11	
Chlorophyll-*a*	minimum	0.10	0.11	0.36	0.43	S-SU ns S-A*
(mg/m^3)	maximum	2.21	2.37	3.38	0.94	S-W ns SU-A*
In surficial	Mean	0.57	0.57	1.08	0.59	SU-W ns A-W**
Water	SD	0.40	0.52	0.67	0.13	
Chlorophyll-*a*	minimum	0.19	0.26	0.36	0.62	S-SU ns S-A ns
(mg/m^3)	maximum	1.31	3.15	3.05	1.32	S-W ns SU-A ns
In mix	Mean	0.70	0.97	1.04	0.91	SU-W ns A-W ns
Water	SD	0.33	0.59	0.74	0.18	
Chlorophyll-*a*	minimum	0.06	0.18	0.07	0.39	S-SU ns S-A ns
(mg/m^3)	maximum	1.66	2.16	2.11	1.39	S-W** SU-A ns
'Chl-*a* (BW)'	Mean	0.42	0.55	0.40	0.89	SU-W** A-W**
Bottom water	SD	0.38	0.47	0.40	0.28	
Total Organic	minimum	0.59	1.04	1.17	1.58	S-SU ns S-A ns
Matter (%)	maximum	13.33	10.48	12.73	14.24	S-W** SU-A ns
'TOM'	Mean	7.34	6.71	7.42	10.00	SU-W** A-W**
Sediments	SD	3.08	3.07	3.13	3.77	
Total Organic	minimum	0.32	0.42	0.76	0.42	S-SU ns S-A ns
Carbon (%)	maximum	3.18	3.98	2.86	3.74	S-W ns SU-A ns
'TOC'	Mean	1.56	2.02	1.71	2.03	SU-W ns A-W ns
Sediments	SD	0.74	1.00	0.61	0.88	
Total	minimum	0.03	0.01	0.02	0.05	S-SU ns S-A ns
Nitrogen (%)	maximum	0.27	0.18	0.32	0.77	S-W** SU-A ns
'TN'	Mean	0.15	0.10	0.16	0.33	SU-W** A-W**
Sediments	SD	0.07	0.05	0.07	0.19	
Carbon/Nitrogen	minimum	0.13	11.45	6.22	2.76	S-SU** S-A ns
ratio	maximum	20.29	69.48	53.36	18.09	S-W** SU-A**
'C:N'	Mean	10.67	23.75	13.52	7.43	SU-W** A-W**
Sediments	SD	3.67	13.40	9.04	3.46	
Chlorophyll-*a*	minimum	0.01	0.05	0.01	0.15	S-SU ns S-A ns
(ug/g)	maximum	0.89	2.75	2.96	5.02	S-W** SU-A ns
'Chl-*a* (S)'	Mean	0.26	0.47	0.51	1.54	SU-W** A-W**
Sediments	SD	0.25	0.60	0.69	1.16	
Phaeopigment	minimum	0.24	1.15	0.06	0.52	S-SU ns S-A ns
(ug/g)	maximum	34.06	35.28	22.20	95.78	S-W** SU-A ns
'Phaeo (S)'	Mean	11.86	12.34	7.68	24.77	SU-W** A-W**
Sediments	SD	8.77	8.20	6.13	19.15	

*, $0.01 < P < 0.05$; **, $P < 0.01$; ns, $P > 0.05$; SD, standard deviation.

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Data analysis

The temporal comparative analysis of physical and chemical variables of bottom water and sediments were carried out applying the Kruskal–Wallis non parametric test and the multiple comparisons Dunn test (Zar, 1996).

Following Fernández et al. (2003), the 'environmental variable×sampling site' matrices expressed as standardized values were analysed using both the cluster analysis and the principal component analysis (PCA). The statistical analysis was performed using the Statistical Program 'Statistica' 1998. Mapping of variables was elaborated with the Graphic Program 'Surfer', version 7 (Golden Software); the kriging method was used to interpolate.

RESULTS

Hydrographical characteristics

The seasonal cycle of bottom water temperature distribution showed large amplitude. In springtime, summertime and autumn spatial thermal gradients were observed; the minimum values corresponded to the central sector and the maximum were detected towards the coast. In wintertime the opposite behaviour was observed. The vertical transect of temperature registers showed the formation of a thermocline in springtime which locates between 40–50 m depth in summertime and descends in the autumn. The statistical analysis indicated highly significant differences ($P<0.01$) among seasons (Figure 2 and Table 2).

As regards salinity of bottom water, the seasonal cycle showed scarce amplitude; registers of extreme values were observed in wintertime. In the periods analysed, a salinity gradient was observed between the south-east and east regions and the central and northern region of the gulf. Seasonal salinity profiles allowed to differentiate values lower than 33.50 psu in the sector next to the coast and surficial nuclei of low salinity (33.00–33.50 psu) in the mouth of the gulf in autumn. The statistical analysis indicated highly significant differences ($P<0.01$) between wintertime and autumn (Table 2).

Bottom water density behaviour was similar to that of temperature. The statistical analysis indicated highly significant differences ($P<0.01$) among seasons (Table 2).

Chemical characteristics of water

Horizontal distribution of oxygen concentration in bottom water showed the maximum values in wintertime and the minimum in autumn, with a decrease from springtime to autumn and a significant increase in wintertime. In springtime, summertime and autumn, spatial gradients were observed with minimum values in the centre of the gulf and maximum in the coastal sectors. In wintertime, the absence of a gradient indicated homogenization in oxygen concentration. The statistical analysis showed highly significant differences ($P<0.01$) among the periods analysed, except between summertime and autumn (Table 2).

Seasonal chl-*a* concentration in bottom water showed maximum values in summertime and autumn. A decrease of the mean value of chl-*a* concentration was observed from springtime to autumn, with a slight increase in summertime and a significant rise in wintertime. In springtime, the maximum concentrations were observed in the south and west coastal sectors; in summertime and autumn it corresponded to the south and mouth sectors of the gulf. In wintertime, chl-*a* distribution with a positive gradient from the south-east toward the centre and north of the gulf was observed. The statistical analysis demonstrated highly significant differences ($P<0.01$) among seasons (Table 2). Registers of chl-*a* concentration showed the maximum concentrations in surface water in autumn; in the mix layer they were observed in summertime and autumn. The statistical analysis indicated significant differences ($0.01<P<0.05$) in chl-*a* concentration in surface water between autumn and springtime and autumn and summertime; highly significant ones were observed ($P<0.01$) between autumn and wintertime. The statistical analysis of chl-*a* concentration in the mix layer indicated that the differences detected were non significant ($P>0.05$) (Table 2).

Chemical characteristics of surficial sediments

The seasonal cycle of TOM concentration distribution presented large amplitude, with maximun values in wintertime and minimum in springtime. The mean value decreased from springtime to summertime, showed a slight increment in autumn and a significant rise in wintertime. The maximum values were observed in the central sector and the minimum toward the coast, mainly in the west coast and in the extremes of the gulf. The statistical analysis indicated highly significant differences ($P<0.01$) among seasons (Table 2).

The TOC seasonal horizontal distribution showed mean maximum values in wintertime and summertime and minimum in springtime and fall. The maximum values were found in the central sector of the gulf and the minimum in the west coast and in the extremes of the gulf. The statistical analysis did not indicate significant differences among the study periods (Figure 3 and Table 2).

The seasonal cycle of TN concentration distribution presented the maximum values in wintertime and the minimum in summertime. Mean values decreased from springtime to summertime, showed a slight increment in autumn and a significant rise in wintertime. The statistical analysis indicated highly significant differences ($P<0.01$) among seasons (Table 2).

In the surficial sediments of the Golfo San Jorge, the C:N relationship values oscillated between 2.41 and 69.48. The mean reached its minimum in wintertime, started to increase in springtime and registered the maximum rise in summertime. Values of the C:N relationship lower than ten concentrated in nuclei in the central sector in autumn and wintertime. In springtime, values lower than ten were registered in the southern sector with a positive gradient from east to west. In summertime values were higher than 11.45; the highest were registered in the south-east sector of the gulf. The statistical analysis indicated highly significant differences ($P<0.01$) among seasons (Table 2).

The seasonal cycle of Chl-*a* S concentration distribution showed maximum values in wintertime and minimum in springtime. An increase of the mean was registered from springtime to wintertime. In autumn and wintertime the

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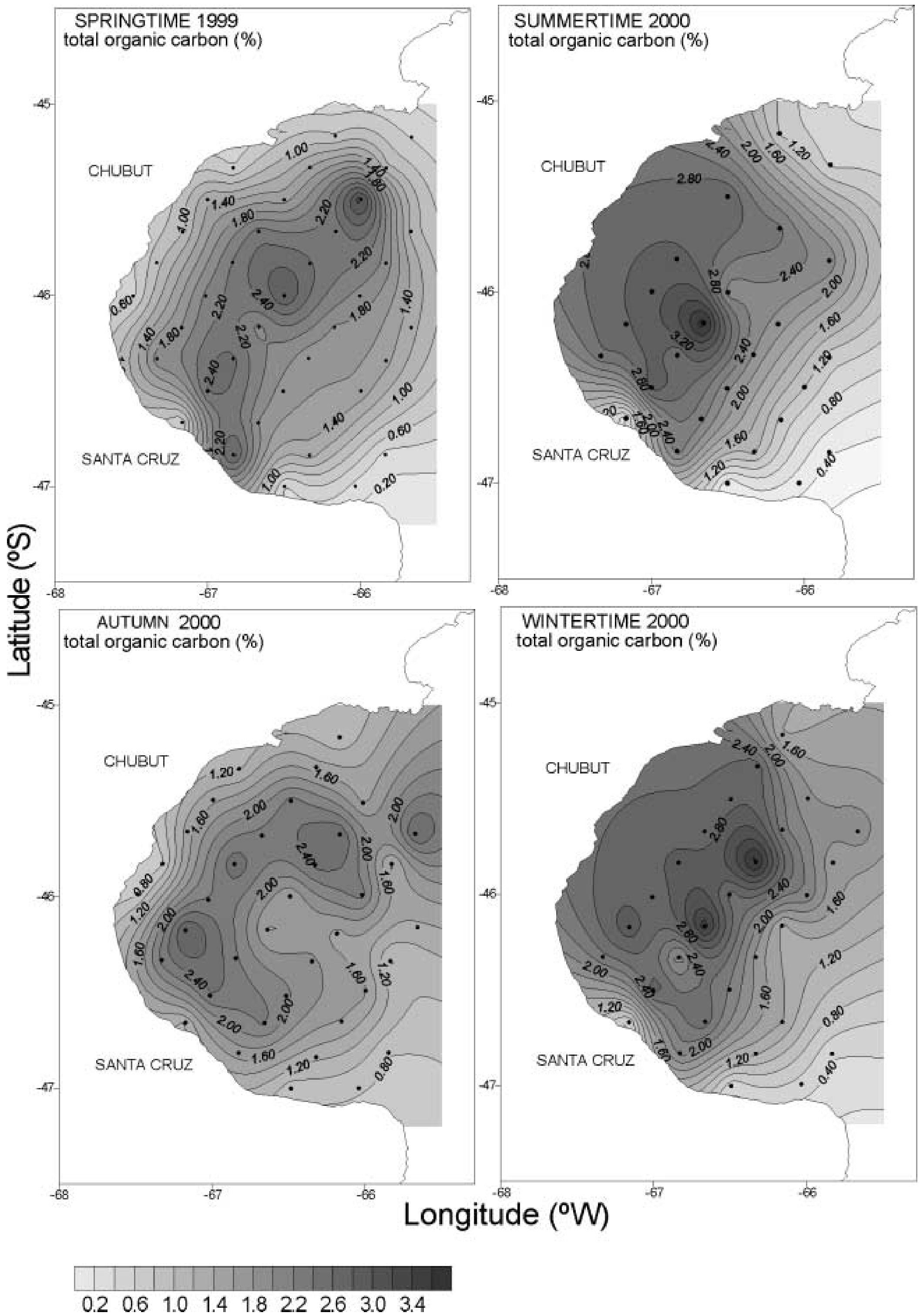

Figure 3. Horizontal distribution of total organic carbon concentration (%) in the surficial sediments of the Golfo San Jorge.

maximum values were observed in nuclei. In summertime they were found in the west coastal sector. In springtime, a more uniform values spatial distribution was registered. The statistical analysis indicated highly significant differences ($P<0.01$) among seasons (Table 2).

Seasonal distribution of Phaeo S concentration showed maximum values in wintertime and minimum in autumn. The mean started to increase in springtime, showed a significant decrease in autumn and reached its maximum in wintertime. The study of horizontal distribution showed concentration of the highest values in the central sector, toward the west coast. The statistical analysis indicated highly significant differences ($P<0.01$) among seasons (Table 2).

Spatial–temporal analysis of stations and of physico-chemical variables

Cluster analysis

The temporal cluster analysis of the 11 physico-chemical variables (Figure 4) revealed two main associations (Group

Table 3. *Descriptive statistics of the water and sediment variables of each defined sector.*

Variables	Value	Springtime 1999			Summertime 2000			Autumn 2000			Wintertime 2000		
		S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Temperature	minimum	8.04	9.55	8.38	8.31	13.76	9.02	8.94	10.90	9.24	7.05	5.66	6.24
(°C)	maximum	9.09	11.43	9.27	9.33	15.37	13.78	11.40	11.60	12.35	8.02	7.63	8.00
	Mean	8.72	10.52	8.89	8.80	14.68	11.23	9.36	11.23	11.28	7.68	6.88	7.16
	SD	0.36	0.68	0.29	0.34	0.83	1.78	0.54	0.53	1.05	0.29	0.88	0.91
Salinity	minimum	33.570	33.260	33.480	33.580	33.300	33.420	33.470	33.130	33.180	33.570	33.070	33.180
(psu)	maximum	33.640	33.690	33.660	33.640	33.440	33.620	33.650	33.240	33.750	33.800	33.570	33.560
	Mean	33.611	33.504	33.611	33.610	33.353	33.518	33.542	33.185	33.543	33.688	33.350	33.398
	SD	0.02	0.17	0.04	0.01	0.08	0.07	0.05	0.08	0.14	0.06	0.25	0.18
Oxygen	minimum	4.83	5.67	4.65	2.57	5.75	4.12	1.82	5.88	3.20	6.34	6.42	6.54
(ml O_2/l)	maximum	5.68	6.61	6.35	4.62	6.43	5.63	5.36	6.03	6.02	6.70	6.79	6.82
Bottom	Mean	5.28	6.24	5.60	4.01	6.06	4.85	2.84	5.96	5.06	6.56	6.61	6.61
water	SD	0.24	0.30	0.58	0.56	0.34	0.53	0.71	0.10	1.09	0.08	0.16	0.06
Chlorophyll-*a*	minimum	0.13	0.40	0.10	0.11	1.27	0.20	0.36	0.49	0.56	0.43	0.44	0.49
(mg/m^3)	maximum	2.21	1.21	0.79	0.84	2.37	1.30	2.17	0.77	3.38	0.80	0.60	0.94
Surficial	Mean	0.57	0.87	0.42	0.30	1.64	0.66	1.08	0.63	1.12	0.62	0.51	0.63
water	SD	0.48	0.37	0.18	0.18	0.63	0.38	1.09	0.20	0.75	0.11	0.07	0.21
Chlorophyll-*a*	minimum	0.31	0.71	0.19	0.26	1.30	0.40	0.36	0.42	0.51	0.80	0.69	0.62
(mg/m^3)	maximum	1.31	1.19	0.86	3.15	2.26	1.35	2.34	1.21	3.05	1.32	1.02	0.93
Mixing	Mean	0.77	0.97	0.51	0.99	1.78	0.79	0.92	0.81	1.20	0.98	0.86	0.74
water	SD	0.34	0.24	0.22	0.68	0.48	0.37	0.67	0.39	0.84	0.16	0.14	0.13
Chlorophyll-*a*	minimum	0.10	0.35	0.06	0.18	1.33	0.23	0.07	0.36	0.10	0.39	0.57	0.50
(mg/m^3)	maximum	1.66	1.01	0.63	0.88	2.16	0.70	0.99	1.65	2.11	1.39	0.68	1.06
Bottom	Mean	0.38	0.75	0.26	0.40	1.75	0.40	0.26	1.01	0.61	1.03	0.60	0.66
water	SD	0.42	0.39	0.18	0.21	0.59	0.17	0.22	0.91	0.52	0.23	0.05	0.26
Total Organic	minimum	8.42	0.96	0.59	5.38	1.04	4.07	6.30	1.17	1.79	5.99	1.58	2.10
Matter (%)	maximum	13.33	7.96	8.72	10.48	1.12	4.83	12.73	1.38	9.68	14.24	13.06	10.71
Sediments	Mean	9.82	3.73	5.98	8.92	1.08	4.51	9.66	1.28	5.26	11.69	6.57	6.70
	SD	1.10	2.47	2.23	1.24	0.06	0.27	1.45	0.15	2.21	2.00	5.34	3.63
Total Organic	minimum	1.38	0.32	0.54	2.12	0.42	1.10	1.31	0.81	0.76	1.33	0.42	0.43
Carbon (%)	maximum	3.18	1.23	1.77	3.98	0.49	1.46	2.86	0.84	2.24	3.74	2.53	2.09
Sediments	Mean	2.17	0.70	1.22	2.74	0.46	1.17	2.10	0.83	1.31	2.35	1.18	1.11
	SD	0.46	0.34	0.42	0.50	0.05	0.14	0.46	0.02	0.41	0.66	0.97	0.79
Total	minimum	0.12	0.03	0.04	0.10	0.01	0.04	0.15	0.02	0.04	0.11	0.05	0.05
Nitrogen (%)	maximum	0.27	0.32	0.18	0.18	0.01	0.08	0.32	0.02	0.17	0.77	0.26	0.21
Sediments	Mean	0.21	0.13	0.10	0.14	0.01	0.07	0.21	0.02	0.10	0.40	0.14	0.12
	SD	0.04	0.09	0.04	0.03	0.00	0.01	0.04	0.00	0.04	0.15	0.09	0.08
Carbon/	minimum	5.50	0.13	7.69	11.45	53.15	17.34	6.22	40.85	7.19	2.76	6.03	8.52
Nitrogen ratio	maximum	20.24	13.58	20.29	29.59	69.48	28.98	12.75	53.36	23.19	18.09	9.72	10.18
Sediments	Mean	10.61	7.29	12.25	20.19	61.32	17.17	9.96	47.11	13.80	7.13	8.12	9.16
	SD	3.13	4.72	3.27	3.96	11.55	4.77	1.99	8.85	4.48	3.95	1.56	0.75
Chlorophyll-*a*	minimum	0.01	0.04	0.03	0.09	0.05	0.13	0.04	0.01	0.01	0.51	0.15	0.87
(ug/g)	maximum	0.89	2.41	0.81	2.75	0.33	0.68	2.96	0.10	1.11	5.02	1.16	1.29
Sediments	Mean	0.29	0.53	0.25	0.56	0.19	0.32	0.68	0.06	0.35	1.78	0.70	1.13
	SD	0.30	0.84	0.21	0.71	0.20	0.22	0.87	0.06	0.35	1.30	0.44	0.20
Phaeopigment	minimum	6.83	0.24	2.91	7.47	1.15	5.81	1.28	0.06	0.34	10.57	0.52	2.97
(ug/g)	maximum	30.54	9.56	34.06	35.28	3.42	8.55	22.20	0.46	18.48	95.78	23.04	23.00
Sediments	Mean	15.85	3.64	10.80	15.47	2.29	9.15	9.24	0.26	6.60	30.28	8.17	14.31
	SD	8.28	3.61	8.37	8.41	1.61	1.19	6.12	0.28	5.77	20.01	10.10	8.32
Stratification		yes	no	yes/no	yes	no	yes/no	yes	no	yes/no	no	no	no

SD, standard deviation.

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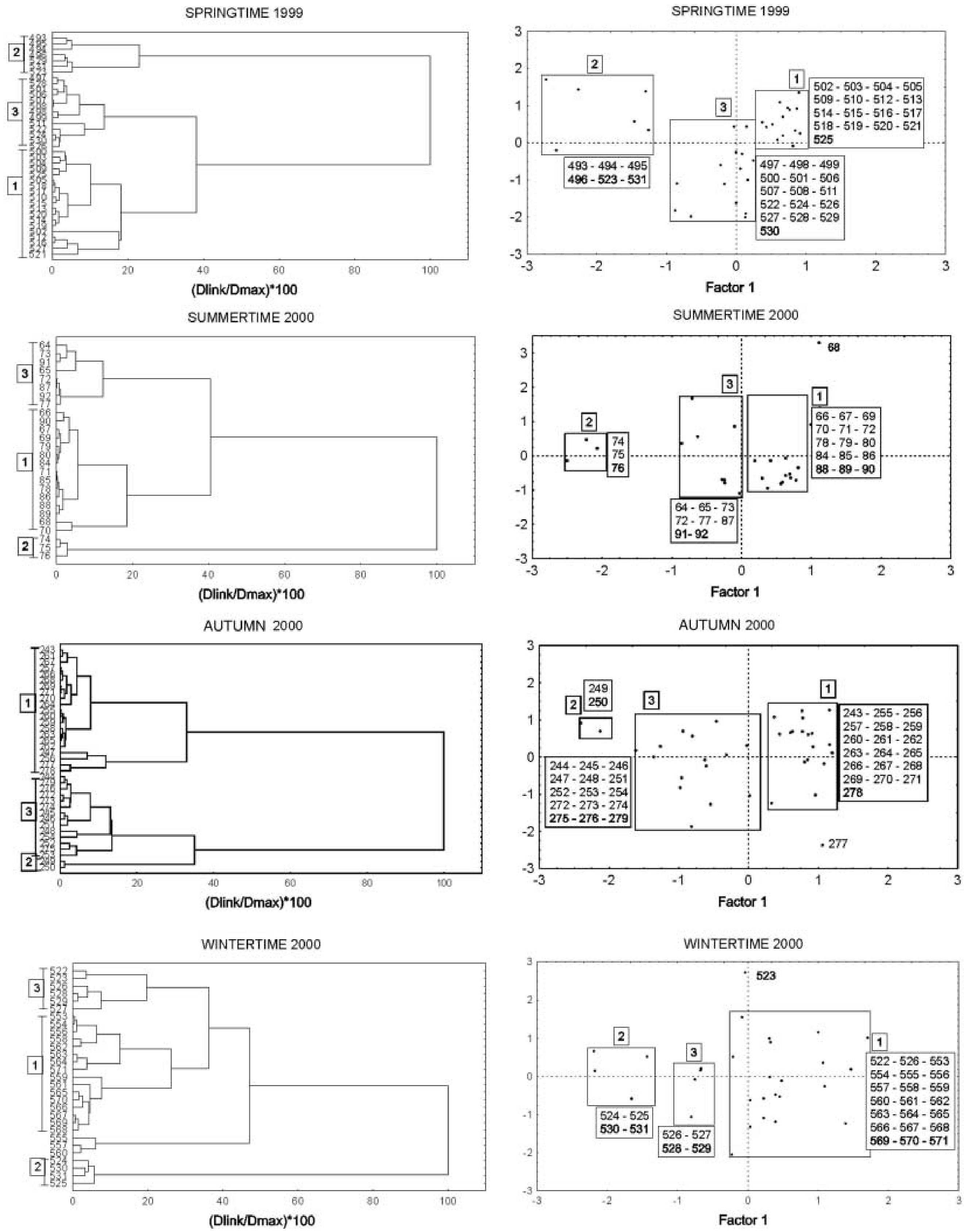

Figure 4. Dendrograms of similarity among variables and principal component analysis.

1 and Group 2). In springtime, summertime and autumn, Group 1 was characterized by temperature, oxygen concentration and Chl-*a* concentration in bottom water and Group 2 by the TOM, TOC, TN concentration, Chl-*a* S and Phaeo S, salinity and density. In wintertime, temperature was associated with Group 2 and Chl-*a* S and Phaeo S to Group 1.

The cluster analysis of the sampling stations (Figure 5) allowed to define three important groups:

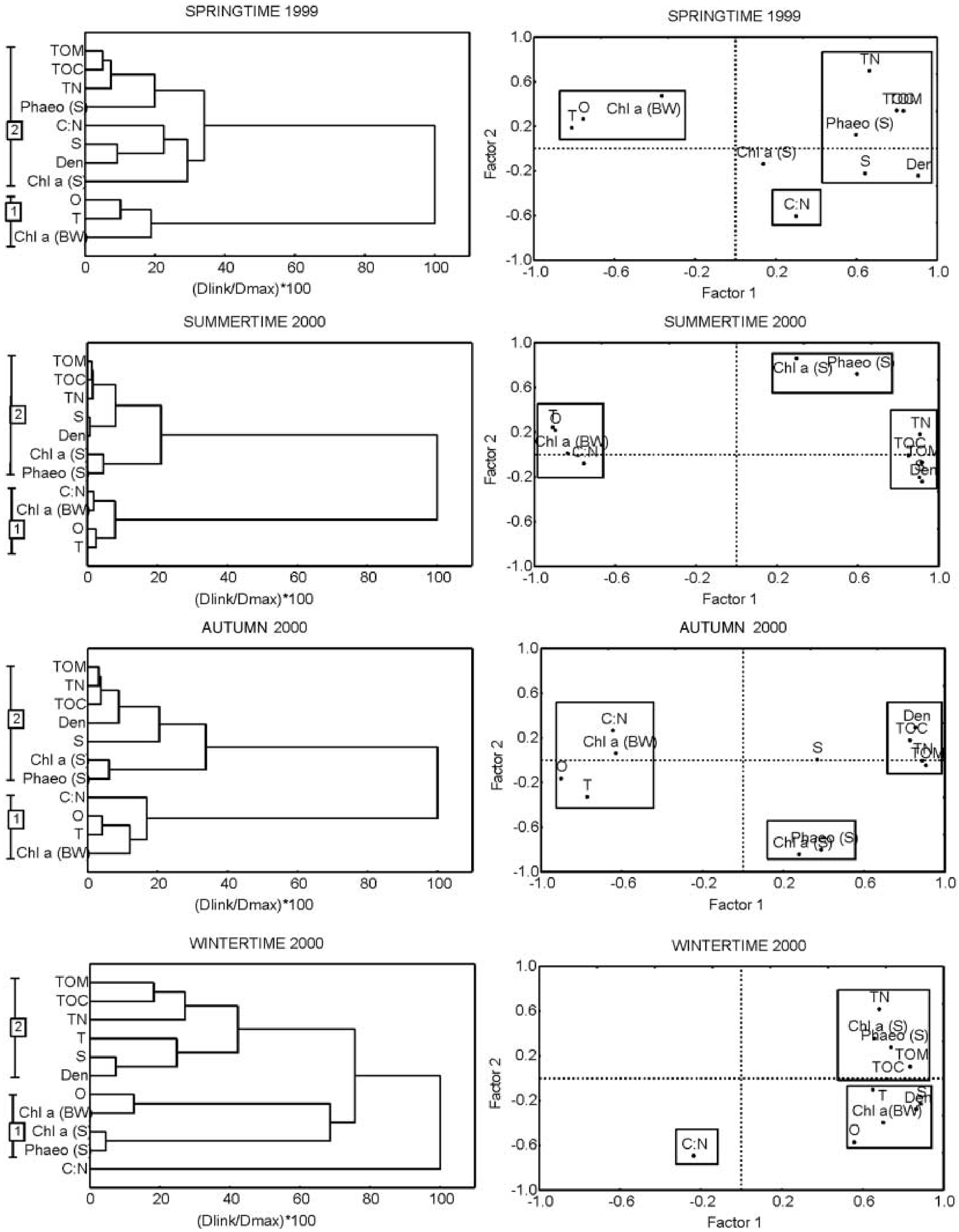

Figure 5. Dendrograms of similarity among sampling stations and principal component analysis.

Group 1 integrated by stations located in the central area of the gulf; Group 2 by those located next to the north and south extremes; and Group 3 by the ones located in the coastal area and the south-east sector.

Principal component analysis (PCA)

As defined by the first component, in springtime, summertime and autumn, the PCA indicated a contrast among temperature, oxygen concentration, Chl-*a* concentration, C:N relationship and TOM, TOC, TN variables, salinity and density. The second component defined the C:N relationship in springtime; in summertime and autumn it defined Chl-*a* S and Phaeo S. In wintertime, the first component defined TOM, TOC, TN, Chl-*a* S, Phaeo S, temperature, salinity, density, oxygen concentration and Chl-*a*; the second component defined the C:N relationship. The ordination of the physical and chemical variables of the different study periods is presented in Figure 4. The ordination of the sampling stations (Figure 5) revealed three associative groups: Group 1 formed by stations located in the centre of the gulf; Group 2 by stations next to the Cabo Tres Puntas and Cabo Dos Bahías; and Group 3 by the coastal stations and those of the south-east sector.

The statistical analysis allowed to identify three sectors with particular characteristics (Table 3) corresponding to the station Groups 1, 2 and 3 defined.

DISCUSSION

The results obtained using statistical multivariate techniques based on the spatial distribution of granulometric fractions, on the chemical composition of the surficial sediments, on the physico-chemical composition of the bottom water and on seasonal variations allowed to characterize three well differentiated sectors in the gulf which geographically coincide with those identified by Fernández et al. (2003). The authors analysed the textural degree and the granulometric parameters of sediments and the physical factors that regulate the dynamics of water masses in the Golfo San Jorge.

Sector 1, the largest and deepest one, comprises the central area defined by the 80 m isobath and corresponds to a depositional environment. In this sector, a turn in a clockwise direction and low and stable hydrodynamic conditions that facilitate the sedimentation processes were observed (Fernández et al., 2003). The system shows a typical seasonal cycle of temperate waters characterized by the formation (in springtime) and rupture (in wintertime) of a seasonal thermocline. As observed by Fernández et al.(2003), the sediments of the sector are characterized by the prevalence of fine granulometric fractions such as silts and clays, originated as a consequence of the erosive environment of the gulf and the accumulation of organic detritus derived from the water column, as reflected in high TOM, TOC, TN concentrations and the presence of Phaeo S. Throughout the year, TOM concentrations showed values much higher than those usually reported for marine sediments (Establier et al., 1984). It should be pointed out that values ranging 12–20% are characteristic of environments enriched with organic matter (Farias et al., 1996). Total organic carbon values were also higher than those reported for sediments of the Argentine continental shelf (0.25–2.00%) (Premuzic et al., 1982). Values can be compared to those observed in other coastal areas with similar characteristics such as St Lawrence Gulf, Canada; Carpentaria Gulf, Australia; California Gulf, USA; Guayaquil Gulf, Ecuador and Santa Barbara Bay, USA (Fernández & Roux, 1999) and to the fiords central region and southern channels of Chile (Nelson et al., 2001). Total nitrogen values can be compared to those observed in systems characterized by an important contribution of organic matter of planktonic marine origin such as in the St Lawrence Gulf, Canada (Pocklington, 1976); Ría de Ares-Betanzos, Spain (Sánchez-Mata et al., 1999) and in the fiords central region and southern channels of Chile (Nelson et al., 2001). The C:N relationship can be used as an approximate index to determine the origin of organic matter present in sediments. According to Redfield et al. (1963), the organic matter of sediments with a 6–7 C:N relationship derives from recent plankton sedimentation; values above 15 indicate the presence of detritus rich in cellulose originated in terrestrial vegetation (Majeed, 1987). Stein (1991) considers that values below ten have organic components of marine origin; that ten C:N values imply organic components of marine and terrestrial origin and that those above ten indicate prevalence of organic matter of terrestrial origin. The origin of the organic matter defines its nutritional value. A 6–7 C:N relationship indicates phytoplankton, faecal pellets and other easily degradable organic materials. Such a relationship also indicates high nutritional value (Sargent et al., 1983). Values ten and above indicate accumulated organic matter of terrestrial and planktonic origin with low nutritional value. The C:N values registered in sediments of the sector in springtime and summertime suggest accumulated organic matter of marine origin. In autumn and wintertime the values obtained indicate components of phytoplankton origin. The Golfo San Jorge receives poor contributions of continental waters and presents a scarce pluvial regime (Akselman, 1996). Therefore, values of the C:N relationship higher than ten in springtime and summertime show the prevalence of organic material of accumulative type.

The TOM, TOC, NT values and C:N relationship registered in the surficial sediments present a clear seasonal variation related to the stabilization cycle and rupture of the thermocline. Total organic matter and TN mean minimum values observed during summertime and the decrease of dissolved oxygen in the bottom water between springtime and summertime indicate high biological consumption of organic material in water (Bordovsky, 1965).

According to Wassmann (1985), in coastal areas there exists a direct relationship between the concentration of organic matter deposited in the marine bed and the intensity of the productive processes that take place in the water column. In periods of high primary production sediments have high concentrations of organic compounds (Nelson et al., 2001). Cucchi Colleoni & Carreto (2003) pointed out that seasonal variations of biomass and phytoplankton production are characterized by a bimodal cycle of temperate waters, with a maximum during springtime and another secondary during autumn. Seasonal studies of Chl-*a* concentration in water by Akselman (1996) indicate: (1) a mean value of 0.83 mg/m^3 in wintertime with a remarkable homogeneity in the vertical and horizontal distribution of values; (2) an increase of values in springtime with a two layers distribution: upper (ξ=3.16 mg/m^3) and lower (ξ=1.15 mg/m^3); and (3) continuity of a two layers vertical distribution with concentrations in the upper layer that go from 3.16 mg/m^3 in springtime to 2.07 mg/m^3 in summertime and 2.66 mg/m^3 in autumn. No high Chl-*a* concentrations were observed in the surface layer in springtime probably due to the fact that bloom occurred before the cruise started. Throughout the

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seasons sediments showed moderate TOM, TOC and TN concentrations and intermediate values of C:N relationship. As indicated by Wassmann (1985), the flow of carbon toward sediments would not be synchronized with seasonal production pulses in the surface layer. The lack of synchronicity would suggest that the labile carbon compounds were degraded by heterotrophic organisms in the surface layer limited by the thermocline and that only a small proportion of larger particles (particularly faecal pellets) and macroaggregates were deposited in sediments. These results coincide with those observed by different authors in the neritic zone of the north-west Mediterranean (Cahet et al., 1972), in Norway fiords (Sargent et al., 1983) and in Beatrix Bay, New Zealand (Gibbs et al., 2002). In similar environments, breakage of the pycnocline by wind and hydrodynamic conditions favour the export of autochthonous material towards the bottom (Olesen & Lundsgaard, 1995; Pesant et al., 2002).

It must be pointed out that in the system studied, TOM, TOC and NT maximum values and C:N relationship minimum values were observed at the end of wintertime. Chlorophyl-*a* concentration showed homogeneous vertical distribution. Absence of physical barriers seems to be responsible for the maximum values of Chl-*a* in bottom water and Chl-*a* S and Phaeo S observed during the season. Coupling of pelagic and benthic systems and the low biological activity caused by the low temperature account for the greater abundance of the organic matter in sediments.

From a biological and ecological point of view, the sector is characterizated by typical soft bottom benthic communities. Faunal association is dominated by molluscs, filter feeding bivalves of the *Nuculana sulculata* and *Nucula puelcha* species, equinoids *Pseudechinus magellanicus* and the polychaete deposit feeder *Asychis amphyglipta* (Roux et al., 1995; Roux & Fernández, 1997).

Sector 2 comprises the areas next to the extremes of the gulf (Cabo Tres Puntas and Cabo Dos Bahías). According to Fernández et al. (2003) it corresponds to a flow or erosive environment characterized by the continuous movement of water that generates a high kinetic energy and erosion of granulometric particles. The action of tide currents and the entrance of Coastal Waters coming from the Magellan Strait would be responsible for the water flow (Bianchi et al., 1982). As observed by Fernández et al. (2003) gravels, very coarse sand, carbonates and low TOM, TOC, TN and Phaeo S concentrations in sediments were found. Lack of thermocline formation favours the homogenization and suspension of particulated organic matter (POM) in the water column and accounts for the low values of organic matter sedimentation. Suspended POM could be transported to other sectors. According to Ríos & Cisterna (1998) it is a ventilated system with high levels of oxygen concentration. The TOM, TOC and TN minimum values were observed in summertime; the maximum corresponded to springtime. The resulting 5.85 C:N relationship value in springtime indicates planktonic contribution and correlates with the maximum Chl-*a* and Phaeo S values registered. The Chl-*a* values in water were higher than those observed in Sector 1. Once again, the delayed start of the cruise would explain why no high concentrations of Chl-*a* were observed in springtime and autumn. The TOM maximum values were found in springtime. As indicated by Wassmann (1985), the low depth and absence of physical barriers would explain the flow of carbon towards sediments as a consequence of seasonal pulses of euphotic layer production.

Limitations produced by hydrodynamic conditions in the sedimentation process should also be considered. As indicated earlier, concentrations of organic matter in sediments were low.

South of the Golfo San Jorge, the sector presented spatial variations in wintertime, springtime and summertime, probably as a result of a larger contribution of Coastal Waters (Bianchi et al., 1982) which would be responsible for the features that define the erosive or flow environment. Guerrero & Piola (1997), observed a larger Coastal Waters contribution from wintertime to springtime probably due to a greater continental input during springtime.

In the sector, hard and sandy bottom benthic communities, mainly formed by colonial elements such as bryozoans, hydrozoans and sponges are settled. A great number of crustacean and echinoderm species and scallop banks of the *Zygochlamys patagonica* species are found (Roux et. al., 1995; Roux & Fernández, 1997).

Sector 3 comprises the coastal area and the south-east sector of the gulf. It belongs to a transitional environment that has characteristics intermediate to those mentioned for Sectors 1 and 2 (Fernández et al., 2003). The sector presents: (1) in its coastal part characteristics of Sector 2 such as low depth and high hydrodynamics which does not allow the stratification of the water column; and (2) in its deep part characteristics of Sector 1 such as low hydrodynamics and seasonal thermocline. These hydrographic particularities allow the formation of frontal systems of sustained productivity and marked spatial variability. The coastal fronts are very important in the south-east sector of the gulf (Guerrero & Piola, 1997). The sediments of the sector are composed of fine sand. They present moderate TOM, TOC, NT and Phaeo S concentrations which can be considered intermediate compared with those registered in Sectors 1 and 2. The values determine a positive gradient that raises with the increase of depth and the decrease of kinetic energy. The values of Chl-*a* concentration in water were intermediate to those observed for Sectors 1 and 2. Non-high concentrations during springtime and summertime were registered. However, analysis of chlorophyll-*a* SeaWIFS images of year 2000 for the Golfo San Jorge showed relatively high and sustained Chl-*a* concentrations during springtime and summertime which relates to the development of the frontal systems. The sediments organic matter content presented moderate TOM, TOC and NT concentrations during springtime, summertime and autumn. This suggests that the flow of carbon toward the sediments is not synchronized with seasonal production pulses of the euphotic zone; this was also observed in Sector 1. The TOM, TOC mean maximum values and C:N relationship mean minimum values were observed in wintertime. The Chl-*a* concentration in water was relatively low and homogeneous during the season which indicates that the absence of a thermocline seems to be responsible for the seasonal maximum of Chl-*a* observed in bottom water and for Chl-*a* S and Phaeo S in sediments. As in Sector 1, greater abundance and higher nutritional quality of organic

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matter in sediments observed in wintertime allowed to identify a coupling between the pelagic and benthic systems. The TOM, TOC and NT mean minimum values and oxygen concentration in bottom water observed in summertime could be related to the oxidation processes of the deposited organic matter. This characteristic was also observed in Sector 1. Sector 3 which corresponds to a transitional environment presents characteristics more related to Sector 1 than to Sector 2.

The extension of the Sector in the south area of the Golfo San Jorge in wintertime, springtime and summertime was limited by the development of Sector 2 and the dynamics of water masses coming from the Magellan Strait.

The benthic communities of the sector are characterized by the presence of diverse faunal associations. In south coastal areas the main association is the one dominated by colonial celenterata *Renilla* sp. and equinoids *Trypilaster philippi* and in the west coastal area by the crustaceans *Munida subrrugosa* and *Pterygosquilla armata armata*. In the area covering part of the mouth of the gulf, affected by the shrimp fleets' activities, the benthic association is dominated by scavenger crustacean, asteroids and ascidians (Roux et al., 1995; Roux & Fernández, 1997; Roux, 2000).

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