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Chemical composition of the small coastal lagoons of the Mediterranean Spanish littoral

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SUMMARY: About sixty small water bodies (coastal lagoons, marshes, salt pans, channels, springs, etc.) of the Spanish Mediterranean coast were sampled seasonally for one year (1979-1980), in order to study different aspects of their chemical composition. The concentrations of major ions (alkalinity, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, and K^+), nutrients ($N.NO_3^-$, $N.NO_2^-$, TRP and Si), oxygen and pH were determined for this purpose. The salt concentrations measured range between 0.4 and 361.3 g l^{-1}. The samples have been divided into four classes of salinity (in g l^{-1}): C1, $S < 5$; C2, $5 < S < 18$; C3, $18 < S < 40$; C4, $S > 40$. Within these classes, the pattern of ionic dominance recorded is remarkably constant and similar to that found in most coastal lagoons ($Cl^- > SO_4^{2-} >$ Alk., for the anions, and $Na^+ > Mg^{2+} > Ca^{2+} > K^+$, for the cations), although other models occur especially in the first class. The dominance of Na^+ and Cl^-, as well as the molar ratios Mg^{2+}/Ca^{2+} and Cl^-/SO_4^{2-} clearly increase from class C1 to class C4. The hyperhaline waters include different subtypes of the major brine type «c» of EUGSTER & HARDIE (1978), the $Na^+ - (Mg^{2+}) - Cl^- - (SO_4^{2-})$ being the most frequent. Nutrient concentrations fall within a wide range ($N.NO_3^-$ from 0.1 to 1100 µg-at l^{-1}; PRT from 0.01 to 23.56 µg-at l^{-1} and Si from 1.0 to 502.0 µg-at l^{-1}). The oxygen values are very variable too, ranging between 0 and 14.4 ml l^{-1}. Four different patterns of nutrient distribution have been distinguished based on the mean concentrations of $N.NO_3^-$ and TRP (mean values in µg-at l^{-1}): A, $N.NO_3^- < 10$, $TRP > 1$; B, $N.NO_3^- > 100$, $TRP < 1$; C, $10 < N.NO_3^- < 100$, $TRP < 1$; D, $N.NO_3^- < 10$, $TRP < 1$. As a rule, lagoons of low salinity (C1 and C2 classes) display the nutrient pattern C, and lagoons of high salinity (C3 and C4) show the nutrient pattern D. Model A only appears in waters of very low salinity, whereas model B does not seem to be related to salinity.

Key words: coastal lagoons, chemistry, nutrients, Mediterranean lagoons, Spain.

INTRODUCTION

Because of their situation in fertile and flat lands near the sea, coastal epicontinental waters have suffered, in a particular way, the impact of human, not always rational activity. Until recent decades, wet areas with more or less saline waters were abundant on the Mediterranean coast of Spain. Even though typical coastal lagoons were scarce, marshy areas and small water masses were relatively common. Nowadays, as a result of years of poor management, many of these areas are in decline or have changed into cultivated fields or into industrial or residential sites.

In spite of their reduced size, the littoral water bodies still remaining are of considerable ecological interest, as they display an extraordinary morphological and hydrological variability. Until now, the extent of knowledge on the state of the Spanish Mediterranean coastal lagoons has been relatively limited and only the larger lagoons (Ebro Delta, Albufera of Valencia) have been studied with regularity (MARGALEF & MIR, 1974; CAMARASA *et al.*, 1977; CHINCHILLA & COMÍN, 1977; COMÍN & FERRER, 1978, 1979; FERRER & COMÍN, 1979; COMÍN, 1982, 1984; MIRACLE *et al.*, 1984; OLTRA & MIRACLE, 1984; SERRA *et al.*, 1984). In 1979, the Department of Ecology of the University of Barcelona initiated a multi-disciplinary research aimed at providing comparative data about the physicochemistry and biology of almost all the bodies of water along the Spanish Mediterranean coast, except for the Ebro Delta from which the information already existed. Some of the results of this study have already been published (MARGALEF-MIR, 1981; TOMÀS *et al.*, 1980; TOMÀS, 1981a, 1981b, 1988; LÓPEZ, 1984, 1986). In this paper, some aspects concerning the mineralization and concentration of nutrients and oxygen are discussed.

STUDY AREA

The 56 aquatic systems studied are located on a coastal strip over 1000 Km in length and 5-50 Km in width, which extends from the north of the province of Girona (Catalonia) to the west of Almeria (Andalusia) (Fig. 1). This coastal band is closed to the west by the spurs of different mountain systems formed mainly by calcareous rocks (marls and limestones). The coast is occupied by recent sediments which fill old areas of subsidence. It is an exorrheic area, with a highly important underground water circulation. The most important river is the Ebro, the rest being small rivers and streams, often with a pluvial regime.

The climate is typically Mediterranean, with irregular rainfall concentrated especially in the spring and autumn. The average annual precipitation decreases towards the South, varying from between 600 mm in the NE and 150 mm in the SE (FONT, 1983).

MATERIAL AND METHODS

The water samples were collected on a seasonal basis (April 1979, July 1979, October 1979 and February 1980) from a depth of 10 cm. The pH was measured *in situ* with a Lovidond tester (GOLTERMAN, 1967) and oxygen was determined using the Winkler method (CARPENTER, 1966). For the analysis of alkalinity, chloride, sulphate and nutrient concentrations the methods described by GOLTERMAN (1967), APHA (1975), FRITZ & YAMAMURA (1955) STRICKLAND & PARSONS (1965), respectively, were followed. The fraction of phosphorus analysed was the total reactive phosphorus, TRP (reactive phosphorus in unfiltered water). Calcium and magnesium were analysed by atomic absorption spectroscopy; sodium and potassium by atomic emission spectroscopy. Salinity was calculated from the sum of the major ions.

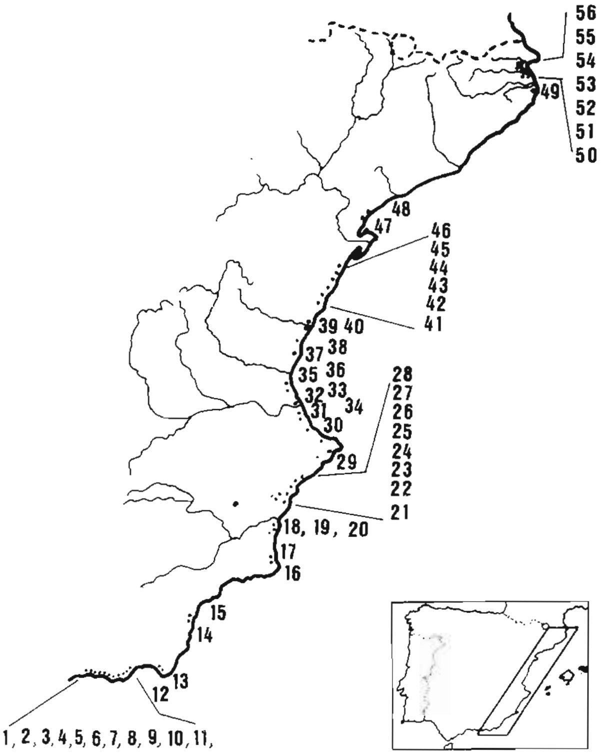

FIG. 1. — Location of the systems sampled. The correspondence between the number and the name of each coastal lagoon is given in Table 1.

RESULTS

Salinity and major ions

The salinities in the systems studied range from between 0.4 and 361.3 g l^{-1}, their average value being about 33 g l^{-1}. Following the Venice System of classification of brackish waters, all the samples have been divided into four classes of salinity, C1: $S \leq 5$ g l^{-1}; C2: 5 g $l < S \leq 18$ g l^{-1}; C3: 18 g $l^{-1} < S \leq 409$ g l^{-1}; C4: $S \geq 40$ g l^{-1}. 13 of the lagons studied belong to class C1; 11 to class C2; 6 to class C3 and 10 to class C4 (Table I). The remaining systems display great fluctuations in their total concentration of salts, varying from between $S < 40$ g l^{-1} and $S > 40$ g l^{-1}; they are included in class C3 or C4 depending on the season considered.

The pattern of dominance for the major ions (Cl^-, SO_4^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+ and K^+) varies according to mineralization. 86 % of the waters sampled are dominated by sodium and chloride and the most frequently encountered ionic pattern (found in more than the 70 % of samples) is $Cl^- > SO_4^{2-} > HCO_3^-$ for anions and $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ for cations. Only in the first class of salinity, C1, are other ionic patters relatively common: 13.8% of these waters are dominated by alkalinity and divalent cations; 8.6% by chloride and divalent cations; 10.4% by sulphate and divalent cations, and 13.8% by sulphate and sodium. $SO_4^{2-} - Na^+$ waters also appear in class C2, but they only represents 2.2% of this group.

The waters included in class C4 are hypersaline. According to the nomenclature stated by EUGSTER & HARDIE (1978) 75% of them belong to type $Na^+ - (Mg^{2+}) - Cl^- - (SO_4^{2-})$, 20% to type $Na^+ - (Mg^{2+}) - Cl^-$, and the remaining 5% to types $Na^+ - (Mg^{2+} - (Ca^{2+}) - Cl^- - (SO_4^{2+})$, $Na^+(Ca^{2+}) - Cl^- - (SO_4^{2-})$ and $Na^+ - Cl^- - (SO_4^{2-})$.

TABLE I. — Average of four seasonal samples, minimum and maximum values of the variables studied for each water body. * : Lagoons sampled only once. ** : These lagoons present a strong picnocline and they remain stratified almost all the year. The values given in this table correspond to the surface water. The physicochemical cycle of these lagoons has been described in ARMENGOL *et al.* (1983) and LOPEZ *et al.* (1984).

		S *g l⁻¹*	*Alk* *meq l⁻¹*	*Cl* *meq l⁻¹*	SO_4^{2-} *meq l⁻¹*	Ca^{2+} *meq l⁻¹*	Mg^{2+} *meq l⁻¹*	Na^{+} *meq l⁻¹*	K^{+} *meq l⁻¹*	*pH*	O_2 *ml l⁻¹*	$N.NO_3^-$ *μg-at l⁻¹*	*TRP* *μg-at l⁻¹*	*Si* *μg-at l⁻¹*
1	Albufera Nueva	2.7 2.4-3.0	3.5 1.9-4.8	29.1 22.8-37.7	1.4 9.3-13.0	3.0 1.8-4.9	11.0 5.4-13.7	29.5 26.7-35.1	0.9 0.6-1.0	9.0 8.7-9.4	7.8 5.1-9.4	0.7 0.4-1.5	0.15 0.05-0.33	28.4 12.5-62.9
2	Albufera Honda	3.2 3.0-3.4	6.9 5.8-7.8	33.2 30.1-37.7	11.6 10.1-13.2	2.7 1.2-1.4	13.1 5.4-16.9	36.2 30.9-44.2	0.8 0.6-0.9	8.9 8.5-9.2	7.5 4.5-11.3	29.4 11.3-38.9	0.05 0.03-0.06	136.0 11.8-221.5
3	Guardias Viejas	43.4 24.3-68.9	4.9 2.4-7.5	602.8 306.0-1067.6	141.8 90.0-196.4	45.1 23.3-71.6	138.8 87.9-185.8	512.8 287.3-775.0	12.2 7.8-17.7	9.1 8.4-9.8	5.2 1.2-7.9	13.2 0.1-43.1	0.14 0.06-0.19	231.2 66.5-394.0
4	No name	49.8 35.3-73.7	3.5 3.0-4.3	720.8 513.6-1049.8	121.4 75.8-204.5	35.2 17.9-62.9	105.5 15.7-210.0	677.6 458.0-962.9	14.8 8.9-26.2	8.7 8.3-9.2	3.8 0.7-7.4	2.4 1.2-3.5	0.31 0.01-0.86	81.4 22.1-216.1
5	No name	44.4 39.1-51.2	3.0 2.9-3.2	656.8 564.0-822.2	90.3 59.0-123.5	33.3 20.4-58.1	109.4 99.0-124.0	613.5 506.0-709.0	12.6 11.1-15.7	8.7 8.3-9.2	1.0 0.0-2.0	2.2 1.4-3.0	0.27 0.01-0.53	182.7 59.2-306.2
6	Punta Entinas	46.6 31.2-62.8	2.6 1.5-3.5	673.6 438.0-930.7	101.5 61.5-138.5	44.4 12.8-80.7	134.2 90.9-223.0	644.9 420.6-900.0	8.1 7.6-8.6	8.5 8.3-8.8	3.7 0.5-6.4	12.1 0.2-47.0	1.00 0.31-1.89	173.5 92.9-235.3
7	Punta Entinas	52.7 25.8-89.4	3.3 2.0-4.1	753.0 366.0-1341.0	134.6 81.7-200.3	51.6 27.0-89.7	104.7 45.6-230.0	711.9 287.5-1200.0	15.1 11.0-25.0	8.5 8.3-8.7	3.5 0.0-5.6	1.8 0.3-3.1	0.48 0.10-1.50	183.9 97.8-315.3
8	Hoyo Romero	100.9 83.1-134.5	3.1 2.9-3.5	1443.0 1228.0-1835.0	181.3 160.4-210.4	79.7 62.9-100.5	221.7 164.4-280.4	1640.5 1146.0-2312.0	23.8 16.3-31.6	8.3 8.2-8.5	2.5 1.0-4.1	1.1 0.1-2.1	0.01 0.01-0.01	90.2 71.5-109.0
9	Cerrillos	63.2 29.4-84.4	2.8 2.6-3.0	950.8 465.0-1315.0	133.5 54.8-191.2	61.7 29.5-83.8	174.2 153.2-190.7	817.7 302.0-1113.6	19.6 16.3-25.2	8.4 8.2-8.7	7.1 6.4-7.9	13.9 0.1-52.9	0.30 0.07-0.57	81.8 46.9-169.3
10	Salinas Viejas	90.5 56.3-118.7	3.3 3.3-3.4	1345.3 933.0-1875.0	163.4 140.6-194.0	57.6 15.6-100.4	238.7 116.0-327.0	1278.8 568.9-1950.0	32.3 16.8-54.3	8.5 8.4-8.7	3.2 0.6-4.8	63.6 21.5-126.7	0.19 0.12-0.34	91.4 52.9-130.7
11	Salinas Viejas (channel)	18.5 11.8-25.2	7.9 5.7-10.1	264.9 146-7-383.0	52.5 46.5-58.4	7.5 4.2-10.8	36.9 32.6-41.2	233.0 121.0-345.0	4.0 2.3-5.7					
12	Rambla Morales	90.6 69.2-136.9	3.0 1.9-4.1	1395.5 989.0-2160.0	186.2 136.0-244.0	55.7 24.8-92.0	317.8 122.0-654.0	1150.2 924.0-1692.8	13.7 6.8-16.1	8.5 8.1-8.9	3.3 2.6-3.7	1.2 0.1-3.1	1.00 0.06-2.92	15.4 1.0-42.7
13	Salinas Acosta	86.7 70.2-113.0	3.3 2.6-3.8	1241.5 1066.0-1670.0	136.8 125.8-151.3	55.8 41.5-82.5	238.0 146.0-288.0	1297.0 990.0-1788.0	22.5 18.1-30.3	8.8 8.5-9.1	4.1 3.1-5.0	1.8 0.7-2.6	1.73 0.01-4.82	21.9 3.2-33.4
14	Rambla Mojácar	8.8 5.1-18.5	3.6 2.1-4.5	103.3 38.3-266.7	40.4 34.9-52.4	22.9 12.3-37.6	27.1 13.6-53.5	91.2 48.8-216.4	3.2 0.7-7.2	8.4 8.1-8.7	6.8 4.7-8.1	51.6 5.8-88.8	0.15 0.03-0.28	328.8 216.3-406.6
15	Rambla Antas	43.1 40.5-47.8	3.9 2.1-5.3	606.8 566.0-672.0	118.3 93.9-134.0	38.1 21.6-65.9	127.2 110.0-149.2	561.5 518.0-668.0	10.5 9.5-11.3	8.3 8.1-8.6	6.1 5.4-6.6	1.0 0.1-3.9	0.31 0.01-0.62	36.1 13.9-83.0
16	Marchamalo	67.2 57.2-84.0	3.5 2.8-4.3	1004.8 875.0-1244.0	124.6 89.3-184.6	40.7 17.0-67.6	226.6 133.3-317.0	887.3 760.0-1010.0	34.2 16.6-73.9	8.8 8.3-9.8	3.3 1.3-4.5	1.8 0.1-3.6	0.18 0.02-0.28	7.8 1.0-17.5
17	Cotorrillo	53.7 47.0-60.4	3.2 2.8-3.6	819.8 735.0-916.0	114.6 79.6-161.7	33.4 18.1-56.3	133.3 112.0-164.0	696.3 632.0-762.0	14.7 13.0-18.3	8.4 8.3-8.7	4.6 3.6-5.6	0.8 0.1-2.9	0.16 0.01-0.30	13.3 4.1-21.0
18	Salinas de Torrevella	339.7 312.9-361.3	14.8 10.4-19.6	5011.0 4400.0-5800.0	663.3 524.0-848.0	142.0 20.5-351.0	2269.7 2039.0-2492.3	3452.2 3206.0-3660.6	252.0 246.0-258.0					

TABLE I. *(Continued)*

	S $g\ l^{-1}$	Alk $meq\ l^{-1}$	Cl^- $meq\ l^{-1}$	SO_4^{2-} $meq\ l^{-1}$	Ca^{2+} $meq\ l^{-1}$	Mg^{2+} $meq\ l^{-1}$	Na^+ $meq\ l^{-1}$	K^+ $meq\ l^{-1}$	pH	O_2 $ml\ l^{-1}$	$N.NO_3^-$ $\mu g\text{-}at\ l^{-1}$	TRP $\mu g\text{-}at\ l^{-1}$	Si $\mu g\text{-}at\ l^{-1}$
19 Salinas de Torrevella channel	55.2 29.5-117.0	4.0 2.6-4.8	887.0 433.0-1970.0	90.4 64.0-123.7	60.0 36.8-98.0	162.0 95.8-318.4	685.0 313.0-1500.0	6.3 2.6-15.0	8.1 7.6-8.3	4.3 2.4-6.6	62.1 0.2-163.1	0.45 0.20-1.14	82.5 11.8-127.7
20 Salinas de la Mata	96.0 86.6-104.4	3.7 3.3-4.1	1476.5 1255.0-1697.0	160.8 148.0-178.0	80.6 64.4-96.7	273.4 269.8-277.0	1320.5 1231.0-1410.0	24.2 16.3-32.0	8.9 8.6-9.2	4.1 3.4-5.3	6.6 0.3-14.5	0.20 0.01-0.43	24.4 4.2-78.2
21 El Hondo	12.8 11.4-16.1	5.3 4.0-6.7	138.8 125.6-148.2	57.9 48.3-76.3	27.3 15.3-39.2	39.4 36.4-45.0	162.5 95.6-311.5	1.0 0.3-1.3	8.3 8.0-8.4	7.1 5.6-8.9	32.1 11.0-47.1	0.44 0.20-0.76	366.6 286.9-469.9
22 El Hondo, Embalse	2.5 2.2-2.7	2.4 1.4-3.5	20.3 14.9-26.7	16.7 10.2-20.7	7.6 5.5-12.1	10.9 6.4-12.4	20.8 17.8-23.2	0.9 0.3-2.3	9.1 8.5-9.7	10.7 9.1-14.1	0.6 0.1-1.4	2.02 0.32-3.19	245.2 134.0-302.0
23 El Hondo, Sur	9.9 7.6-12.4	4.5 1.8-6.3	108.4 82.2-139.4	53.7 43.4-75.3	21.9 15.5-35.4	31.8 18.6-45.1	101.6 53.0-135.0	1.0 0.8-1.3	8.5 7.8-9.3	6.3 3.7-8.9	19.1 0.2-69.8	0.56 0.37-0.94	164.0 126.6-216.2
24 Salinas del Pinet	66.2 61.8-70.6	3.4 2.5-4.0	1005.0 993.0-1040.0	121.0 101.2-137.0	48.1 23.0-81.5	171.2 148.5-230.3	904.9 836.0-1001.2	17.7 14.8-20.4	8.5 8.3-8.8	6.0 5.4-6.4	1.9 0.4-2.7	0.55 0.25-0.71	60.6 14.9-92.9
25 La Marina (a)	8.6 7.0-9.3	7.8 6.8-9.1	77.1 65.6-95.0	49.5 35.1-76.3	22.9 6.0-57.9	21.5 18.3-24.6	96.1 83.0-124.0	0.8 0.5-1.1	8.2 7.8-8.6	6.0 4.3-8.0	34.1 7.4-76.0	0.35 0.19-0.63	299.1 230.0-385.9
26 La Marina (b)	10.6 9.6-11.8	5.6 4.9-6.1	118.4 100.0-142.2	50.4 34.5-69.6	32.9 27.2-40.7	22.4 19.7-24.2	115.3 97.5-129.3	0.8 0.5-1.0	8.6 8.5-8.7	10.6 8.9-12.4	2.4 0.3-6.2	16.12 11.77-23.14	267.1 152.5-324.6
27 No name	12.7 11.8-13.5	6.1 5.3-6.6	162.9 148.7-172.4	44.3 39.1-46.4	25.4 15.6-38.5	40.1 22.1-50.0	145.3 118.6-160.0	1.4 0.9-1.7	7.8 7.5-8.3	3.1 0.4-4.5	19.1 0.3-64.5	0.21 0.01-0.43	268.6 177.9-340.5
28 El Saladar	80.1 38.8-127.3	6.0 4.4-7.8	815.1 489.0-1050.0	281.1 157.2-459.6	69.0 33.4-95.9	171.2 108.2-241.8	934.7 495.0-1223.0	24.8 5.5-35.5	8.4 8.4-8.5	4.1 3.3-5.0	2.0 1.9-2.2	0.83 0.14-1.53	60.0 42.7-77.3
29 Salinas El Saladar	59.2 13.1-99.6	3.4 2.8-4.0	904.0 177.0-1480.0	106.4 51.6-164.6	39.2 10.9-100.3	165.5 36.4-318.0	799.8 146.0-1403.0	14.8 1.4-21.5	8.6 8.3-9.0	5.6 0.3-9.6	1.7 1.0-3.1	0.79 0.67-0.94	84.0 53.1-113.0
30 Manantial de Pego	1.2 0.8-1.6	3.4 3.1-3.7	13.6 7.6-17.7	2.2 0.9-3.3	4.9 1.7-7.5	2.9 2.0-3.9	12.1 5.4-17.2	0.2 0.1-0.2	7.8 7.5-8.1	7.5 6.3-9.3	126.6 74.8-203.6	0.20 0.01-0.40	106.6 99.0-110.7
31 Manantial de Gandía	0.5 0.5-0.6	4.4 4.1-4.7	1.3 1.1-1.5	1.7 1.3-2.0	1.3 3.9-5.0	2.0 1.5-2.3	1.5 0.6-3.0	0.1 0.02-0.06	7.5 7.3-7.8	5.7 5.2-6.1	185.9 66.1-442.9	0.15 0.05-0.21	157.4 135.5-168.1
32 No name (*)	11.6	6.5	105.0	19.2	21.5	25.3	251.0	1.3					
33 No name (*)	4.3	2.8	53.2	8.4	7.3	7.3	65.4	0.9					
34 Estany Cullera (**)	2.9 1.1-7.8	4.0 3.0-5.0	33.4 4.1-109.4	10.6 6.4-19.0	10.5 3.6-22.2	9.4 2.5-23.2	28.0 1.4-85.7	0.7 0.1-2.0	8.1 7.5-9.2	7.3 4.5-12.1	37.5 31.7-41.8	2.26 0.56-4.74	137.8 72.4-242.4
35 San Lorenzo	1.6 1.2-1.8	3.4 2.5-4.4	2.7 11.0-13.3	8.9 6.9-10.4	5.1 2.5-8.2	5.3 3.4-6.4	2.8 4.8-20.1	0.3 0.1-0.5	8.2 7.8-9.0	6.7 5.1-8.5	31.6 0.2-60.2	0.28 0.06-0.52	180.7 69.5-318.1
36 Albufera de Valencia	1.1 1.0-1.3	1.8 1.3-2.6	9.0 4.9-13.4	7.3 2.5-10.4	3.5 3.1-3.7	4.0 2.6-5.7	7.9 3.6-14.9	0.2 0.1-0.2	9.2 8.7-9.5	9.1 6.1-11.4	4.1 0.5-11.5	4.19 2.04-5.41	111.7 30.2-222.9
37 Canal Michera	1.2 1.0-1.7	5.0 4.1-5.7	6.4 4.2-9.6	7.3 5.3-9.7	5.8 4.7-7.8	5.9 5.3-6.4	7.2 3.9-13.5	0.1 0.1-0.1	7.0 7.0-7.0	4.7 1.7-6.4	79.6 11.3-152.9	0.45 0.01-1.20	145.2 45.5-195.1

TABLE I. *(Continued)*

	S $g\ l^{-1}$	Alk $meq\ l^{-1}$	Cl^- $meq\ l^{-1}$	SO_4^{2-} $meq\ l^{-1}$	Ca^{2+} $meq\ l^{-1}$	Mg^{2+} $meq\ l^{-1}$	Na^+ $meq\ l^{-1}$	K^+ $meq\ l^{-1}$	pH	O_2 $ml\ l^{-1}$	$N.NO_3^-$ $\mu g\text{-}at\ l^{-1}$	TRP $\mu g\text{-}at\ l^{-1}$	Si $\mu g\text{-}at\ l^{-1}$
38 Almenara	2.9 1.6-4.0	4.1 3.4-4.8	25.8 9.6-39.4	16.5 9.9-20.3	15.5 4.8-27.9	8.9 3.6-14.2	23.8 15.8-33.4	0.8 0.2-1.8	8.1 7.4-8.4	6.4 5.8-7.5	107.1 0.6-334.0	0.21 0.09-0.42	113.3 105.3-133.2
39 Rambla de Millars (S)	1.4 1.0-1.7	3.6 3.3-4.0	11.4 7.6-16.6	7.5 6.0-9.2	6.4 5.0-8.9	3.4 1.9-4.6	9.7 4.2-14.2	0.2 0.1-0.2	7.8 7.7-7.9	7.4 6.6-8.3	16.7 0.1-40.6	0.15 0.01-0.41	83.3 16.5-175.3
40 Rambla de Millars (N)	1.0 0.7-1.3	3.1 2.4-3.5	5.5 1.6-9.8	7.4 6.0-8.7	5.2 3.0-9.0	3.1 1.6-3.9	5.3 1.6-9.0	0.1 0.1-0.2	7.8 7.6-8.0	7.3 6.0-8.4	208.3 71.3-532.5	0.12 0.01-0.33	105.4 37.8-199.1
41 Canal de Torreblanca	16.4 6.7-42.8	5.1 3.5-6.9	244.0 77.7-714.6	29.0 13.8-66.8	25.5 19.4-36.3	47.1 16.0-102.3	216.5 66.3-514.2	4.9 1.1-12.1	8.2 7.7-8.7	5.0 7.2-7.7	56.1 0.2-142.4	0.19 0.05-0.28	159.4 70.1-312.0
42 Laguna de Torreblanca (a)	7.6 6.0-8.8	4.1 2.2-5.2	100.3 78.9-115.0	16.6 13.5-21.5	25.1 15.1-41.2	15.6 7.2-20.1	97.9 71.7-143.9	1.2 0.8-1.5	8.5 8.3-8.8	7.4 7.2-7.7	37.9 4.4-97.4	0.15 0.07-0.24	92.2 31.4-165.2
43 Laguna de Torreblanca (b)	7.1 6.1-8.0	3.8 3.0-4.1	94.6 87.7-103.3	12.6 6.4-18.3	18.6 10.2-33.8	18.4 17.4-19.0	99.7 75.3-141.7	1.3 1.1-1.4	7.9 7.7-8.0	5.9 5.2-6.7	24.9 0.2-58.9	0.11 0.01-0.18	174.2 74.6-240.3
44 Manantial de Peñíscola	5.7 5.0-6.7	5.4 5.0-5.6	80.8 60.4-123.1	13.2 10.4-15.5	20.9 10.5-36.6	9.4 7.5-11.0	54.9 51.0-59.9	0.9 0.7-1.1	7.1 7.0-7.2	5.6 3.9-8.6	112.5 73.0-156.5	0.15 0.01-0.28	152.0 134.6-166.1
45 Aigua d'Oliva	4.6 3.5-6.0	4.4 3.7-4.7	59.4 40.8-77.7	11.2 8.5-12.8	16.9 7.4-27.0	18.5 9.5-32.9	49.7 37.4-67.1	0.7 0.7-0.8	8.0 7.7-8.1	7.5 6.8-8.4	363.5 76.7-1109.2	0.20 0.01-0.44	94.2 75.0-120.3
46 El Servol	30.2 27.6-34.1	3.3 2.9-3.8	396.9 382.8-411.0	75.1 70.2-79.9	35.1 22.1-48.1	82.9 22.1-48.1	363.3 349.0-377.0	6.7 4.8-8.5	8.7 8.6-8.8	5.2 3.5-7.0	56.3 7.9-135.6	0.17 0.01-0.29	45.5 12.4-95.9
47 Rambla d'Ametlla	20.4 15.5-29.9	4.9 3.6-7.3	285.6 205.0-422.2	47.8 24.3-79.3	22.8 11.9-35.6	52.3 35.1-80.3	278.8 208.0-399.0	4.5 3.9-5.0	8.4 8.3-8.6	7.3 6.2-8.7	7.0 0.1-18.5	0.08 0.01-0.28	74.3 23.6-140.5
48 Rambla d'Ametlla	11.8 10.7-13.6	4.2 3.5-4.8	157.6 150.4-177.7	28.6 15.5-56.3	18.8 9.5-25.9	29.8 26.6-32.3	162.0 148.0-199.0	2.4 1.8-2.7	8.3 8.2-8.4	6.7 5.6-8.4	0.8 0.2-1.9	0.09 0.01-0.24	44.2 25.4-77.5
49 Estanys de Pals	1.8 0.8-2.8	4.7 4.6-4.7	14.9 1.9-28.0	9.2 5.5-12.0	6.5 5.4-7.5	4.3 1.1-7.4	15.4 2.6-28.8	0.7 0.2-1.1	8.2 8.0-8.3	7.0 6.1-7.9	0.6 0.4-0.9	7.21 6.03-8.40	130.3 94.0-166.0
50 La Massona (**)	5.2 4.4-6.0	4.5 4.3-4.7	74.5 69.9-79.1	14.1 11.7-16.6	11.6 8.0-15.2	19.0 16.0-22.0	47.1 16.2-78.0	1.7 1.4-1.9	8.3 8.3-8.3	6.8 6.1-7.5	39.2 0.14-78.4	0.20 0.04-0.37	189.1 145.5-232.7
51 La Llarga	34.8 33.6-35.9	3.7 3.4-4.0	468.4 433.2-503.6	91.4 76.4-106.4	41.8 33.7-49.8	129.7 107.8-151.6	465.7 458.3-473.0	10.8 10.3-11.2	8.3 7.9-8.8	4.4 4.3-4.5	1.1 0.1-2.1	1.68 1.68-1.68	135.4 34.5-236.4
52 La Fonda	34.7 33.5-35.9	3.8 3.7-4.0	475.8 447.9-503.6	79.4 76.4-82.4	42.3 34.8-49.8	133.0 114.3-151.6	472.7 472.3-473.0	11.2 11.2-11.2	8.2 7.9-8.5	4.4 4.3-4.4	0.2 0.1-0.4	0.33 0.28-0.33	60.5 58.9-62.1
53A La Rogeda	36.4 36.0-36.7	4.2 4.2-4.3	510.8 477.7-543.8	85.3 76.4-94.2	43.0 35.5-50.4	118.2 111.3-125.0	485.0 437.0-532.9	10.8 10.1-11.6	8.2 8.0-8.3	4.8 4.5-5.0	0.2 0.1-0.3	1.89 0.68-3.95	50.9 29.7-72.2
54 Muga mouth (S)	27.3 21.4-33.1	4.2 3.4-4.9	375.1 266.7-483.4	84.3 76.4-92.9	37.0 24.7-49.3	85.4 64.7-106.1	326.6 245.8-407.4	9.2 6.7-11.8	8.4 8.4-8.5	5.6 5.4-5.8	0.3 0.1-0.5	2.32 1.63-3.02	26.8 26.8-26.8
55 Muga mouth (N)	31.0 31.0-31.1	4.6 4.4-4.7	422.2 422.2-453.2	80.0 70.3-89.6	40.4 29.7-50.1	101.5 95.7-107.2	391.4 386.1-396.1	9.1 8.4-9.8	8.5 8.4-8.5	5.8 5.4-6.1	0.4 0.3-0.5	4.55 2.16-5.00	70.8 36.2-98.0
56 Vilahut	0.7 0.4-1.1	3.4 2.8-4.2	3.3 1.6-5.1	3.6 1.6-7.1	4.3 3.8-4.8	2.1 0.6-4.1	3.3 0.6-5.8	0.4 0.04-0.62	8.3 8.1-8.5	7.1 5.0-8.9	0.2 0.1-0.4	2.72 0.10-6.37	143.0 130.6-155.4

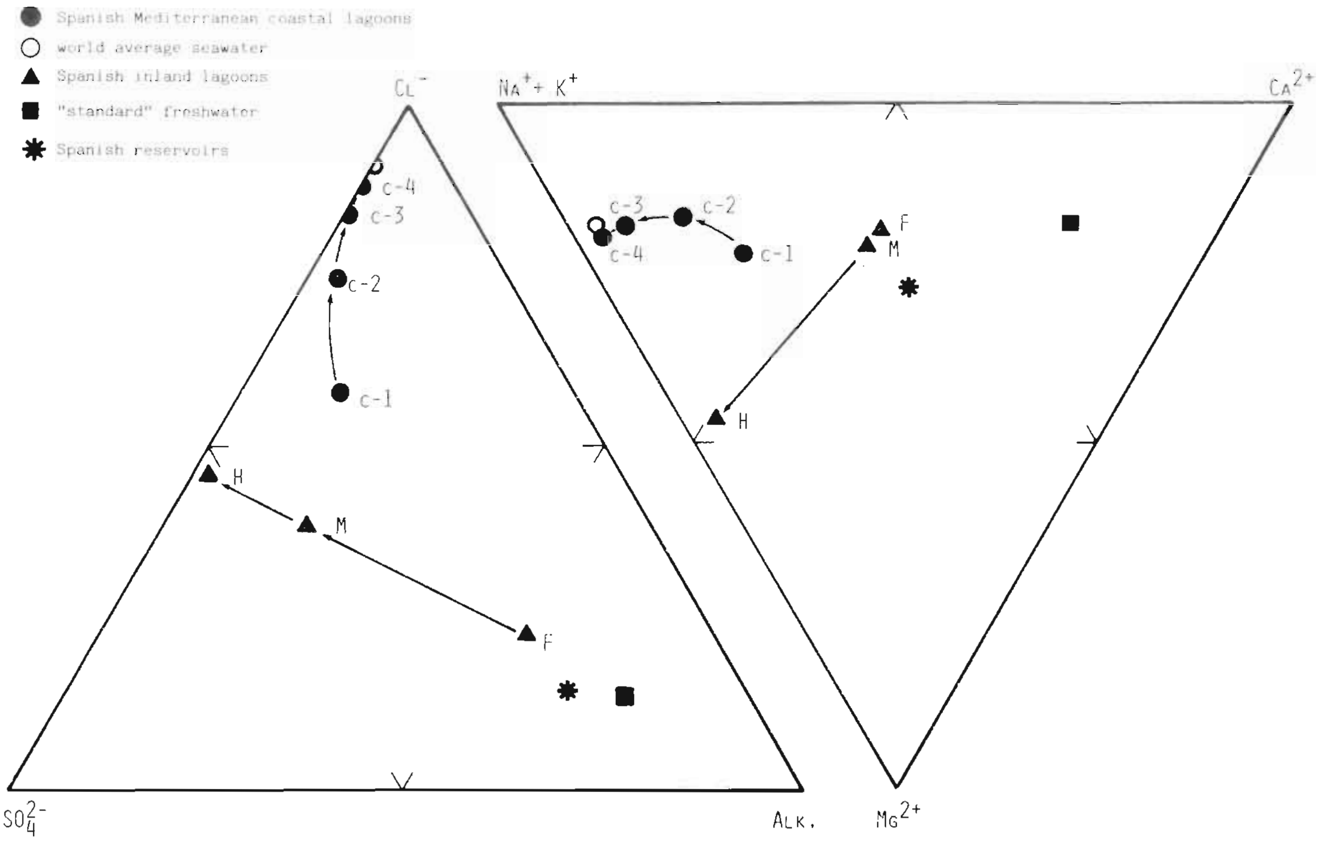

FIG. 2 — Position, on a triangular diagram, of the different types of aquatic systems according to their average relative anionic and cationic compositions. The coordinates of each point are given in equivalent percentages of each of the variables. World average seawater, from BAYLY & WILLIAMS (1981); Spanish inland lagoons, from ALONSO (1985); "standard" freshwater, from CLARKE (1924); Spanish reservoirs, from MARGALEF *et al.* (1976).

The relative ionic proportions also vary when salinity increases. On average, the percentage of chloride and sodium rises from class C1 to class C4, whereas alkalinity and calcium percentage decrease strongly, as to a lesser extent do those of magnesium, sulphate and potassium (Fig. 2). These changes affect the molar ratios between the different ions. Figure 3 shows the mean values of the molar ratios most frequently used in limnology (Mg^{2+}/Ca^{2+}, $Mg^{2+} + Ca^{2+}/Na^{+} + K^{+}$ and Cl^{-}/SO_4^{2-}) in the four classes of salinity considered. Although the relative standard deviations can be considerable, certain trends may be noted.

The Mg^{2+}/Ca^{2+} quotient tends to increase in a continuous way together with mineralization. Among the analysed samples, only three show a Mg^{2+}/Ca^{2+} quotient lower than the average value for freshwaters; and in twenty of them this ratio is greater than that found in seawater.

The relation between divalent and monovalent cations tends to decrease when salinity increases. Forty nine high salinity samples have an average value below that of seawater, while only six (of low salinity), surpass that of freshwaters.

The Cl^{-}/SO_4^{2-} ratio increases slightly from less mineralized waters to the more saline ones. Most of the values are between those of seawater and the average of freshwaters. Only 4 % of the water samples display Cl^{-}/SO_4^{2-} ratios lower than that calculated in the world's average freshwater, and in 7.5% them, the ratios are higher than the seawater value.

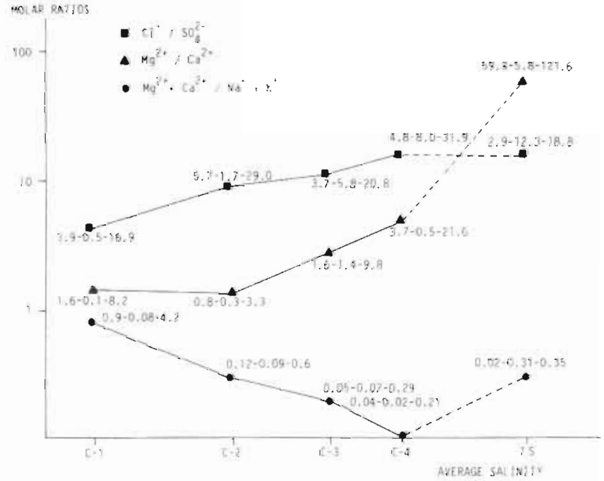

FIG. 3 — Average values of the molar ratios at different salinities. The numbers for each point are, from left to right: the standard deviation of the mean, minimum and maximum of the given molar ratio at a given average salinity. (T. S., Torrevella salt pans).

Nutrients, oxygen and pH

The concentration of nutrients and oxygen fall within a wide range of variability (N.NO$_3^-$ from 0.1 to 1100 μg-at l^{-1}; TRP from 0.01 to 23.56 μg-at l^{-1}; Si from 1 to 502 μg and O_2 from 0 to 14.4 ml l^{-1}).

The most variable nutrient is N.NO$_3^-$ with average values that vary from between 0.2 and 363 μg-at l^{-1} (Table I). The seasonal variation of this compound is also considerable; in some lagoons maximum and minimum values differ more than 1000 μg-at l^{-1} (e.g., locality 45). The highest concentrations are usually reached during the cold seasons (autum and winter) and the lowest ones during the summer.

When considered globally, the observed concentrations of TRP do not differ very much and they are usually between 0.1 and 0.8 μg-at l^{-1} (Table I). However, it is worth nothing the existence of eleven lagoons (13, 22, 26, 34, 36, 49, 51, 53, 54, 55 and 56) where mean TRP values rise to more than 1 μg-at l^{-1}. All of these systems can be considered as highly eutrophic and are characterized by the fact that they receive important inputs of urban sewage. The seasonal variations of TRP are as a rule quite pronounced, the maximum values being reached in summer.

The silicate concentrations usually vary from 11,0 to 200 μg-at l^{-1}. Only a small number of lagoons (21, 22, 23, 24, 25, 26, 27), located in the El Hondo area (once occupied by the Albufera de Elche, Alicante), display unusually high concentrations, occasionally greater than 500 μg-at l^{-1}. The seasonal variations are small, the maximum values being reached during the summer.

Although the lagoons in question are shallow and the samples were taken close to the water surface, some variations are observed in oxygen concentrations. The most frequently found values are between 4 and 9 ml l^{-1}, but lower levels are observed in hypersaline waters, especially during the summer and autumn. Anoxic conditions were found at surface level in two lagoons (5, 7), and values below 1 ml l^{-1} in five other locations (4, 6, 10, 27, 29).

The pH values fall within a relatively limited range. The extreme values are 6.9 and 9.8, although more than 90% of the cases are between 7.5 and 9.0 (Table I).

In spite of the great variability shown by the concentration of nutrients in these systems, the average values of N.NO$_3^-$ and TRP have revealed themselves as useful for comparative purposes. On the basis of these values four different nutrient patterns have been distinguished in the Spanish Mediterranean coastal lagoons.

A) Lagoons with mean TRP values greater than 1 μg-at l^{-1}; they always present very low nitrate concentrations (Fig. 4), high pH values and high levels of oxygen (Table I). As mentioned before, they can be considered as hypereutrophic waters.

B) Lagoons where the mean concentration of N.NO$_3^-$ is greater than 100 μg-at l^{-1}, and the content of this nutrient throughout the year always surpasses 50 μg-at l^{-1}. The mean TRP concentrations are low (Fig. 4), as well as pH values (Table I).

C) Systems with mean N.NO$_3^-$ levels ranging from 10 to 100 μg-at l^{-1}. These waters are also characterized by seasonal fluctuations of the concentration of this nutrient, the values of which vary from less than 10 μg-at l^{-1} in summer to more than 30 μg-at l^{-1} in winter. Mean TRP values never exceed 1 μg-at l^{-1}.

D) Lagoons with low mean N.NO$_3^-$ concentrations ($<$10 μg-at l^{-1}), and moderate mean values of TRP ($<$1 μg-at l^{-1}).

Relationships between nutrients and salinitiy

The chemical heterogeneity of these concerned coastal systems has been summarised in table II, where the two classifications based respectively on salinity and nutrient concentrations are combined. Because the nutrient patterns are based on mean values over the four seasons, the lagoons which due to their fluctuating salinity have been included in C3 or C4 classes depending on the season, are considered in another group, designated as C3/C4.

The distribution of the lagoons in the diverse combinations of salinity and nutrients, as illustrated in table II, is not uniform. Whilst systems with a low concentration of salts (C1, C2) usually display nutrient pattern C, and pattern D exceptionally, high salinity waters (C4, C3/C4) are in the opposite posi-

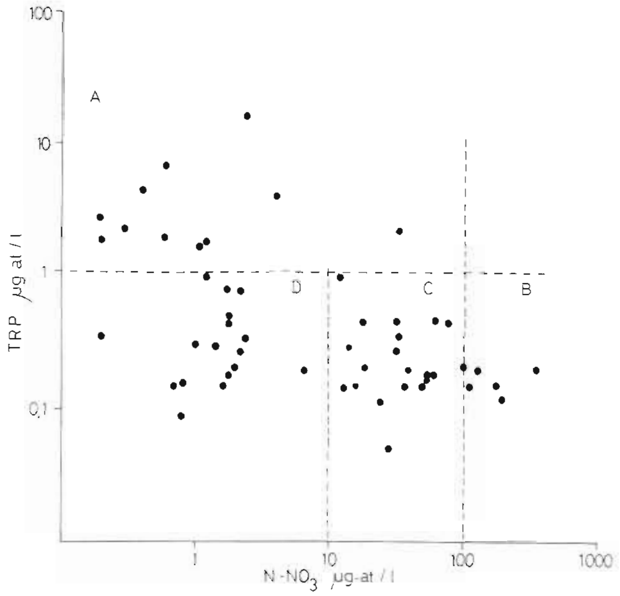

FIG. 4. — Relationship between the mean concentration of N.NO$_3^-$ and TRP. Letters (A, B, C, D) correspond to the different nutrient patterns described in the text.

TABLE II. — Classification of the studied water bodies according to the mineralization (C1 to C3/C4) and nutrient pattern (A to D).

	A	B	C	D
C1	22 34 36 49 56	30 31 40 45	2 35 37 38 39	1
C2	26	44	14 21 23 25 27 41 42 43 50	48
C3	51 53 54 55		46	47 52
C4	13		10	8 12 15 16 17 20 24
C3/C4			3 6 9 19	4 5 7 28 29

tion, model D being the most frequent, whilst model C appears in a few cases (mainly, in classe C3/C4).

Pattern A is observed in systems where the salinity is lower than or equal to that of the sea (C1 to C3), but is rarely found in those with a saline concentration of more than 40 g l^{-1}.

Pattern B appears in waters of very low salinity (C1). The only lagoon belonging to class C2 that presents these nutrient features has a low salinity when compared with the other systems of this group.

Silicate and oxygen values have not been used to discriminate different kinds of waters. However, some relationships with salinity can be established. As a whole, the concentrations of these parameters are high in classes C1 and C2 (around 125 µg-at l^{-1} for Si and 6 ml l^{-1} for O_2), decrease in class C3 (about 50 µg-at l^{-1} and 4.2 ml l^{-1} respectively) and reach minimum levels in class C4 (20 µg-at l^{-1} and 3.0 ml l^{-1}).

Lagoons belonging to C3/C4 may be considered as a special case because they present oxygen concentrations similar to those characteristic of class C4, whereas their silicate content is close to that observed in the less saline waters (around 100 µg-at l^{-1}.

DISCUSSION

The variability of the chemical composition of the water in the Spanish Mediterranean coastal lagoons is similar to that reported for other marine littoral areas in the world (BOWLING & TYLER, 1984; GEDDES & BUTLER, 1984). Although this composition always depends on many factors, in the systems studied it is mainly controlled by the mixing proportions of two different kings of water: 1) the seawater, which is characterised by its high salinity, by the constancy of the principal ionic molar ratios and by its relatively low content of nutrients (CULKIN, 1965; ARMSTRONG, 1965; VACCARO, 1965), and 2) the inland ("fresh-") waters, that in the zone sampled usually have a salinity of about 0.5 g l^{-1}, are frequently dominated by the HCO_3^- (or sometimes the SO_4^{2-}) and Ca^{2+} ions (MARGALEF *et al.*, 1976; DGOH, 1981; ALONSO, 1985), and are often rich in nutrients of urban or agricultural origin (DGOH, 1981; PRAT *et al.*, 1984; SABATER, 1987).

The characteristics of the water mineralization and the concentration of nutrients in those lagoons included in the C1, C2 and C3 classes of salinity, agree with the former considerations: in class C1, both the ionic patterns amb the values of the principal molar ratios are close to those found in many of the Iberian Mediterranean rivers, and their $N.NO_3^-$ content is commonly high or very high (as, for example, in those lagoons that receive waste waters from nearby farms: pattern B); in class C3 all these variables are much more similar to those typical of seawater; while, in class C2 they show some intermediate characteristics. In some places, the phytoplankton activity can strongly modify the concentration of nutrients. This is the cause of the summer depletion of $N.NO_3^-$ in many coastal lagoons (COMÍN & FERRER, 1979; COMÍN, 1984; NIXON, 1982) (i.e., in those that follow pattern C) and the reason for its total exhaustion in those with a high concentration of phosphorus (pattern A). From all that has been mentioned before, one would expect to find such an excess of phosphorus only in lagoons with a great continental influence. Certainly, this is the most usual case, but high values of phosphorus can also be found in fairly salty water bodies, affected by the input of waste waters very rich in that element (i.e., some lagoons in the Empordà: 51, 53, 54 and 55).

The typical hyperhaline systems (C4) are always a consequence of the intense evaporation of more or less salt waters. During this process, not only does the salinity becomes higher and higher, but the chemical composition of the water may also change, due to the precipitation of the less soluble salts (NADLER & MAGARITZ 1980). In the region studied, this kind of water can be considered as belonging to type "c" ($Na^+ - Mg^{2+} - Cl^- - SO_4^{2-}$) of the EUGSTER & HARDIE (1978) major brine's classification, which corresponds to evaporated seawater. Only the brines of the Torrevella salt-works, which have a salinity of about 360 g l^{-1} and where the calcite and gypsum have already precipitated, belong to the $Na^+ - Mg^{2+} - Cl^-$ type. In coastal areas with an arid climate (Israel, Australia; LEVY, 1971; WILLIAMS & BUCKNEY, 1976; BOWLING & TYLER, 1984), the hypersaline lagoons can be subjected to irregular inflows of continental water, which may cause great and unpredictable fluctuations in salinity, in the principal ionic molar ratios and, occasionally, in the concentration of the main nutrients. This is the case of the lagoons included in the class C3/C4, which show an occasionally high N.NO_3^- content, and an excess of sulphate and calcium.

The geographical distribution of classes C4 and C3/C4 agrees with the variation of the climatic factors along the Spanish Mediterranean coast. Because the evaporation rates increase towards the South (Font, 1983) hypersaline lagoons are mainly located in the meridional half of the area studied.

To conclude, it can be stated that the chemical heterogeneity found in the Mediterranean coastal lagoons of the Iberian peninsula is mainly due to the conditions in which the mixing of freshwater and seawater takes place in each site, and also depends on the climate (rainfall, evaporation rates, etc.) as well as human activity (domestic, industrial and agricultural).

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