Seasonal changes of phytoplankton in three coastal lagoons of the Ebro delta in relation to environmental factors

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ABSTRACT

Seasonal changes in phytoplankton cell numbers and species composition were studied in three coastal lagoons of the Ebro delta (Encanyissada, Tancada, Buda) from May, 1978 to May, 1979 in relation to salt concentration, nutrients and other environmental factors.

Chloride concentration was low in Encanyissada (0.5 g Cl⁻/l) and Tancada (0.6-4 g Cl⁻/l) during late spring, summer and autumn due to an artificial influx of freshwater. It increased up to 19 g Cl⁻/l in both lagoons from December to April. In Buda the concentration was kept between 4-11 g Cl⁻/l most of the time because of the inflow from the Ebro river mouth where fresh and sea water mix up.

Nutrient levels were high in late spring in Encanyissada (125 μg-at N-NO₃⁻/l; 1.5 μg-at P-P₂O₅²⁻/l) and decreased gradually towards late summer with a shift in the N/P ratio. Maximum concentrations were observed in winter (27 μg-at N-NO₃⁻/l), and early spring (2.5 μg-at P-P₂O₅²⁻/l). A similar pattern was observed in Tancada and Buda, although the concentrations were lower than those of the Encanyissada.

A typical succession of algae, diatoms-chlorophyceans-blue green algae, occurred during the period from May to December in Encanyissada. Standing stocks varied between 10⁸ and 10⁹ cells/ml. From January to April, Dunaliella sp. developed an almost unspecific population up to 2.10⁹ cells/ml (99 % of the total density). A less number of species and a higher proportion of Chrysophyceae and Cryptophyceae characterized the warm season in Tancada with densities between 10⁵-10⁶ cells/ml. Dunaliella was dominant in December and January while other small flagellates replaced it in dominance from February to April. In Buda, Selenastrum capricornutum and Prymnesium parvum were dominant all the year round, and small dinoflagellates accompanied them, with marked spatial heterogeneity and seasonal differences in phytoplankton abundance that varied between 5.10⁵ and 2.5.10⁶ cells/ml.

Species composition, abundance and seasonal distribution of the phytoplankton along the year depend mainly on salinity changes produced by the balance between fresh and salt water inflows, and also on the nutrient concentration which is related to the freshwater inflows. If the water circulation between the lagoons and the sea is restricted, the lagoons change to a high eutrophic state, with the gross development of the phytoplankton that takes the lead over the phyto-benthos.


RÉSUMÉ

Variations saisonnières du phytoplancton dans trois lagunes côtières du delta de l’Ébre par rapport aux facteurs du milieu.

Dans ce travail, on étudie la variation saisonnière de la biomasse et de la composition spécifique du phytoplancton de trois lagunes côtières du delta de l’Ébre (Encanyissada, Tancada, Buda), de mai 1978 à mai 1979, pour évaluer l’influence des nutriments, de la salinité et d’autres facteurs du milieu.
La concentration en ions chlorures est faible dans les lagunes l’Encanyissada (0,5 g Cl⁻/l) et Tancada (0,6-4 g Cl⁻/l) pendant la fin du printemps, en été et en automne, étant donné qu’il existe un apport d’eau douce artificiellement favorisé. Cette concentration se trouve être fortement augmentée jusqu’à 19 g Cl⁻/l à partir du mois de décembre jusqu’au mois d’avril. Dans la lagune de Buda, la chlorinité est à peu près constante à cause du flux d’eau de mer et d’eau douce mélangées provenant de l’embouchure de l’Èbre.

Les concentrations en nutriments sont élevées au début du printemps dans l’Encanyissada (12 µg-at N·NO₃⁻/l ; 1,5 µg-at P·PO₄²⁻/l), et décroissent graduellement jusqu’à la fin de l’été, avec une inversion des valeurs du rapport N/P. Le même schéma se retrouve dans les lagunes de Tancada et de Buda, où les concentrations sont plus faibles pendant toute l’année.

Entre mai et décembre, on trouve dans l’Encanyissada la succession typique des diatomées-chlorophylles-cyanophylles, le nombre de cellules/ml étant compris entre 10⁹ et 10¹⁰. À partir du mois de janvier et jusqu’au mois d’avril, le phytoplancton est constitué principalement d’une population de Dunaliella sp., qui arrive à atteindre des densités de 2 .10⁹ cellules/ml, ce qui représente 99 % du nombre total de cellules. Un nombre total plus faible d’espèces et une plus forte proportion de Chrysophylles et de Cryptophylles caractérisent la saison chaude dans la Tancada, avec des densités de 10⁸ et 10⁹ cellules/ml. Très rapidement, les populations de Dunaliella sont remplacées par d’autres espèces de petite taille. Dans la lagune de Buda, Selenastrum capricornutum et Prymnesium parvum sont les espèces dominantes. Ces espèces sont accompagnées par des petites dinoflagellées, avec une hétérogénéité spatiale et temporelle telle que le nombre de cellules peut varier entre 5 .10⁵ et 2 .5.10⁹ cellules/ml.

La composition spécifique, l’abondance et la distribution saisonnière du phytoplancton tout au long de l’année sont surtout influencées par les changements de salinité qui se produisent à cause des entrées d’eau douce et d’eau marine. L’effet des nutriments, également en rapport avec les entrées d’eau douce, est lui aussi important. La limitation des processus de mélange avec la mer nous conduit vers une eutrophisation de ces systèmes lagunaire, avec un développement en masse du phytoplancton qui devient beaucoup plus important que le phytothentos.


INTRODUCTION

Coastal lagoons are ecosystems which are characterized all around the world by the mixture of fresh and marine water. Regulation of fluxes can produce drastic changes in the balance of that process and also reduce the fluctuations of the physical and chemical characteristics that are the basis of its high productivity (Margalef, 1969). Phytoplankton population development is subject to this dynamism. Water circulation regime imposes the conditions for the colonization and development of phytoplankton species (Ketchum, 1954).

Figure 1

*The Ebro delta showing the situation of the sampling stations in the Encanyissada, Tancada, and Buda lagoons, and the simplified network of irrigation channels.*
A comparative study of the seasonal cycle of phytoplankton in three coastal lagoons of the Ebro delta — Encanyissada, Buda — related to environmental factors was carried out to show the different aspects produced by the reduction of the interchange of water with the sea by increasing artificial freshwater inflows. This paper is part of a vast limnological study of the Ebro delta lagoons (Comín, 1981).

The Ebro delta (NE Spain) is highly valued as an agricultural and fisheries resource (Demestre et al., 1977). It is also a very important habitat of waterfowl, that occupy the wet ecosystems distributed along the coastal strip (Ferrer, 1977). Rice fields spread over 40 % of its 300 km². A very dense network of irrigation channels is laid out all around the Delta (Fig. 1). As a consequence of the rice cultivation, freshwater flows to the lagoons from May to December. They remain dry or without flow from January to April. The drainage area of each lagoon is determined by the distribution of the channels. It is of 40 km² in the Encanyissada lagoon, 8 in Tancada, and 3 in Buda. All the three are very shallow. Water level fluctuates during the year between 80 and 120 cm in Encanyissada and Buda, except in the eastern part of Encanyissada where fluctuations range between 20 and 60 cm. In the Tancada lagoon it varies between 40 and 60 cm. Encanyissada and Tancada are directly connected to the sea by a canal. In Buda, water mainly flows from the mouth of the river whereby fresh and sea water mix is typical of a positive estuary.

MATERIALS AND METHODS

Eighteen surface samples were taken in two locations of each lagoon (Fig. 1) from May 1978 to May 1979. Analysis of fixed samples were made in the laboratory three days after sampling. They included determinations of: Chloride (volumetric; American Public Health Association, 1975); sulphate (volumetric; Fritz, Yamamura, 1955); total alkalinity (volumetric; Golterman et al., 1978); Ca²⁺ and Mg²⁺ (atomic spectroscopic absorption); dissolved inorganic nitrogen by colorimetric methods (nitrate: Morris, Riley, 1963; nitrite: Strickland, Parsons, 1965; ammonia: Koroleff, 1970); soluble reactive phosphorus (colorimetric; Murphy, Riley, 1963). The methods employed are also described in Margalef et al. (1976).

Counting and identification of phytoplankton was made at 840 X magnification with an inverted microscope, following Utermöhl's technique (Utermöhl, 1958), after the sedimentation of algae contained in 10 ml of samples fixed with lugol. Pigments were extracted with methanol from algae contained between 500 ml and 1 l of water. Their concentration was determined by spectrophotometric analysis following Vollenweider (1969). The primary production was determined by the ¹⁴C method (Steemann Nielsen, 1952; see also Vollenweider, 1969).

RESULTS

Mineral and nutrient characteristics

In Encanyissada and Tancada, the salt concentrations fluctuated the same, following a very clear pattern along the year. From May to December 1978 they remained in relatively low concentrations within the oligohaline range (Fig. 2), and increased continuously from December 1978 to April 1979 until they reached the value of the adjacent sea (19 g Cl⁻/l). The differences between the two lagoons are significant. During the year of 1978, in the Encanyissada lagoon, chloride concentration was almost uniform and less than 1 g Cl⁻/l. In the Tancada lagoon these low values were obtained only from the end of July to the end of November. From May to July, the chloride concentration decreased, but it remained higher than 2 g Cl⁻/l. While in December 1978 it was of 3.5 g Cl⁻/l, the chloride concentration of Encanyissada was still 1.5 g Cl⁻/l. Little spatial differences in each lagoon were observed during the months of rapid change in salinity, within the periods of May-June and December-January.

![Figure 2](https://example.com/figure2.png)

*Figure 2* Seasonal variation in chloride concentrations at both sampling stations in the Encanyissada, Tancada, and Buda lagoons.

![Figure 3](https://example.com/figure3.png)

*Figure 3* Relation between the concentrations of Mg and Ca(mg/l) in Encanyissada, Tancada, and Buda (circles: station 1; triangles: station 2. White: May-December; Black: January-April).
Buda lagoon values were in the mesohaline range almost all year round and spatial heterogeneity was also quite constant as the data from the two sampling stations show (Fig. 2). Near the sea, chloride concentration was less than 5 g Cl⁻/l only once, during the annual cycle, and it never exceed 15 g Cl⁻/l. In the western part of the lagoon, where freshwater inflow arrives, the chloride concentration was comparatively lower. The maximum value was 10 g Cl⁻/l in May 1978, with an 0.7 g Cl⁻/l in June 1978.

The major cations concentrations maintained in the three lagoons the order of the sea water along the year: Na > Mg > Ca > K. But the relative concentrations of them varied as it is set by the equivalent ratio Mg/Ca (Fig. 3). It was higher than 5.3 (the general value of sea water, Margalef, 1974) in the months of March and April of 1979, when the pH was between 8.6 and 9 and the carbonate concentration reached values between 10 and 20% of the total alkalinity — 4 meq/l — (Comin, 1981).

The lowest values of the ratio Mg/Ca were observed during the months of low chloride concentration when the freshwater inflows were higher. During this period, in Buda the pH varied in a narrow range, between 8 and 8.3, while alkalinity stayed around 2 meq/l. In Tancada and Encanyissada both parameters fluctuated in a wider range, with a pH between 7.5 and 8.5, and an alkalinity between 1.5 and 4 meq/l.

The maximum values of nitrogen oxidized forms were observed in winter in the three lagoons (Fig. 4). In Encanyissada: 25 µg-at N-NO₃/l and 3 µg-at N-NO₂/l. In Tancada and Buda the values were similar, 15 and 11 µg-at N-NO₂/l, and 1 and 2 µg-at N-NO₂/l. There were relatively high concentrations in May and June of 1978 with the freshwater inflows. The concentrations were 15 µg-at N-NO₂/l and 5 µg-at N-NO₂/l in Encanyissada, while Tancada was 3 µg-at N-NO₂/l and 2 µg-at N-NO₂/l, and Buda with the lowest, which was less than 1 µg-at/l.

The same differences were observed in Encanyissada and Tancada with respect to ammonia. The maximum concentration reached the value of 50 µg-at N-NH₃/l in both lagoons at the end of July, subsequent to the high values of nitrate and nitrite. Low values, of 1 and 2 µg-at N-NH₃/l were observed in the winter, when the nitrate was at its maximum (Fig. 4); only a few data of ammonia from Buda are available. In general they must be similar to that of Tancada in view of the similarity of the N-NO₃ and N-NO₂ concentrations in both lagoons.

Soluble reactive phosphorus concentrations in the three lagoons showed uniformity in marked seasonal variation (Fig. 5). Maximum values were observed in May 1978 which were 5, 1.5, and 2 µg-at P-PO₄³⁻/l respectively in Encanyissada, Tancada and Buda. The subsequent depletion of this nutrient, during the hot months, was between 0.5 and 1 µg-at/l in Encanyissada, and less than 0.5 µg-at/l in Tancada and Buda, while at the same time it was paralleled by increases of phytoplankton populations. The minimum concentrations corresponded to the month of December 1978 and January 1979, when the exchange of water with the sea was very active and tiny algae populations developed quickly. The nitrogen and phosphorus concentrations differ greatly in Encanyissada from the other two lagoons, although the variations during the annual cycle studied follow the same pattern. This pattern is characterized by a lack or very low values of oxidized compounds of combined dissolved nitrogen (N-NO₃ ; N-NO₂) during the hot months in the three lagoons. However, if ammonia concentration were take into account the balance between N and P would be much higher than 15 (the normal sea water value; Redfield, 1958).
Phytoplankton

Seasonal variation of cell numbers

There were no remarkable differences between the countings from the two sampling stations of Encanyissada and Tancada (Comin, 1981). In Encanyissada the algae density records were not lower than \(10^5\) cells/ml during the annual cycle studied (Fig. 6) but a marked increase occurred in June and July of 1978, whereby the algae density reached \(10^6\) cells/ml. From January to April of 1979 it increased even more and at the end of March and beginning of April it reached \(2 \times 10^6\) cells/ml.

In the Tancada lagoon, the number of cells/ml decreased to \(10^5\) cells/ml during the period of May-July, 1978. Higher densities, around \(10^6\) cells/ml, were counted during summer and autumn. Unlike Encanyissada, the maximum here was counted in January 1979 (\(1.3 \times 10^6\) cells/ml), while from February to April it decreased to \(10^5\) cells/ml.

Total number of cells/ml at station 2 in Encanyissada and Tancada, and Buda (circles : station 1; triangles : station 2).

In Buda, the differences in density between the two sampling stations are evident (Fig. 6). Near the freshwater influence (station 1), the density varied between \(10^5\) to \(10^6\) cells/ml. Those over \(10^5\) cells/ml were counted in June 1978 and April 1979. In the station closest to the sea (station 2), the density varied between \(10^2\) to \(10^3\) cells/ml, while the peaks were observed at the same time as those in station 1. During autumn both stations provided densities around \(10^5\) cells/ml.

In the Table the approximate limits of variation of chlorophyll a concentration and primary production are stated. Their annual fluctuations paralleled those of the cell numbers (Comin, 1981).

Seasonal succession of important taxa

There have been identified 200 species in Encanyissada, 100 in Tancada, and 50 in Buda (lists of algal taxa and cell countings have been compiled and are available from the author).

Table

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<td>April</td>
<td>mg Chl a/m³</td>
<td>17-160</td>
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<td>mg C/m³/h</td>
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Figure 7 and Figure 8 represent the percentages of the total density of the different taxonomical classes of phytoplankton. Figure 9 shows the succession of the main species in the three lagoons during the annual cycle studied.

Encanyissada

In the Encanyissada lagoon the phytoplankton was composed of typical freshwater species from May to December of 1978. Centric diatoms of the genus Cyclorella and Chaetoceros muelleri were dominant in May, June and July (\(3 \times 10^6\) cells/ml; Fig. 9) representing 50% of the total density of planktonic algae (Fig. 7). There was a large decrease during the summer with a much lower peak in November and December (\(3 \times 10^5\) cells/ml).

Chlorophyceae are the algae class represented by a greater number of species during the period of May to December 1978. Flagellated chlorophyceans and Chlorococccaceae succeeded the diatoms in dominance from the end of June to the end of July. Spermatozopsis exultans, Chlamydomonas sp. pl., Chlamydomonasaca were the most abundant volvocales during this period of low salinity. They reached the maximum number of cells/ml in July, \(15 \times 10^3\) cells/ml. The chlorococccaceae with denser populations were Pediatrum broyanum, Oocystis lacustris, Chlorella vulgaris, Scenedesmus quadricauda, S. acuminatus, Chodatella quadriseta, Tetraedron minimum, Dicyoysphaerium pulchellum. All of which reached their maximum at the end of June or in July, when the number of species was also the highest. The
Figure 8: Seasonal distribution of major classes of phytoplankton at station 1 (above) and station 2 (below) in Buda.

- **Cyanophyceae**
- **Chlorophyceae**
- **Euglenophyceae**
- **Chrysophyceae**
- **Bacillariophyceae**
- **Cryptophyceae**
- **Dinophyceae**

The total number of cells of Chlorophyceae during these months was $5.10^5$ cells/ml with its relative abundance of 50% of the total density.

Planktonic blue-green algae were observed from May to December 1978 (Fig. 7). The algae were dominant with *Phormidium tenue* since the end of July until the end of November. The density was counted with units of trichoome of 10 µm long per milliliter. Huge densities of $10^5$ units/ml were recorded in September and November (Fig. 9), which represented between 35 and 80% of the total density of planktonic algae (Fig. 7). Less abundant species were the heterocysted *Anabaena laxa*, *Aphanizomenonides*, *Anabaenopsis turgidum*, *Oscillatoria acuta*, *Spirulina major* and the *Chroococcaceae*. *Merismopedia tenissima*, *Microcystis flos-aquae*, *Chroococcum minor*, *C. minutus*, and *Gomphosphaeria aponina*.

The most important species in Encanyissada from January to May 1979 was *Dunaliella* sp. whose population increased since January and dominated greatly over the other species. They reached a maximum of several millions of cells/ml during the end of March and in April (Fig. 9). This represented 99% of the total number of cells/ml (Fig. 7). Other small flagellates followed the same pattern in their population development as well. The maximum of the *Prasinophyceae*, *Pyramimonas grossi* and *Tetraselmis* sp. were of $3.10^5$ cells/ml in March 1979. *Cryptophyceae* are well represented by *Cryptomonas acuta* and *Hemiselmis rufoescens* during this salty period (Fig. 9), totaling a count of $15.10^5$ cells/ml in March. The presence of the chrysophyces *Pseudopedinella pyriformis* and *Chromulina* sp. was not strictly limited by the increasing salty months of the annual cycle in Encanyissada but were observed during the period of November 1978 to January 1979 (Fig. 9) as well. The maximum density of the former species was $8.10^5$ cells/ml in November 1978, while that of the latter species was $15.10^5$ cells/ml at the end of February 1979.

**Tancada**

Some of the species present in Encanyissada during the low salinity period were also present in Tancada but from August to December, instead. The maximum densities of *Pediastrum tetras*, *Tetraedron minimum*, *Selenastrum capricornutum*, *Scenedesmus quadricauda*, *S. eornis* and *Dictyosphaerium pulchellum* were observed in September 1978 (Fig. 9). At the same time $6.10^5$ cells/ml was the total density of Chlorophyceae, representing 30% of the total algae in the phytoplankton community (Fig. 7). The maximum of *Cyanophyceae* was $10^7$ individuals/ml, constituted by *Microscopicla tenuissima*, *Coelosphaerium kuehneiga*, *Anabaena sphaerica*, Oscillatoria sp., which stood for 50% of the total number of individual/ml in the western part of the lagoon, in September 1978. In the eastern basin they accounted for only $7.10^5$ individual/ml (10%; Fig. 7), while *Prymnesium parvum* developed in August but reached its maximum of $3.10^5$ cells/ml in September 1978 (85% of the total density of planktonic algae).

Low densities of *Chlamydomonas acuta*, *Chlamydomonas* sp., *Spermatozopsis eutantis* with maximum of $3.10^5$ cells/ml in June and July were counted. *Selenastrum capricornutum* and *Scenedesmus quadricauda* lasted the longest over time (Fig. 9). Both these species and *Scenedesmus eornis*, *Scenedesmus sp.*, *Pediastrum tetras*, *Kirchneriella oseae*, *Tetraedron minimum*, *Oocystis lucispira*, *Monoraphidium setiforme*, *Coelastrium microporum* were the most abundant within the *Chlorococcaceae*. They all together represented 50% of the total algae at November's end (Fig. 7) with a maximum of $9.10^5$ cells/ml (Fig. 6). The planktonic diatoms also reached their maximum in November 1978 (Fig. 7 and 9).

From December 1978 to May 1979 the most important species in the Tancada lagoon were some of the same species cited in Encanyissada. *Dunaliella* sp. was restricted in the dominance of the phytoplankton during the months of December 1978 and January 1979, when it reached $5.10^5$ cells/ml (50% of the total number of cells/ml; Fig. 8). During these months its population decreased and was substituted by *Chromulina* sp. and *Tetraselmis* sp. in the beginning of February, while in March and April, the most abundant species was *Hemiselmis rufoescens*. However, the higher densities were observed in January and February ($10^5$ cells/ml – 10% of the total density). At the same time the phytoplankton community was at its maximum (Fig. 6 and 9). *Cryptomonas acuta* had little importance in the samples taken in 1979, but was present during the months of May to August 1978. During this period of decreasing salinity, it was the most abundant species together with *Tetraselmis* sp. and *Hemiselmis rufoescens*. The maximum concentration of *Cryptomonas acuta* was counted in May 1978 ($6.10^5$ cells/ml), which represented 98% of the total number of algae, (Fig. 8 and 9).

**Buda**

During the period of this investigation, *Selenastrum capricornutum* was the most important species observed in Buda. The species dominated almost all year round representing more than 50% of the total density. A peak of $1.610^5$ cells/ml was observed in the eastern part of the lagoon in June 1978, but the maximum peak of $2.5.10^5$ cells/ml was that of April 1979 (Fig. 9). In the eastern part of the lagoon
the highest peaks were observed at the same time as those in the western part but instead with the maximum density of $17 \times 10^6$ cells/ml in June 1978 and $4 \times 10^5$ cells/ml in April 1979. 

The planktonic blue-green algae were quantitatively important during the period of July through October and only in samples collected in the western part of the lagoon (Fig. 8). Merismopedia tenuissima, Spirulina subtilissima, Oscilatioria sp. and Phormidium tenue were the species noted. Phormidium tenue had a higher density than the others which was at a maximum of $10^5$ in October 1978.

The spatial heterogeneity noted was followed by other species as well, belonging to Bacillariophyceae, Chlorophyceae and Cryptophyceae. Yet these species Chaetoceros muelleri, Scenedesmus quadricauda, Chlamydomonas sp., Ankistrodesmus gracilis, Monoraphidium setiforme, Dunaliella sp., Cryptomonas acuta, Hemiselmis rufescens were more abundant, and remain longer in station 1 than in station 2.

**Seasonal changes of minor taxa**

Dinoflagellates were common in the samples taken from the three lagoons during the months of May-December, 1978. The decreasing order of the number of Dinophyceae species and cell amounts in each of the three lagoons is as follows: Encanyissada, Tancada, Buda. The only exception to this
rule is the proliferation of *Amphidinium* sp. (6.10^3 cells/ml) in Buda during December 1978, in the part closest to the sea (Fig. 9). The contribution of dinophyceans to the total density of phytoplankton was scanty. In general it was less than 2% of the total number of cells in Encanyissada and the western part of Buda, with 2-15% in Tancada, and 1-5% in the eastern part of Buda; while the proliferation of *Amphidinium* cited represented 67% of the total density of algae (Fig. 8).

**Gymnodinium simplex**, *G. cl. splendens* and *Gymnodinium* sp. pl. were the only dinoflagellates observed in station 1, located in the western part of Buda. Their density altogether was less than 10^2 cells/ml from January to April 1979 and 3.10^3 cells/ml in June 1978. But no species were observed at all from July to December of 1978. In station 2, located in the eastern part of the lagoon, *Gymnodinium fossarum, Oxyrrhis marina and Amphidinium* sp., together the above mentioned species had a total density of several units of 10^3 cells/ml in December 1978. In Tancada, besides the dinophycean species cited above, *Gymnodinium mirabile, Peridinium trichocentum, Peridinium* sp. pl. together reached a maximum of 3.10^3 cells/ml in February and April of 1979. In Encanyissada, *Gymnodinium fossarum* was the main dinoflagellate, with a maximum density of 4.10^4 cells/ml at the beginning of February 1979. *Polykrikos kofoidi, Dinophysis saccularis, Proceroncium scutellum and Oxytosum scloparces* were observed in both stations, from January to May 1979, with densities as low as 10^2 cells/ml each.

The presence of euglenophycean species was common in the waters of Encanyissada. Twelve different species of the genus Euglena were identified, nine of *Phacus*, four of *Trachelomonas*, five of *Strombomonas*, and *Leptocylindrus ovum*, from May to December of 1978; although together generally represented less than 1% of the total number of cells/ml (Fig. 9). Two peaks of algal abundance were observed (Fig. 9). The first peak in June was due to the abundance of *Euglena multiformis, 15.10^3 cells/ml (15% of the total density of planktonic algae)*, although of low count of several other species was noted as well. In November, the second peak appeared (4.10^3 cells/ml; 3%), but of all of the previously mentioned species.

Twelve euglenophycean species were observed in Tancada which also appeared in Encanyissada, but were absent in the samples collected during the period of May-August. During the remainder of the annual cycle the densities reached between 10 and 3.10^3 cells/ml (Fig. 9), representing less than 1% of the total phytoplanktonic individuals (Fig. 8). From January to April 1979, *Eutreptiella marina* was the densest of all the species observed from the *Euglenophyceae* class.

In Buda, *Euglenophyceae* were only represented by 10 cells/ml of *Euglena* sp. in station 1 in January 1979. The uncoloured cryptomonad *Leucocylindrus marina*, *Eutreptiella marina*, and *Oxyrrhis marina*, were observed in the samples from Encanyissada and Tancada during the months of high salinity, with densities usually between 10 and 10^2 cells/ml but always higher in Encanyissada. *Oxyrrhis marina* was the only species present, of the three, in Buda, but only from September 1978 to January 1979, in the eastern part of the lagoon, and with a very low density of 10 cells/ml. Important populations of benthic diatoms were present in the samples collected throughout the year in Encanyissada. *Nitzschia kuetzingiana, N. apiculata, Navicula cryptopsis, Phaeocystis globosa, Gyrosigma mucron*, were the most frequent and remarkably abundant during the low salinity period, which had a maximum density of 5.10^2 cells/ml (50% of the total density). In Tancada and Buda, these species were much less frequent and had much lower densities.

**DISCUSSION**

It has been proved that the counting of cells numbers alone is not an adequate measure of the phytoplankton standing stock and its relation to the environmental factors (Smayda, 1978). In our case study of the three lagoons, the similarity between the species that compose the algae populations, as well as the differences in phytoplankton densities, has been used to compare the seasonal changes of phytoplankton because the data seems promising. This is also supported by the fact that the differences in cell numbers are similar to the differences in chlorophyll a concentration and primary production as well (Comin, 1981).

Turbulence has been proved to be an important ecological factor in determining the composition and quantitative characteristics of the phytoplankton in tidal brackish waters (Bakker, de Pauw, 1974). The turbulence in the Ebro delta lagoons is less important due to the narrow tidal amplitude of the Mediterranean Sea. The shallowness of the lagoons allows for a wind driving circulation to remove the sediment from the bottom. The suspension of the sediment reduces Secchi disk visibility to 7 cm (Comin, 1981), and therefore influences on the phytoplankton communities. In Encanyissada, for example, the relative abundances of species was altered and the total number of cells/ml decreased during the period of three very windy days in October 1978 (Fig. 6 and 7). The number of species and density of blue-green algae decreased at that time; and the number of benthic diatoms observed in surface samples of water increased, reaching its annual maximum (25.10^3 cells/ml, 50% of the total phytoplanktonic density). In Tancada and Buda this effect does not take place due to the very dense beds of submerged macrophytes (mainly *Ruppia cirrhosa* and *Potamogeton pectinatus*). The very dense populations of phytoplankton in Encanyissada, with their maximum densities during June-July (diatoms and chlorophyceans), and March-April (*Dunaliella* sp.), also had the effect of reducing the transparency of the water to 20 cm Secchi disk visibility depth.

**Encanyissada and Tancada**

Irrigation channels flow into the lagoons during the rice cultivation period (from May to November), which whereby dilutes the water and prevents the natural flow of sea water. This external factor exerts a powerful influence on salinity and clearly divides the annual cycle in two periods. During the first period, from May to December, the water has a low salinity, whereby the second period, from December to May, is characterized by a progressively increasing salinity rate as sea water flows into the lagoons (Fig. 2). The differences in phytoplankton composition between the two periods of the annual cycle in Encanyissada and Tancada are striking (Fig. 5), being due to be the ecological factor that limits the distribution of algae over time, in each of the two lagoons. The changes, during the first period in Encanyissada, of the densities in each of the taxonomical groups, dominating the phytoplankton community, are characteristic of an eutrophic freshwater lake (Nicholls, 1976). The order of the dominant taxa is: diatoms, chlorophyceans, blue-green algae, with a total density between 10^4-10^3 cells/ml, which shows the very eutrophic character of this lagoon. While on the other hand, a similar succession takes place in Tancada, although in a shorter period of time, between July-December, when the densities were between 10^2-10^3 cells/ml (Fig. 6). The higher concentrations of nitrogen and phosphorus in the Encanyissada lagoon explain the higher phytoplankton density than that of Tancada. The ratio N/P of water is usually above the optimum ratio of planktonic cells (16 (Redfield, 1958), which was also during the hotter months of the year. This is due to the high and fluctuating levels of ammonia during the warmer months while nitrate and nitrite concentrations are constantly low. Such conditions favor the proliferations of *Cyanophyceae* including those which the heterocystous forms of the genera *Anabaenopsis* and *Anabaena* capable of fixing atmospheric nitrogen (Fogg, 1966; Shilo, 1975). The presence of a high number of *Euglenophyceae* and their
proliferation of relatively high densities in November, and may through June is linked to the high concentrations of iron and ammonia (Comin, 1981). This is a consequence of the species ability to uptake both elements (Hutchinson, 1967).

The biomass difference between these two lagoons is observed during the second period of the annual cycle. From December to May cell counts varied between 10^6 and 10^7 cells/ml in Encarnissada due to the proliferation of Dunaliella sp.; while in Tancada it is between 10^5 and 10^6 cells/ml, and Dunaliella is being replaced by other small flagellates. The difference reflects a higher concentration of nutrients in Encarnissada than Tancada, originated from the mineralization of organic matter during the end of autumn and winter (Fig. 4, 5 and 6).

**Buda**

In Buda chloride concentration remains in the mesohaline range most of the time (Fig. 2), as a consequence of the hydrological regime which depends mainly on the influences of water from the Ebro river mouth. Many of the species found in Encarnissada and Tancada are present in Buda as well. However, the structure of the species community is completely different in Buda. Here the euryhaline species favor the intermediate salinity range. *Selenastrum capricornutum* is dominant practically all year round, reaching a maximum of 99.9 % of the total phytoplankton (2.5 10^9 cells/ml; Fig. 9). *Prymnesium parvum* is the second most important species in abundance during the annual cycle studied. Preceding the investigation, large populations of this *Haptophyceae* (2.10^9 cells/ml) were observed producing the massive death of fishes (Comin, Ferrer, 1978).

**CONCLUSION**

Nutrients and salinity prove to be the principal ecological factors determining the development of phytoplanktonic populations in the Ebro delta coastal lagoons. Reduction of salinity fluctuations and an increasing eutrophic state, as it is evident comparing present with previous data of the Encarnissada (Comin, Ferrer 1979), seem to be the explanations of the differences in qualitative and quantitative relationships of phytoplankton in the three studied lagoons. Both processes are consequences of the artificial influx of freshwater and the corresponding restricted interchange of lagoon and sea water.

In spite of the fact that there are many other implicated factors, these conditions determine the gross development of the phytoplankton and the extinction of the submerged macrophytes, while in Tancada and Buda the phytoenthos is still conserved in extensive beds.

**REFERENCES**


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