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# Limnological comparison of two peridunar ponds in the Doñana National Park (Spain)

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With 9 figures and 4 tables in the text

## Abstract

The ponds Santa Olalla and Dulce belong to the peridune pond system on the E—W coastline of the Doñana National Park.

The water that fills these ponds originates in the groundwater tables of the dunar system, and these ponds also contain rainwater (run-off and drainage). Despite the fact that they are contiguous ponds,which join up during determined periods, they present differences, both in water chemical characteristics and in their phyto- and zooplanktonic communities.

Santa Olalla shows conductivity values of 3 to 10 mS/cm in the dry period, and of 0.5 to 3 mS/cm in the rainy one. Its water is sodium chloride enriched. The pH values vary between 7 and 11. It is a hypereutrophic pond with chlorophyll-a at higher concentration than 100 mg/m$^3$ in most of the samples. The phytoplankton community is dominated by *Spirulina platensis, Anabaenopsis circularis, Microcystis aeruginosa, Aphanothece clathrata* and *Coelosphaerium kuetzingianum*. The zooplankton is dominated by *Brachionus plicatilis, Keratella quadrata, Daphnia magna* and *Acanthocyclops robustus*.

Dulce presents a lower salinity (conductivity values between 0.8 and 2.5 mS/cm in the dry period and between 0.25 and 1.7 in the rainy one) and althouhg it also has sodic chloride enriched water, the proportion of divalent cations is higher than Santa Olalla. The pH values vary between 6 and 9.5. Macrophyte develop in this pond. The phytoplankton community is dominated by *Chroococcus dispersus, Merismopoedia punctata, Aphanocapsa elachista, Kirchneriella microscopica, Monoraphidium* spp and *Scenedesmus* spp. The zooplankton is dominated by *Acanthocyclops robustus* and *Arctodiaptomus wierzejski*.

## Introduction

The limnology of two peridune ponds, Santa Olalla and Dulce, in Doñana National Park (Biosphere Reserve of the MaB program), is compared in this work.

The great importance of these wetlands has yielded numerous studies. Those dealing with the ponds, as in this case, refer to the origin of their waters

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(García Novo et al., 1975; Vela, 1984; Vela & Llamas, 1986), the vegetation around them and its long-term changes (Allier et al., 1974; García Novo et al., 1983; Granados Corona et al., 1988), the bird populations (Aguilar, 1980) and the geomorphology and edaphogenesis of the sands close to the ponds (Siljeström, 1985).

From a limnological point of view, there have been previous studies on water chemistry (Margalef, 1976; Furest & Toja, 1981, 1984; Montes et al., 1982), phyto- and zooplankton (Bigot & Marazanoff, 1965; Margalef, 1976; Armengol, 1976; Furest & Toja, 1984, 1987), which showed differences between the two ponds in spite of their proximity. Nevertheless these studies, being sporadic and short-termed, have not allowed us to understand how long-term fluctuations affect the limnological features of both ponds.

In this study the eutrophic level, salinity, planktonic populations, fluctuations and the effect of precipitation-evaporation cycles on both ponds, are discussed.

## Material and methods

Samples were taken monthly from October 1985 to November 1987 at three sites, located between the littoral and the center of each pond at a depth of 50 cm (Fig. 1).

Since the differences among the three sites of each pond were found to be not significant, only the data obtained from the surface of each central sampling site is discussed in this article.

Water samples were taken by a peristaltic pump from 11 to 12 am, and the samples were stored in polyethylen bottles. The sediment was sampled by a 4.2 cm diameter corer. Temperature (mercury thermometer), pH (Crison pHmeter), transparence (Secchi disk) and conductivity (YSI, conductivimetre) were measured in situ. Samples for oxygen analysis (Winkler, in APHA 1985) were fixed immediately. The rest of the samples were stored at 4 °C until they were analyzed in the laboratory within 24 hours after sampling, following the recomendations of Golterman & Clymo (1969).

The chemical parameters were analyzed according to APHA (1985) and Strickland & Parsons (1972). Sodium and potassium concentrations were estimated by finding the differences between anions and divalent cations in miliequivalents.

Photosynthetic pigments were extracted with methanol (Margalef, 1983; Marker & Jinks, 1982) at 4 °C in the dark over a period of 24 hours. Chlorophyll-a concentration was calculated using the formula of Talling & Driver (Vollenweider, 1969).

Samples for the phytoplanktonic study were fixed in situ with lugol; species identification and counting were accomplished with an inverted optic microscope (Nikon Diaphot), following Utermöhl's technique (1958).

A qualitative sampling was carried out in order to identify the zooplankton species: samples were taken with a 60 $\mu$m pore conic net with a 12 cm diameter. The quantitative study of zooplankton was realized after filtration of a known volume of water (4 to 10 litres) using a 60 $\mu$m pore net disk. In both cases, samples were preserved in 4 % formol.

Submersed macrophytes were found only in the Dulce pond. After studying the distribution of macrophytes on the pond surface, three quantitative transects were designed (Fig. 8) to estimate the biomass of the species present. The samples were taken by a Van Veen dredge which had a surface cut of 290 cm$^2$. Then they were washed with water to eliminate the epiphytes and detritus. The different species were separated and dried at 80 °C until a constant weight was reached. This was only done during the hydrological cycle of 1986—87.

Sediment samples were taken at the same sites as the water and macrophytes. The samples were extracted by a corer of 4.2 cm (internal diameter) and frozen immediately. Then the following parameters were measured: texture (Bouyoucus, 1962), organic matter (ignition at 550 °C for 4 h), humic substances (Golterman et al., 1984) and total phosphorus (perchloric acid digestion; Andersen, 1976).

## Description of the study zone

Santa Olalla and Dulce belong to the group of peridune ponds of the littoral dune ridge that lies East to West in the Doñana Biological Reserve. They are located approximately 2500 m from the SW Spanish Atlantic seashore (Fig. 1).

They lie between the mobile dunes and the ridges of the stabilized sands, the dominant vegetation species being *Erica scoparia*, *E. ciliaris*, *Calluna vulgaris* and *Ulex minor* (Allier et al., 1974).

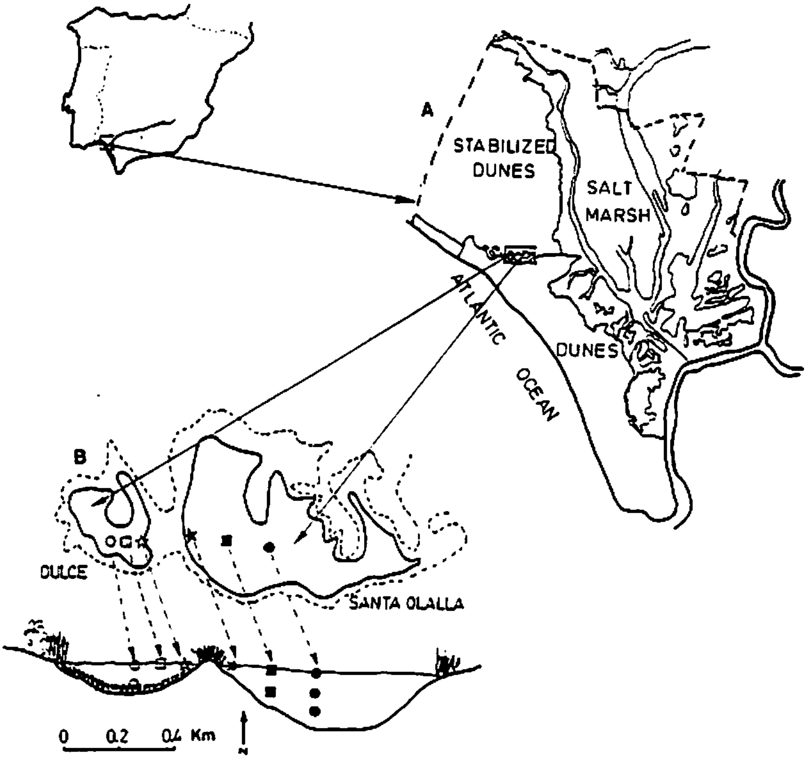


Fig. 1. Study zone. A: Location of the Ponds Santa Olalla and Dulce in Doñana National Park. B: Location of samples sites (The dashed contour-line shows the area when the ponds are linked).

Santa Olalla has an approximate area of 44.8 ha while Dulce has one of 8.2 ha. Their hydrologic regime depends on direct rainfall, run off and water table oscillations

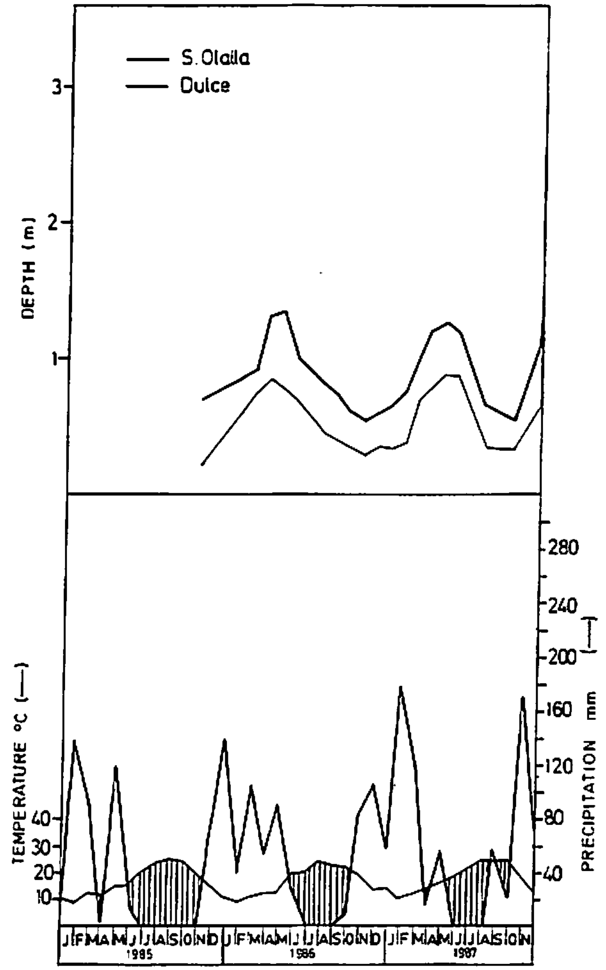


Fig. 2. Climatic diagram and changes in the depth of the ponds.

Table 1. Morphometric parametres of Santa Olalla and Dulce ponds.

| | Santa Olalla | Dulce |
|---|---|---|
| Area | 447 850 m² | 81 400 m² |
| Maximum length | 1 460 m | 430 m |
| Maximum effective length | 1 020 m | 430 m |
| Maximum width | 580 m | 350 m |
| Maximum effective width | 550 m | 280 m |
| Contour line | 6 150 m | 1 900 m |

(Vela & Llamas, 1986). In a soil profile obtained from the shore of Santa Olalla in October 1979, the water table was in a depth of 85 cm (Siljeström, 1985).

Fig. 2 shows an ombrothermic diagram of the period studied, clearly demonstrating marked seasonal and annual differences.

The water depth of the two ponds varies. During the study period Santa Ollala's maximum level was 190 cm (April, 1986) and the minimum 20 cm (October 1986 and September, 1987) while those of Dulce were 85 cm at its maximum (March, 1986) and of 20 cm (October, 1985) (Fig. 2) at its minimum.

As can be seen from Fig. 2 the volume increase of the ponds occurred just after maximum rainfall peaks. This delay is due to the inert period needed to reestablish water levels and for the runoff to accumulate.

Oscillations of the water depth are greater in Santa Olalla (145 cm) than in Dulce (65 cm), in spite of its smaller surface. During the high rainfall season the ponds can be linked (Fig. 1, dotted line), and at times even connect with the salt marsh. This phenomenon did not happen during the period studied, but there is a previous reference for 1976 (Garcia Novo, personal communication) and another for January 1988, when rainfall surpassed 400 mm (authors' observation).

The morphometric parameters in both ponds (Table 1), were measured at the maximum water level reached during the study period, and these parameters show that the ponds are shallow with a gentle slope.

The basin of the ponds are formed by sands stabilized in the Holocen period (Vanney & Menanteau, 1985; Granados Corona et al., 1988).

In the more shallow zones sandy bottom sediments can be observed, changing to sandy-silty in areas of high accumulation at the pond's center. The granulometry data is given in Table 2, showing only the mean values of the first 6 centimeters for each pond.

Analysis of the superficial layer reveals a black organic sediment with an organic matter value higher than 40 % in both ponds, and total phosphorus values of 1740.9 μg/g in Santa Olalla and 1492 μg/g in Dulce.

## Results

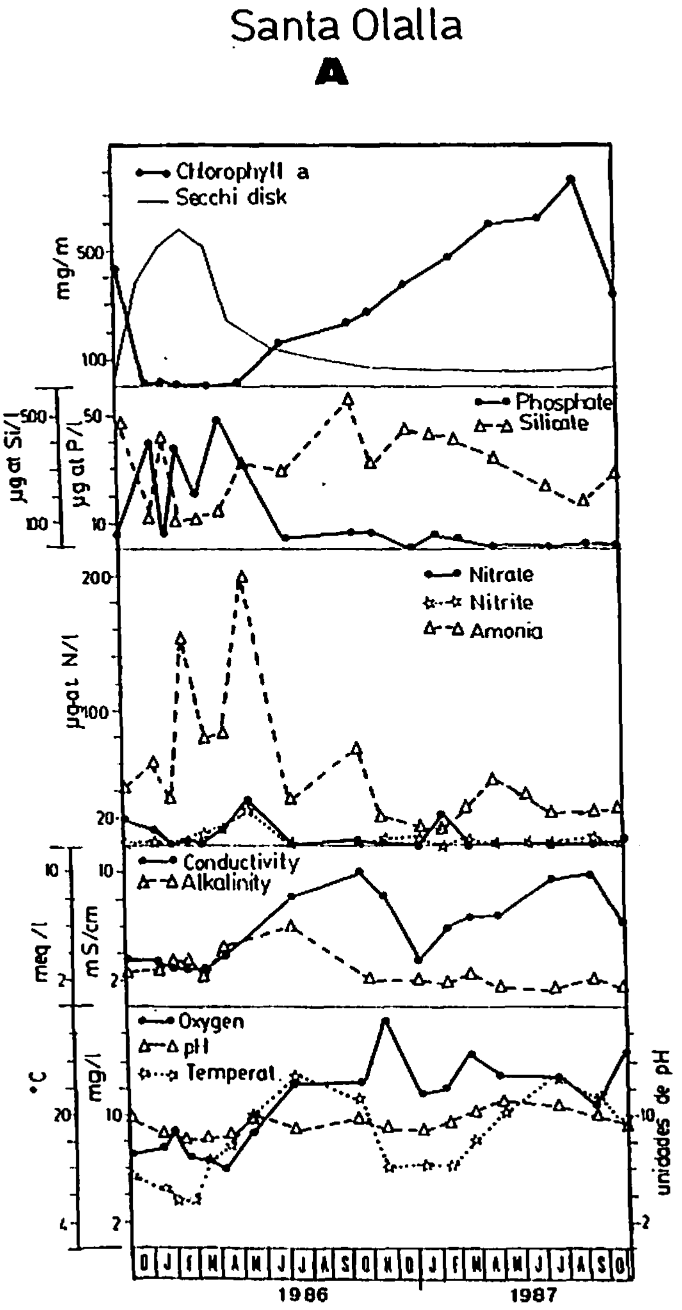
### Physical and chemical

Results of the physico-chemical and biological analyses for the period studied are shown in Fig. 3.

The surface temperature of both ponds reached extreme values, Dulce showed greater oscillations. Minimum temperatures were reached in January 1986: 7 °C in Santa Olalla and 6 °C in Dulce. During the second winter, minimum temperatures were higher; 11 °C in both ponds. Maximum temperature of 25 °C (Santa Olalla) and 27 °C (Dulce) were measured in July.

Temperature was measured at different depths. Since the variations registered did not exceed 1 °C, it is concluded that thermic stratification does not occur, probably due to a combination of wind conditions and shallow water.

Transparency values in Santa Olalla oscillated between 58 cm in February 1986 and 7 cm in July 1987 (Fig. 3). Dulce usually had a higher transparency, with minimum values of 10 cm at the end of summer (September 1987) and 60 cm in February 1986. Transparency variations in both ponds are closely linked to photosynthetic pigment concentrations.


Santa Olalla
A
Chlorophyll a
Secchi disk
mg/m
500
100
Phosphate
Silicate
μg at Si/l
μg at P/l
500
50
100
10
Nitrate
Nitrite
Amonia
μg at N/l
200
100
20
Conductivity
Alkalinity
meq/l
mS/cm
10
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O J F M A M J J A S O N D J F M A M J J A S O
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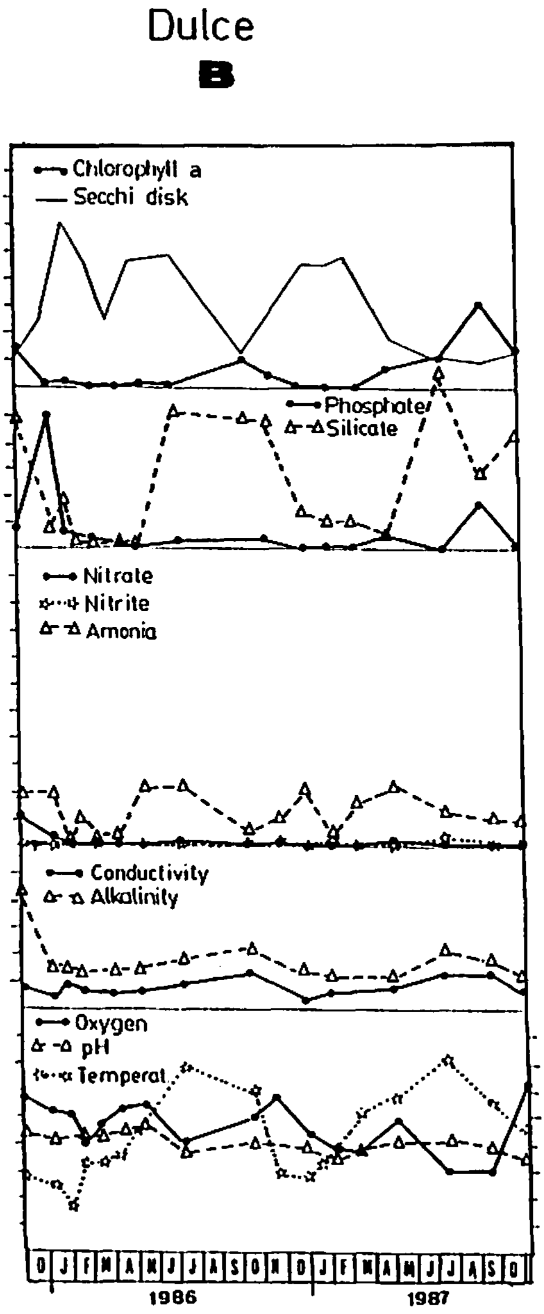


Fig. 3. Variation during the study period in physical, chemical and biological parameters in ponds Santa Olalla (A) and Dulce (B).

The pH values range from 8 to 11 in Santa Olalla and from 7 to 9 in Dulce. These values are almost always high, the difference in both ponds being related to photosynthetic production, which is higher in Santa Olalla (higher chlorophyll-a values, Fig. 3). The proportion of alkaline ions, unlike land-alkaline ions, is also higher in Santa Olalla.

Water ionic content is related to the rainfall cycles. When the water level rises after rainfall peaks, alkalinity, conductivity and pH values drop. Even though the ponds are connected to each other during certain periods of time, Santa Olalla always showed higher ionic concentration values. The differences between the rainy and dry period were more marked in Santa Olalla than in Dulce (Fig. 3).

Both ponds have sodium chloride enriched waters as a result of their proximity to the sea and the succession of rainfall-evaporation cycles.

High alkalinity can be related to their contact with the lagoons and the tidal creek of the marsh zones where values of 25 meq/l (Montes et al., 1982) can be reached.

In many endorrheic zones, soil lixiviation and ionic concentration resulting from high evaporation rates contributes to the enrichment of the waters with sodium bicarbonate. In these cases the ratio of calcium carbonate deposits and chloride/sulfate increases (Margalef, 1983). Therefore these waters are more fertile than expected at such high pH values, which contributes to maintaining silicates in solution.

When the water level rises in Dulce, the pH and alkalinity values drop, and diatoms proliferate. Diatoms are not important in the number of cells per milliliter (Fig. 4 b), but they are important in terms of biomass. These factors caused a decrease in soluble silica concentration. These interrelations are not shown in Santa Olalla. Silica variations seemed to be more related to fluctuations in the ionic composition of the environment since cyanophytes clearly dominated and diatoms were poorly represented.

Whereas in Dulce the temperature and oxygen follow an almost inverse relationship, in Santa Olalla this is not clearly noticed, due to supersaturation during periods of high temperature and productivity, and taking into account that the measurements were made between 11 and12 a.m.

Table 2. Surface sediments features of Santa Olalla and Dulce ponds.

| | Santa Olalla | Dulce |
|---|---|---|
| Sand | 73.85 % | 72.13 % |
| Silt | 21.83 % | 21.31 % |
| Clay | 4.42 % | 6.54 % |
| Organic matter | 0.42 g/gdw | 0.40 g/gdw |
| Total phosphorus | 1.74 mg/gdw | 1.49 mg/gdw |
| Humic compounds | 0.053 g/gdw | 0.099 g/gdw |

Both ponds, especially Santa Olalla, support a large bird population along with other animals during the summer. This load is of great importance in extremely dry years when only few aquatic ecosystems remain in the Park. Together with autochthonous production, this explains the large amount of organic matter and phosphorus in the sediment.

This phosphorus (Table 2) can be released into the water under sediment anoxic conditions (Wetzel, 1981). This would explain the peaks of soluble phosphorus in the winter of 1986 in Santa Olalla. During this period oxygen and chlorophyll showed low concentration values and an extraordinary development of large-sized cladocera (*Daphnia magna*) took place. Clarification of the water, caused by Crustacea, permitted the development of a benthonic bed of filamentous algae (*Cladophora* sp., *Oedogonium* sp. and *Spirogyra varians*) which rapidly consumed almost all the nutrients in the water. The disappearance of this bed in May coincided with the development of the ciliate population (Perez-Cabrera & Toja, 1989).

In Dulce, variations of soluble phosphorus can be influenced by the submersed macrophyte population and its epiphytes. During the study period of this population (December 1986 to May 1987), an increase in water phosphorus content was observed just after they had died, thus producing a simultaneous increase in phytoplankton activity. Phosphorus resolubilization of submersed macrophytes is important in this pond.

Water volume increase did not necessarily imply a decrease in nutrient concentration in this period as happened with the other parameters analyzed (Fig. 3). Especially during the first winter of the study, phosphorus and ammonium concentrations increased in Santa Olalla due to the prevalence of the nitrification process. This agreed with Margalef (1983) since ammonium, as the first product of decomposition of organic matter and therefore dominant in the sediment surface, particularly under anoxic conditions, does not usually oxidize in the sediment. Generally ammonium flows towards the water where it can be the predominant nitrogen compound even though oxygen is present.

During the second winter, since oxygen levels were higher and an important phytoplanktonic population developed, this ammonium increase could not be observed and the same nitrate level remained.

Nutrient dilution caused by an increase in water volume, is more marked in Dulce (Fig. 3).

## Phytoplankton

In Santa Olalla maximum chlorophyll-a values were observed at the end of summer 1987, reaching values of more than 900 mg/m$^3$, higher than that which Margalef (1983) considered a useful chlorophyll-a concentration (400 mg/m$^3$; Margalef, 1983).

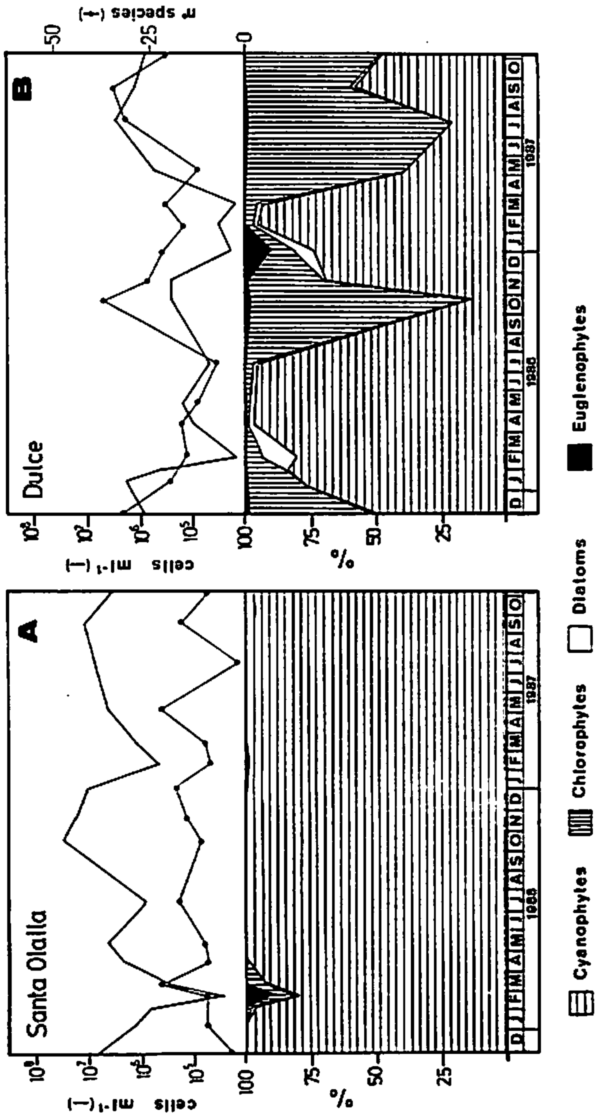


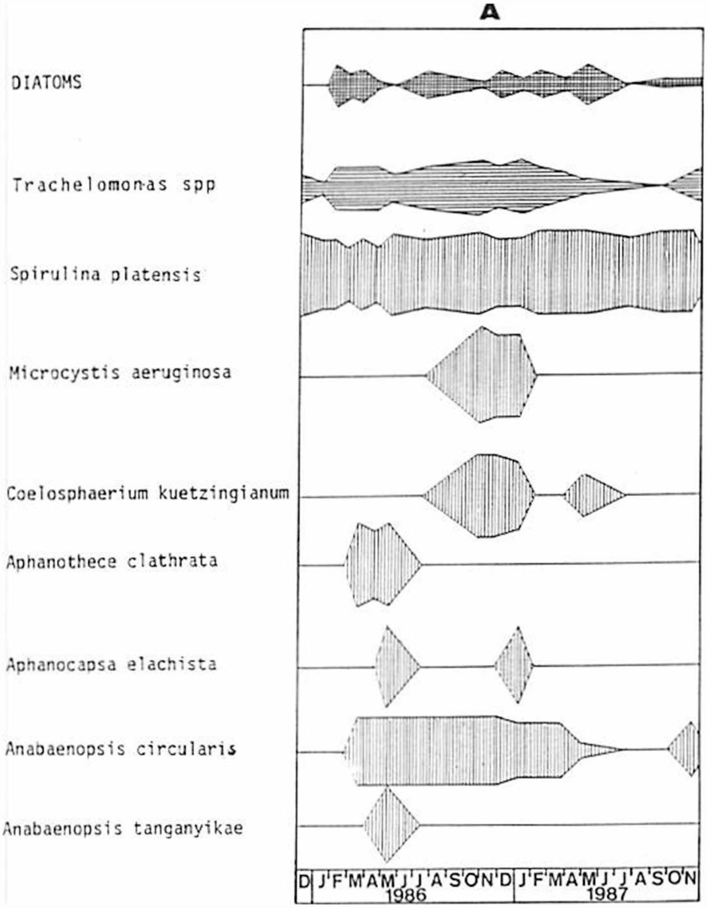
Fig. 4. Phytoplanktonic composition during the study period in the ponds Santa Olalla (A) and Dulce (B).

A vertical stratification is not produced due to the shallowness of the ponds especially when the number of phytoplankton is high (Fig. 4), the turbulence caused by wind, and the stirring produced by aquatic birds.

The higher eutrophic degree of Santa Olalla can be seen not only in the density of phytoplankton but also in the fact that cyanophytes are present in greater proportions than the rest of the algal groups. *Spirulina platensis* and

*Anabaenopsis circularis* were the dominant species throughout almost the whole period of study (Fig. 5 a). MALACK (1979 in MARGALEF, 1983) quotes *Spirulina platensis* as the dominant species in sodium bicarbonate enriched lakes in Kenya where he finds chlorophyll-a values of 300 to 1000 mg/m$^3$, similar to those obtained in this pond (Fig. 4 a).

In Santa Olalla cyanophytes can represent 99 % of the total phytoplankton biomass, with *Spirulina platensis, Anabaenopsis circularis, Microcystis aeruginosa, Aphanothece clathrata* and *Coelosphaerium kuetzingianum* being the most important species. Only during the winter of 1986 did those chlorophytes which are typical of eutrophic water species (HUTCHINSON, 1967; REYNOLDS, 1984) acquire some relevance. Euglenophytes also developed, especially represented by *Trachelomonas*. These are important in biomass terms though not in terms of number. This kind of community is frequent in waters with high iron and organic matter content.



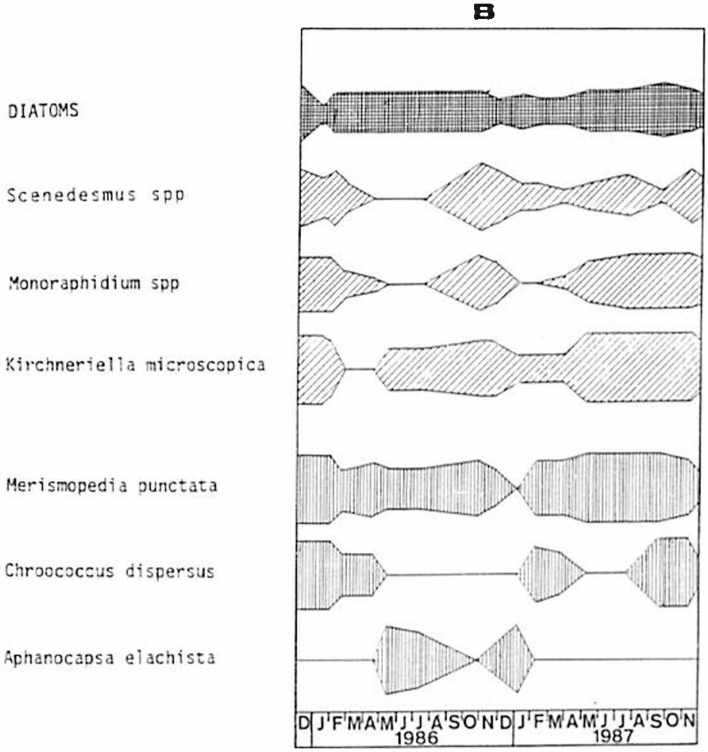


Fig. 5. The seasonal succession in relative abundance of dominant phytoplankton species in the ponds Santa Olalla (A) and Dulce (B).

Phytoplankton is more varied in Dulce and never reaches the density values of Santa Olalla, not even when the decay of macrophytes facilitates its development.

Although cyanophytes as well as *Chroococcus dispersus, Merismopedia punctata* and *Aphanocapsa elachista*, may prevail at certain times (Fig. 4 b), they alternate with chlorophytes (*Kirchneriella microscopica, Monoraphidium* spp. and *Scenedesmus* spp.) and euglenophytes, mainly the genus *Trachelomonas*. The proportion of diatoms was high during both winters of the period studied, although it is rather more important in terms of biomass. The development of diatoms paralleled the soluble silica decrease in the water. Identified dominant species are shown in Fig. 5 b.

Species found in both ponds (Table 3) were small-sized, an indication of the high degree of eutrophy (HUTCHINSON, 1967; and MARGALEF, 1983). Phytoplankton density values were similar to those obtained in La Albufera of Valencia (MIRACLE et al., 1984) and in ponds in the Ebro Delta (COMIN, 1984). Mean chlorophyll content per cell was equal to or lower than 1pg/cell (Fig. 6).

Table 3. List of species of phytoplankton collected in the ponds Santa Olalla and Dulce.

| Santa Olalla | Dulce |
|---|---|
| **Cyanophyta** | **Cyanophyta** |
| *Anabaena aphanizomenoides* | *Anabaenopsis circularis* |
| *Anabaenopsis tanganyikae* | *Aphanocapsa elachista* |
| *Anabaenopsis circularis* | *Chroococcus disperus* |
| *Aphanocapsa elachista* | *Coelosphaerium kuetzingianum* |
| *Aphanotece clathrata* | *Gomphosphaeria aponina* |
| *Chroococcus disperus* | *Lyngbya limnetica* |
| *Coelosphaerium kuetzingianum* | *Merimopoedia punctata* |
| *Gomphosphaeria aponina* | *Spirulina platensis* |
| *Merismopedia punctata* | **Pyrrhophyta** |
| *Microcystis aeruginosa* | *Glenodinium dybowskii* |
| *Oscillatoria tenuis* | **Chryptophyta** |
| *Oscillatoria okenis* | *Cryptomonas erosa* |
| *Spirulina platensis* | *Cryptomonas ovata* |
| **Pyrrhophyta** | *Rhodomonas minuta* |
| *Glenodinium dybowskii* | **Chrysophyta** |
| **Chrysophyta** | *Amphora* cf. *veneta* |
| *Tribonema elegans* | *Amphora commutata* |
| *Amphiprora alata* | *Amphora ovalis* |
| *Amphora commutata* | *Anomoeoneis sphaerophora* |
| *Anomoeoneis sphaerophora* | *Caloneis silicula* |
| *Caloneis silicula* | *Cocconeis* sp1 |
| *Campylodiscus clypeus* | *Cocconeis* sp2 |
| *Campylodiscus noricus* | *Cocconeis* sp3 |
| *Cyclotella kützingiana* | *Cyclotella meneghiniana* |
| *Cyclotella meneghiniana* | *Cyclotella ocellata* |
| *Cyclotella ocellata* | *Cyclotella* sp1 |
| *Cymbella affinis* | *Cyclotella* sp2 |
| *Cymbella ventricosa* | *Cyclotella* sp3 |
| *Fragilaria capucina* | *Cymbella affinis* |
| *Fragilaria construens* | *Cymbella ventricosa* |
| *Fragilaria intermedia* | *Epithemia zebra* |
| *Gomphonema* sp. | *Eunotia* sp. |
| *Gyrosigma acuminatum* | *Fragilaria capucina* |
| *Mastogloia* cf. *smithii* | *Fragilaria construens* |
| *Navicula cryptocephala* | *Fragilaria intermedia* |
| *Navicula* sp3 | *Mastogloia* cf. *smithii* |
| *Nitzschia sigma* | *Navicula cryptocephala* |
| *Nitzschia* sp1 | *Navicula* sp1 |
| *Nitzschia* sp2 | *Navicula* sp2 |
| *Pinnularia* sp. | *Nitzschia* sp1 |
| *Stauroneis* cf. *acuta* | *Nitzschia* sp2 |
| *Surirella ovata* | *Stauroneis* cf. *acuta* |
| *Surirella* sp1 | *Surirella ovata* |
| *Surirella* sp2 | *Synedra ulna* |
| *Synedra ulna* | *Thalassiosira fluviatilis* |

Table 3. (Continued).

| Santa Olalla | Dulce |
|---|---|
| **Chlorophyta** | **Chlorophyta** |
| *Chlamydocapsa planctonica* | *Actinastrum hantzschii* |
| *Coelastrum microporum* | *Chlamydocapsa planctonica* |
| *Cosmarium* cf. *vexatum* | *Chlorella vulgaris* |
| *Cosmarium* sp. | *Chlorella* sp. |
| *Hyaloraphidium rectum* | *Coelastrum microporum* |
| *Kirchneriella microscopica* | *Cosmarium laeve* |
| *Monoraphidium arcuatum* | *Crucigenia rectangularis* |
| *Monoraphidium contortum* | *Crucigenia tetrapedia* |
| *Monoraphidium griffithii* | *Dictiosphaerium pulchellum* |
| *Oocystis parva* | *Diplochloris lunata* |
| *Oocystis* sp. | *Kirchneriella microscopica* |
| *Ourococcus bicaudatus* | *Lagerheimia genevensis* |
| *Pediastrum boryanum* | *Monoraphidium arcuatum* |
| *Pediastrum duplex* | *Monoraphidium contortum* |
| *Scenedesmus ecornis* | *Monoraphidium griffithii* |
| *Scenedesmus intermedius* | *Monoraphidium tortile* |
| *Scenedesmus opoliensis* | *Oocystis parva* |
| *Scenedesmus quadricauda* | *Ourococcus bicaudatus* |
| *Scenedesmus ovalternus* | *Pediastrum boryanum* |
| *Selenastrum capricornutum* | *Pediastrum tetras* |
| *Spirogyra varians* | *Scenedesmus acuminatus* |
| *Tetraedron minimum* | *Scenedesmus acutus* |
| *Tetraedron triangulare* | *Scenedesmus ecornis* |
| *Tetraedron trigonum* | *Scenedesmus intermedius* |
|  | *Scenedesmus opoliensis* |
| **Euglenophyta** | *Scenedesmus ovalternus* |
| *Euglena acus* | *Scenedesmus quadricauda* |
| *Euglena clara* | *Scenedesmus quad. maximus* |
| *Phacus brevicaudatus* | *Scenedesmus spinosus* |
| *Trachelomonas oblonga* | *Selenastrum capricornutum* |
| *Trachelomonas varians* | *Sphaerocystis schroeteri* |
| *Trachelomonas volvocina* | *Staurodesmus dickie circularis* |
|  | *Tetraedron caudatum* |
|  | *Tetraedron minimum* |
|  | *Tetraedron regulare* |
|  | *Tetraedron triangulare* |
|  | *Tetraedron trigonum* |
|  | *Tetrastrum heteracanthum* |
|  | *Treubaria setigera* |
|  | *Treubaria triappendiculata* |
|  |  |
|  | **Euglenophyta** |
|  | *Euglena oxyuris* |
|  | *Phacus brevicaudatus* |
|  | *Phacus caudatus* |
|  | *Phacus curvicauda* |
|  | *Phacus orbicularis* |
|  | *Phacus raciborskii* |
|  | *Trachelomonas oblonga* |
|  | *Trachelomonas varians* |
|  | *Trachelomonas volvocina* |

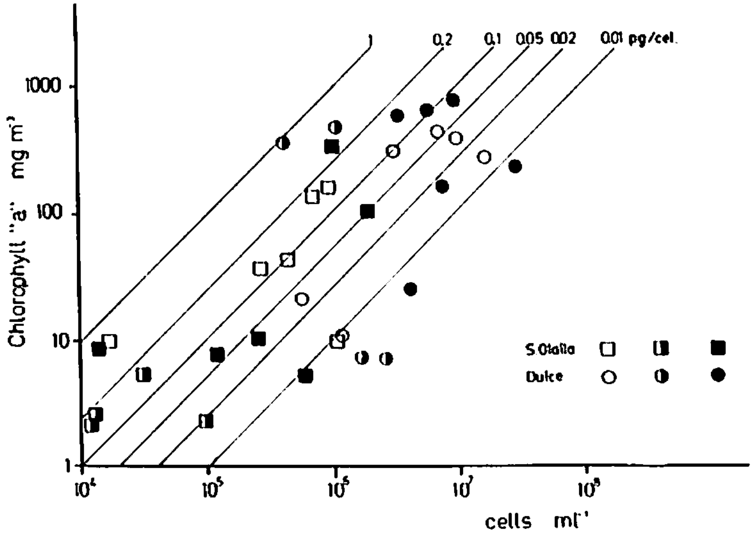


Fig. 6. Relationship between number of cell/ml and Chlorophyll-"a" in Santa Olalla (Dulce): overflow ○ (□), stability ◑ (◧) and evaporation ● (■) periods.

## Zooplankton

Differences between the two ponds are also observed in the zooplankton community (Table 4).

As happens with phytoplankton, Santa Olalla exhibits a higher zooplankton density and a lower number of species. In most of the samples it was usual that only one species prevailed with more than 90% abundance. Species substitution took place according to conditions at determined times (Fig. 7). Rotifers and cladocera (*Brachionus plicatilis*, *Brachionus angularis*, *Keratella quadrata* and *Daphnia magna*) were dominant from October 1985 to May 1986, coinciding with the highest nutrient concentration. During the rest of the period they were substituted by *Acanthocyclops robustus*.

In Dulce the nutrient level remained lower than in Santa Olalla most of the time and copepods prevailed (*Acanthocyclops robustus* and *Arctodiaptomus wierzejskii*, Fig. 7 b). This community is similar to the one that is present in the less saline part of the Guadalquivir estuary (Guisande et al., 1986), where eutrophic and saline conditions are similar.

Population density is high in both ponds, especially in Santa Olalla. Similar data has been obtained in ecosystems with similar characteristics (Oltra & Miracle, 1984; Reynolds, 1984). Nevertheless, even though the absolute values are high, the ratio between zooplankton and phytoplankton density is generally rather low, having less than 2 individues per million cells, except at

Table 4. List of species of zooplankton collected in the ponds Santa Olalla and Dulce.

| Santa Olalla | Dulce |
|---|---|
| **Rotifera** | **Rotifera** |
| *Brachionus angularis* | *Asplachna brightwelli* |
| *Brachionus calyciflorus* | *Brachionus angularis* |
| *Brachionus plicatilis* | *Brachionus budapestinensis* |
| *Keratella quadrata* | *Brachionus calyciflorus* |
| **Cladocera** | *Brachionus plicatilis* |
| *Daphnia magna* | *Brachionus urceolaris* |
| *Diaphanosoma brachyurum* | *Filinia terminalis* |
|  | *Hexarthra quadrata* |
| **Copepoda** | *Keratella quadrata* |
| *Arctodiaptomus wierzejskii* | *Lecane luna* |
| *Acanthocyclops robustus* | *Testudinella patina* |
|  | **Cladocera** |
|  | *Daphnia longispina* |
|  | *Daphnia magna* |
|  | *Leydigia acanthocercoides* |
|  | *Moina brachiata* |
|  | *Simocephalus vetulus* |
|  | **Copepoda** |
|  | *Arctodiaptomus wierzejskii* |
|  | *Acanthocyclops robustus* |

the beginning of spring 1986. A large development of *Daphnia magna* occurred in this period, associated with a great increase of water transparency and minimum chlorophyll values. This kind of event has already been observed by CULVER (1988) in some Australian ponds. Previous studies by FUREST & TOJA (1984) showed similar results.

The same zooplankton/phytoplankton ratios were found in La Albufera of Valencia (OLTRA & MIRACLE, 1984), a normal condition in hypereutrophic ecosystems that favor colonial cyanophytes.

## Macrophytes

With the exception of some filamentous algae that grow sporadically on the sediment (*Cladophora* sp., *Oedogonium* sp. and *Spirogyra varians*) no submersed macrophytes grow in Santa Olalla. Only Dulce exhibits a developed submersed macrophyte community.

In December 1986 the first seedlings were detected, belonging to *Zannichellia obtusifolia*, *Potamogeton pectinatus* and *Chara* sp. The first noticeable biomass values (446.8 $g/m^2$ of dry weight) were not reached until February 1987, *Zannichellia obtusifolia* and *Ranunculus peltatus* were the dominant species.

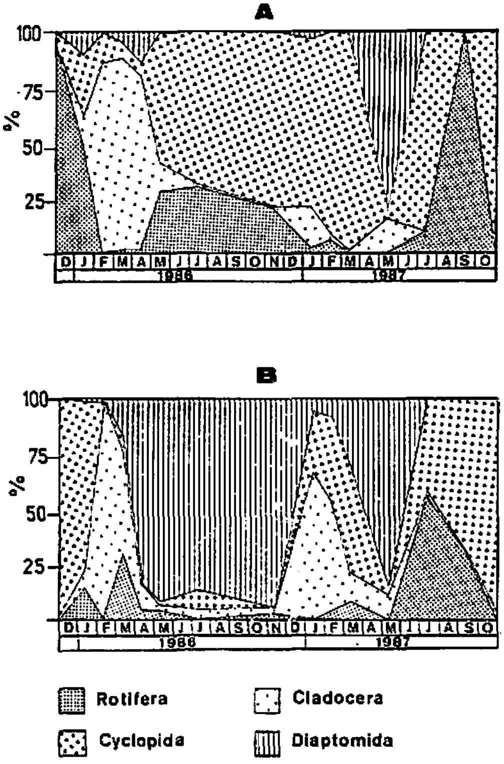
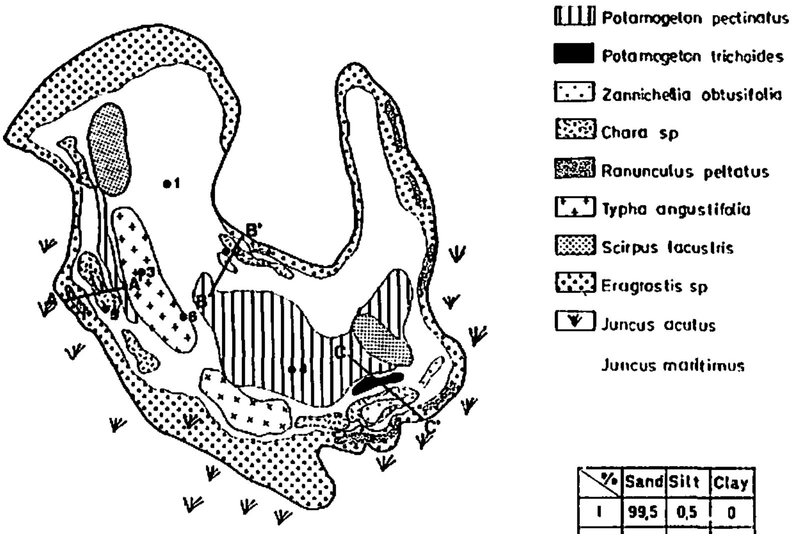


Fig. 7. Zooplankton composition during the study periods in ponds Santa Olalla (A) and Dulce (B).

The highest biomass values were reached in May, i.e. 192 g/m$^2$ dw. *Chara* sp. and *Potamogeton pectinatus* were the most abundant species. *Potamogeton trichoides* biomass increased while that of *Zannichellia obtusifolia* decreased. *Cladophora* sec. cornuta as epiphytic algae were found growing on *Potamogeton pectinatus*, whose population was decaying. Thus the epiphytic algae increased its biomass by taking advantage of the nutrient release from the *Potamogeton pectinatus*.

Biomass value dropped greatly in July (3.18 g/m$^2$ dw) and no macrophytes were found in September.

Macrophyte distribution in the pond (Fig. 8) followed a patch pattern, apparently in correspondence to sediment features such as texture and organic matter content, for they did not grow in zones with coarser sediment and low organic matter content. The organic matter content of the sediment where macrophytes grow can reach 40 %, contrasting with Barko's observations (1982, 1983). Barko found growth inhibited in submersed macrophytes with an organic matter content higher than 10 %.



| % | Sand | Silt | Clay |
|---|---|---|---|
| 1 | 99,5 | 0,5 | 0 |
| 2 | 97 | 1 | 2 |
| 3 | 55,2 | 24,5 | 20,3 |
| 4 | 89 | 8,5 | 2,5 |
| 5 | 90 | 6 | 4 |
| 6 | 72,1 | 21,3 | 6,5 |

Fig. 8. Distribution of macrophytes, sediments texture and sampling transects in pond Dulce.

The contribution of organic matter by submersed macrophytes is considered important: 1960 kg/ha dw as the mean value. All the biomass produced is decomposed in situ. However, an important fraction of this organic matter is composed of humic substances (Table 2) with an allochthonous origin (Wetzel, 1981). Therefore, the contribution to organic matter content in the sediment by macrophytes though important, does not explain the total amount measured. Organic matter and humic substance values found in Santa Olalla were also high, in spite of the absence of macrophytes.

## Discussion

Santa Olalla and Dulce showed differences in their water chemistry, phyto- and zooplankton communities as well as macrophyte development.

These differences existed despite the same origin of the water table under the advancing dune fronts (Garcia Novo et al., 1975). What is more, Dulce, as it is 50 cm higher than Santa Olalla, sends an underground flow toward the latter (Vela, 1984).

Differences persisted even after periods when the superficial water of the ponds were linked together.

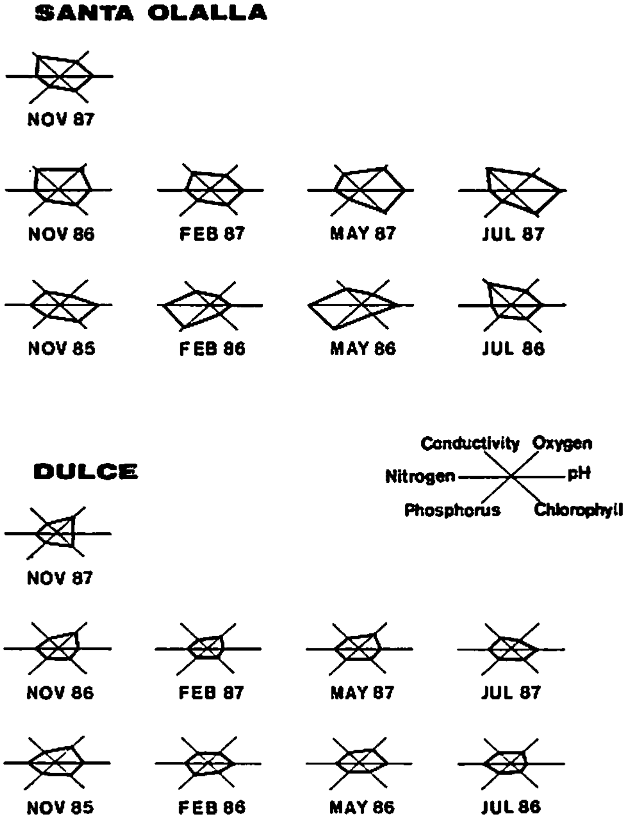


Fig. 9. Differences between both ponds according to standardized matrix from some parameters that indicate water salinity (conductivity, alkalinity and pH) and eutrophic status (nitrogen, soluble reactive phosphorus and chlorophyll-"a").

Differences between the ponds are shown in Fig. 9, considering water salinity and eutrophic degree as parameter indicators. Year to year and annual variations are also shown, along with typical situations of different rainfall and evaporation.

During the autumn months (particularly November) the parameters exhibited a similar behaviour, although the values are always higher for Santa Olalla. However, this behavior differs from one pond to the other during the rest of the year.

Previous physical and chemical data (Montes et al., 1982; Furest & Toja, 1981, 1984) indicated a progressive increase in calcium and pH values. Changes in phytoplanktonic communities can also be observed: the dominant species are different from those quoted by other researchers (Margalef, 1976); and *Spirulina platensis*, a species typical of alkaline waters (Margalef, 1983), not mentioned before, now appears among the phytoplankton.

Zooplankton communities also differed from those quoted by previous studies (Bigot & Marazanof, 1965; Armengol, 1976; Furest & Toja, 1981, 1987). There is a clearly tendency toward a reduction in the number of species found in this waters.

Higher salinity, high pH and eutrophic levels clearly identify Santa Olalla water. High nutrient concentration allowed a massive development of phytoplankton, which contributed to a pH increase of even up to 11 units.

The high pH and light limitation caused by phytoplankton, together with organic matter content and anoxic conditions in the sediments, prevented the development of submersed macrophytes in Santa Olalla.

Although Dulce has sodium chloride enriched water, carbonates have a higher specific weight in the total salinity. The water in the Dulce pond is less alkaline and its pH value rarely surpasses 9 units. Since macrophytes can grow in this pond, they and their associated epiphytes compete favorably for nutrients during part of the year. Therefore, as phytoplankton cannot develop, the water remains relatively clear.

The presence of macrophytes in Dulce is perhaps one of the causes of the differences between the ponds, since these plants support an important epiphytic community, which in turn is responsible for the presence of diatoms in this pond (Fig. 4). The contribution of the macrophytes to the nutrient cycles is of great relevance as they uptake nutrients from the sediment and release them.

Throughout the year the parameter variations in Dulce are of less intensity than those of Santa Olalla. Santa Olalla showed sudden changes, particularly in summer periods (July, 1987) and just after rainfall cycles (February, 1986). Comparing the two summers studied, both ponds seemed to indicate an increase in salinity and eutrophy.

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