WETLAND ALGAE AND CYANOBACTERIA

Diatom Species that Characterize Saline Ponds (Southern Spain) with the Description of a New Navicula Species

David Fernández-Moreno1,2 · Pedro M. Sánchez-Castillo2 · Cristina Delgado3 · Salomé F. P. Almeida4

Abstract

The southern Iberian Peninsula has a high number of saline ponds where electric conductivity (EC) is an important factor that directly affects the distribution and abundance of aquatic organisms. Environmental factors (such as pH, EC, and temperature) were measured, and diatom assemblages were sampled in 15 shallow saline ponds in southern Spain over a range of EC (1.4 mS to 51.6 mS cm⁻¹). Three groups of ponds were defined based on EC (oligosaline 1.4 to 5.3 mScm⁻¹, mesosaline 10.9 to 17.3 mScm⁻¹, and eusaline 32.3 to 51.6 mScm⁻¹), and sediment diatom assemblages were studied. PERMANOVA analysis revealed significant differences in diatom community composition between the three groups of ponds. Non-metric multi-dimensional scaling analysis (n-MDS) showed distinct clusters of diatom assemblages in oligosaline and mesosaline ponds. The dominant diatom species in the eusaline ponds were Tryblionella pararostrata (Lange-Bertalot) Clavero & Hernández-Mariné, Halamphora cf. pertusa J.G. Stepanek & Kociolek, Halamphora sp.1, and Cocconeis euglypta Ehrenberg; the mesosaline ponds were dominated by Navicula veneta Kützing, Nitzschia elegantula Grunow in Van Heurck, and Planothidium delicatulum (Kützing) Round & Bukhtiyarova; and the oligosaline ponds were dominated by Navicula veneta, Pseudostaurosira brevistriata (Grunow) D.M. Williams & Round, and Nitzschia inconspicua Grunow. A new diatom species was described from three eusaline ponds (32-51.6 mS cm⁻¹). A detailed description of N. maiorpargemina sp. nov. is presented in this study based on light and scanning electron microscopy after comparison with morphologically and ecologically related taxa.

Keywords Andalusia · Saline wetlands · Ponds · Sediments · Conductivity · Diatoms · New species

Introduction

In recent decades, different governments and international organizations have pursued efforts to conserve and protect wetlands through the Ramsar Convention as the first global treaty to protect nature (Montes and González-Capitel 2002, Elvan and Birben 2021). According to the Ramsar Convention (2016), wetlands include estuaries, marshes, lagoons, lakes, and ponds. Aquatic ecosystems can be classified according to the number of ions found in them, and the term “saline” is used for continental waters rather than “haline” as indicated in different studies (Gasse 1987; Reed et al. 2012). Particularly, saline ponds are sensitive aquatic ecosystems, as they reflect the consequences of human and natural disturbances (Waiser and Robarts 2009; Potapova 2011). Endorheic systems, such as some saline ponds, are mostly small (< 50 ha) and shallow (< 1 m) (Stenger-Kovács et al. 2014) and, being relatively closed systems, they constitute reliable sentinels of climate change (Gottschalk and Kahler 2012).
Different studies in saline aquatic ecosystems have indicated that the increase in ionic concentration in the water has a progressively negative effect on the number of species (Hammer 1990; Amores et al. 2013). These extreme environments are highly species selective, causing species lacking osmoregulatory mechanisms to disappear (De Deckker 1988). One way that an organism can cope with salinity is to compensate for the high ionic concentration by accumulating organic solutes in their body (Waizer and Roberts 2009). Halotolerant/halophilic organisms can inhabit these environments and therefore a high number of rare or endemic species are usually present (Millán et al. 2011).

Despite this, different groups of organisms such as bacteria, fungi, protozoa, zooplankton (copepods, rotifers or cladocerans), microalgae and macrophytes (Ruppia, Carex, Salicornia) are adapted to high levels of NaCl (Waizer and Roberts 2009). Species belonging to the unicellular flagellate green algae Dunaliella have shown high NaCl concentrations in the cell cytoplasm that can accumulate glycerol as an adaptation to hyperosmotic environments (Schubert et al. 2010; Lowenstein et al. 2011; Oren 2014). Other genera such as Chlorella, Scenedesmus, Desmodesmus or Monoraphidium have also shown tolerance to high salt concentrations (Figler et al. 2019).

Microphytobenthos, which are composed mainly of cyanobacteria, green algae, and diatoms, colonize saline ponds (Stevenson 1996; Waizer and Roberts 2009) and are the main carbon fixers in shallow ponds (Montoya 2009). Photosynthetic activity of the epipelic microalgae make up about 30% of total primary production, especially in the deeper infra-littoral or mid-depth zones (Cantonati and Lowe 2014). Diatoms can be tolerant to high salt concentrations by the active transport of ions out of the cell or into the vacuole (Shi et al. 2002) and by the regulation of cellular osmolytes (Clavero et al. 2000), although these mechanisms are energetically costly. An efficient and less costly mechanism is through the adsorption of salts to the extracellular polymeric substance (EPS) such as uronic acids or sulphates, which provide a competitive advantage to diatoms in salt-stressed environments (Allan et al. 1972; Abdullahi et al. 2006; Steele et al. 2014).

Ecological studies in peryphytic diatom assemblages in ponds/lakes are scarce in Europe, though some have been undertaken in mountain ponds of France (Beauger et al. 2020), coastal ponds in Italy (Della Bella and Mancini 2009) or saline lakes in Hungary (Buczkó and Ács 1996-1997; Stenger-Kovács et al. 2014) and Romania (Nagy et al. 2008). Shallow and hypersaline endorheic ponds in Western Europe are mostly restricted to Spain (Reed 1998a, b; Woodward 2009; Casamayor et al. 2013). The saline ponds of Spain show wide ionic variety (Montes and Martino 1987), due to sediments and seasonal fluctuations along the year (typical of the Mediterranean climate) (Gasith and Resh 1999; Guerrero and Wit 1992; Martín et al. 2010; Lucena-Moya et al. 2012). Diatom studies in saline habitats such as rivers, lakes, estuaries, lagoons, and marshes show that most diatom genera tolerate high levels of salinity and conductivity (Potapova 2011).

Particularly, in south-eastern Spain, many studies have been made in saline ponds (Aboal 1989), in wetlands such as in Pego-Oliva marsh with different ranges of EC (Cantoral-Uriza and Aboal 2008), and in coastal and hypersaline lagoons (Belando et al. 2012; Antón-Garrido et al. 2013). From a palaeoecological approach, Reed (1998a, b) studied more than 50 saline ponds in southern Spain, including some ponds examined in the present study (e.g. Zarracatín, Gosque, Zóñar, Ballestera, Tiscar or Ratosa), where diatom communities were related to chemical variables such as conductivity. Potapova and Charles (2003) reported that EC is a major contributor to the distribution of diatoms, in agreement with Negro and Hoyos (2005) who reported EC and alkalinity as critical variables in the distribution of planktonic diatom communities in reservoirs of Spain. Some other diatom studies published inventories of the benthic diatom communities of the ponds at different sites of Spain (e.g. Armengol et al. 1975; Ubierna León and Sánchez-Castillo 1992; Blanco et al. 2004), as well as certain mountain ponds (Linares-Cuesta 2003; Rivera-Rondón and Catalán 2017), and new species were described for southern Spain (Sánchez-Castillo 1993; Blanco et al. 2013, 2019).

The principal aim of the present study was to describe the diatom communities that characterize 15 saline ponds in the South of Spain, including the description of a new species Navicula maiorpargemina sp. nov. that appeared in three of the ponds studied.

**Materials and Methods**

**Study Area**

Southern Spain has more than 200 ponds, some of them with different levels of governmental protection (Montes and González-Capitel 2002, Consejería de Medio Ambiente 2005) because they are refuges for birds migrating between Europe and Africa (Ntiamoa-Baidu 1991b; Montes and González-Capitel 2002; Waizer and Roberts 2009). Some of these ponds are on the coast but others are endorheic ecosystems. Some of the ponds are included in Ramsar list (e.g. Salada, Zoñar, Rincón) and most (e.g. Taraje, Montellano, Gosque, Zarracatín, Ratosa, Ballester, Tiscar, Pilón) are included in Natura 2000 list (Montes and González-Capitel 2002; Consejería de Medio Ambiente 2020).
Sampling Design

In this study, 15 shallow ponds were selected over a wide EC range (1.4 to 51.6 mS cm\(^{-1}\)) (Table 1) and sampled between April 2004 to June of 2006. The distribution map showing the sampling sites (Fig. 1) was drawn using QGIS Dufour 2.0. Physical-chemical parameters such as pH, electric conductivity, and water temperature were measured in situ with a multiparameter probe (pH/Cond 340i Portable Multi-Parameter, WTW model). Other parameters, such as elevation, distance to the sea or maximum pond depth (Table 1) were determined from the official website of the environmental agency of Andalusia (Consejeria de Medio Ambiente 2020). According to prior studies in these wetlands (Cowardin et al. 1979; Lucena et al. 2012), and based on the conductivity range, the ponds were classified as oligosaline (< 8 mS cm\(^{-1}\)), mesosaline (8 - 30 mS cm\(^{-1}\)), and eusaline (> 30 mS cm\(^{-1}\)).

Several transects were made in the littoral zone in order to take an integrated sample of the epipelic community. A sediment sample from each pond was collected by suction through a one-meter-long glass tube using standard methods (Round 1953; Polge et al. 2010). Samples were transferred to plastic bottles and preserved with formaldehyde (4% final concentration) before laboratory treatment. Diatom samples from sediments were collected from these 15 shallow ponds.

Water and Diatom Sample Processing

In the laboratory, the sediment from each epipelic sample was left to stand in a Petri dish, then the supernatant was removed, and the sediment was covered with coverslips, which were removed at least 12 h later to collect diatoms attached to the coverslip by phototactic movement. The coverslips were washed to remove the diatoms attached to them. Samples were oxidized in glass tubes with hydrogen peroxide 30% w/w. Then, calcium carbonate inclusions were removed by adding a few drops of diluted hydrochloric acid 1 N to the sample. Samples were then washed with distilled water four times by centrifugation (3000 rpm, 5 min), the supernatant removed, leaving the clean pellet. Permanent slides were mounted with synthetic resin (Naphrax®) having a high refractive index (1.74).

The diatoms were counted under a light microscope (LM - Leica DMI3000 B light) equipped with phase contrast with a 1000x oil-immersion objective with numerical aperture (NA) of 1.32. At least 400 valves were counted in each sample. Total counts were transformed into relative abundance. The diatom florals used for identification included: Cumming et al. 1995, Gasse 1986, Krammer and Lange-Bertalot (1985, 1986, 1988, 1991a, b), Lange-Bertalot (2000-2002), Lange-Bertalot (2001), Hustedt (1930), Levkov (2009) and Witkowski et al. (2000a, b).

Light micrographs of the diatoms were taken under a Zeiss Axioplan 2 imaging microscope with differential interference contrast (DIC) and a 1000x immersion objective (NA 1.40) equipped with an Olympus DP70 digital camera. Measurements of valve length, width and number of striae in 10 μm were taken of at least 30 specimens per species, under the light microscope. For scanning electron microscopy (SEM) analysis, metal stubs were prepared with organic-free samples air dried on a thin pellicle of graphite (EMITECH K 950X) and coated with gold palladium (Polaron equipment limited SEM coating unit E5000). All images were digitally edited, and plates were made using CorelDRAW.

Type Material Study

Navicula pargemina Underwood and Yallop was described from Severn Estuary in the UK and the holotype deposited in the Natural History Museum of London (BM-82,311) (Fig. 2). Considering that the newly described Navicula species shows similarities with N. pargemina, we compared it with the original data of Underwood and Yallop (1994).

Witkowski et al. (2000a, b) and by observation in this study under the LM of type material (Fig. 2). Morphological and morphometric characterization was based on measurements of 30 valves from this type material, which was used to compare with the new species described in the present study.

In addition, the new Navicula taxon was compared with the measurements of similar taxa from different bibliographical references with illustrations: Navicula abscondita Hustedt 1939 (Krammer and Lange-Bertalot 1986; Witkowski et al. 2000a, b; Clavero 2009; Ribeiro 2010), Navicula dilucida (Clavero 2009; Ribeiro 2010), Navicula consentanea Hustedt (Witkowski et al. 2000a, b; Clavero 2009), and Navicula groschopfii Hustedt (Witkowski et al. 2000a, b; Clavero 2009).

Data Analysis

The distribution patterns of the diatom communities were explored in the 15 ponds using a non-metric multi-dimensional scaling analysis (n-MDS) based on Bray-Curtis similarity matrix and cluster analysis with all samples. The relative-abundance values of the different species were used for analyses. Statistical differences between the three groups of ponds based on EC (as achieved by the n-MDS) were tested by a permutational multivariate analysis of variance (PERMANOVA test). Moreover, a SIMPER analysis and cluster (double-square root transformed data on a Bray-Curtis similarity matrix) was used to find the most representative taxa for each statistically different salinity. We used Primer 6 and PERMANOVA + (Clarke and Gorley 2006).
Three different groups of ponds were found in this study in terms of EC. The physical-chemical variables of the 15 ponds measured in situ are shown in Table 1. The ponds with the lowest EC (oligosaline; 1.4 to 5.3 mScm⁻¹) were Taraje, Zoñar, Rincón, Calderón, and Pilón. These ponds, at 45 to 95 km from the sea and at elevations of 80-345 m a.s.l., had a pH range of 7.8-8.6 and water temperature between 22 and 31.7°C.

The mesosaline ponds, which were Verde la Sal, Consuegra, Salada, Montellano, and Honda, at 6-100 km from the sea and at elevations of 33-453 m a.s.l., registered EC values between 10.9 and 17.3 mScm⁻¹, pH 8.2-8.5, and water temperature of 22-30.6°C (Table 1). The eusaline ponds were Tíscar, Gosque, Ratosa, Ballestera, and Zarracatín, at 58-99 km from the sea and at elevations of 40-450 m a.s.l., with EC values of 32.3-51.6 mScm⁻¹, pH 7.5-9.1, and water temperature of 23.4-35.2°C, Table 1).

Diatom Community Composition

A total of 150 taxa from 55 diatom genera were identified in the 15 samples from the ponds studied. The n-MDS ordination plot of diatom samples showed a stress of 0.14 (Fig. 3a) and the cluster analysis (Fig. 3b) showed the distance between diatom samples. A clear separation, based on diatom assemblages, between eusaline and oligosaline ponds is visible along axis 1 of the ordination diagram with the mesosaline ponds mediating the other two groups of ponds (Fig. 3a).

The PERMANOVA global test showed that the diatom communities in each type of pond had statistically significant differences according to EC (Pseudo-F = 1.513, p = 0.012). Pairwise tests revealed significant statistical differences between eusaline and oligosaline as well as between eusaline and mesosaline ponds (Table 2). Nevertheless, the communities did not significantly differ between mesosaline and oligosaline ponds (t = 0.952, p = 0.652).

The SIMPER analysis revealed a dissimilarity of 98.37% within diatom assemblages from eusaline and oligosaline ponds and 94.48% within diatoms from eusaline and mesosaline ponds (Table 3). Meanwhile the average dissimilarity between mesosaline and oligosaline ponds was lower in the SIMPER analysis (87.78%).

The main species (Figs. 4-29) show the differences that exist between ponds of different conductivities. Eusaline ponds were differentiated from the rest of the ponds by the following species: *Halambaphora cf. pertusa* J.G. Stepanek & Kociolek, *Tryblionella pararostata* (Lange-Bertalot) Clavero & Hernández-Marín, *Cocconeis euglypta* Ehrenberg, and *Halambaphora* sp. 1. This latter species (Fig. 4-8, Appendix 16) was more abundant in Gosque and Ratosa.
ponds, with more than 25% relative abundance, while Cocconeis euglypta (Fig. 13, Appendix 16) registered more than 60% relative abundance in Gosque. Tryblionella parastrata (Fig. 17, Appendix 16) reached the highest percentage (90%) of relative abundance in Ballestera, and Halamphora cf. pertusa (Figs. 24-26, Appendix 16) appeared in several ponds with a maximum of 49% relative abundance in Zarracatín.

In mesosaline ponds, the most representative diatom taxa were: Planothidium delicatulum (Kützing) Round & Bukhtiyarova (Figs. 9-12, Appendix 16), which reached almost 60% relative abundance in Salada pond; Navicula veneta Kützing 1844 (Fig. 18, Appendix 16), which registered a maximum of more than 50% relative abundance in Consuegra; and Nitzschia elegantula Grunow in Van Heurck (Fig. 19, Appendix 16), which had a maximum relative abundance in Verde de la Sal with 77%.

One species that characterized oligosaline ponds was Nitzschia inconspicua Grunow (Figs. 14-16, Appendix 16), with more than 60% in Taraje. Other species were Navicula veneta (Fig. 18, Appendix 16), with a relative abundance of 11.0% and 18.0% in Taraje and Pilon ponds, respectively and Pseudostaurosira brevistriata (Grunow) D.M. Williams & Round 1988 (Figs. 20-22, Appendix 16), with more that 70% of relative abundance in Zóñar.

Taxonomic Section

Phylum Ochrophyta Caval. -Sm. (Cavalier-Smith 1995)
Class Bacillariophyceae Haeckel emend. Medlin and Kaczmarska (Medlin and Kaczmarska 2004).
Subclass Bacillariophycidae Round (Round et al. 1990).
Order Naviculales (Bessey 1907 sensu emend).
Family Naviculaceae (Kützing 1844).
Genus Navicula (J.B.M. Bory de Saint-Vincent 1822).
**Navicula maiorpargemina** D. Fernández-Moreno, P. Sánchez-Castillo, C. Delgado, S.F.P. Almeida sp. nov.

Figures 30-37: LM. Figures 48-53: SEM.

**Type material**

**Holotype:** Phycotheque GDA-algae slide number 3285 prepared with material from the sample collected in Zaraccatín and housed in the Herbarium of the University of Granada (Spain). Figure 34.

**Isotype:** Slide BM 101 920, prepared with material from the sample collected in Zarracatín, housed in the Natural History Museum, London (UK).

**Type locality:** Zarracatín wetland, Endorheic Complex of Utrera, Seville province, Andalusia (Spain). Geographical coordinates: $37^\circ 2'2.85''$ N, $5^\circ 48'8.30''$ W; coll. Pedro M. Sánchez Castillo and David Fernández Moreno; coll. date 17 June 2006.

**Etymology:** Refers to the larger size when compared with the most similar species *Navicula pargemina*.

**Table 2** Statistical differences between diatom assemblages from ponds with the three different conductivity classes, based on a permutational multivariate analysis of variance, PERMANOVA

| Conductivity class                        | t     | p(perm) |
|------------------------------------------|-------|---------|
| Eusaline - Oligosaline                   | 1.4048| 0.007   |
| Eusaline - Mesosaline                    | 1.2867| 0.034   |
| Oligosaline-Mesosaline                   | 0.95277| 0.652   |

Statistically significant differences ($p < 0.05$) in bold
Description Microscopy observations (LM and SEM)

Valves narrowly lanceolate to rhombic-lanceolate, gradually tapering towards the apices, length 21.3-30 μm, width 4-5 μm (n = 30). Axial area unilaterally widened especially in the central area, which is asymmetrical with a shorter stria on one side (Figs. 30-33, 49-51). Transapical striae radiating slightly near the valve centre (Figs. 34-37), changing to convergent towards the apices (Figs. 33-34) with 15-17 striae in 10 μm. Raphe straight, central pores both deflected in the same direction (Figs. 49, 51). Each stria uniseriate, composed of linear areolae (Figs. 48-53) and the number of lineolae 60-70 in 10 μm. Internal view of the raphe with no intermission in the sternum near the central nodule (Figs. 48, 50). The internal view of the valvar poles showing the distal raphe endings terminating in small helictoglossae (Fig. 52). Externally the raphe at the poles hooked (Fig. 53).

Comparison of the new species with type material of Navicula pargemina and other similar species

Morphological features of Navicula maiorpargemina sp. nov. and comparison with five species of Navicula which appear in high-conductivity waters are presented in Table 4.

In this study, N. maiorpargemina appears in water with high EC, like some other small Navicula. Nevertheless, these have clear morphological and morphometrical differences which easily distinguish them in the same samples.

In terms of length, N. maiorpargemina may overlap with N. dilucida and N. groschopfii, although N. maiorpargemina is wider than N. dilucida (4-5 μm vs. 2-4 μm, respectively) but not wider than N. groschopfii (4-5 μm) (Table 4). The number of striae in 10 μm is lower in N. maiorpargemina (15-17 in 10 μm) compared with N. dilucida (18-24 in 10 μm) and N. groschopfii (20 in 10 μm) (Table 4). In outline, N. dilucida and N. groschopfii are more rhombic compared to N. maiorpargemina, which has a more parallel valve outline. In comparison with the estuarine species N. abscondita (Bate et al. 2013), N. maiorpargemina is longer (21.3-30 μm vs. 18-40 μm). On the other hand, N. consentanea is smaller than N. maiorpargemina (12–20 μm vs. 21.6–30.5 μm), with greater striae density in 10 μm (20-24 vs. 15-17). Another marked difference between N. maiorpargemina and the four Navicula species mentioned above is the occurrence in the former of valves in pairs after the oxidation process and which are visible in the light micrographs (Fig. 35).

Navicula maiorpargemina sp. nov. (Figs. 30-37; 48-53) was compared with the light micrographs of type material of Navicula pargemina (Figs. 38-47) because the valves remain together even after the oxidizing treatment. The specimens measured from the type material of N. pargemina (n = 20) had a narrow range of valve length (15.0-19.3 μm) and a width of 3-4 μm with 22-25 striae in 10 μm. The measurements in the original description of Underwood and Yallop (1994) slightly differ (12-18 μm in length; 2.0-4.0 μm in width; 20-29 striae in 10 μm; Table 4) but do not overlap with the new taxon described in the present study.

N. maiorpargemina varies between 21.3 and 30 μm in length and 4 and 5 μm in width while N. pargemina measures 12-18 μm in length (15-19.3 in this study) and 3-4 μm wide. Both have a linear to lanceolate valve shape, although sometimes N. maiorpargemina appears slightly lanceolate to rhombic (Figs. 31, 33). The valve apices are cuneiform and in no case rounded as in N. pargemina. In N. maiorpargemina the striae are coarser (15-17 in 10 μm) when compared to N. pargemina (20-29 in 10 μm).

| Taxa                                  | Code | Eusalone | Mesosaline | Oligosaline |
|---------------------------------------|------|----------|------------|-------------|
| Tryblionella pararostrata             | TRPA | 22.18    | 1.24       | 0.07        |
| Halamphora sp1                        | HALA | 17.78    | 2.18       | 0.00        |
| Cocconeis euglypta Ehrenberg          | COCO | 15.37    | 0.14       | 0.29        |
| Navicula veneta Kützing               | NVEN | 0.15     | 16.41      | 14.41       |
| Pseudoaulosira brevistriata           | PBRE | 0.00     | 2.00       | 14.18       |
| Planolithidium delicatum               | PDEL | 0.00     | 11.76      | 0.00        |
| Nitzschia elegantula                  | NELE | 0.09     | 15.83      | 0.47        |
| Nitzschia inconspicua Grunow          | NINC | 0.97     | 5.90       | 12.40       |
| Halamphora cf.pertusa J.G.Stepanek & J.P.Kociolek | HPER | 11.83 | 1.09 | 0.06 |
| Nitzschia solita Hustedt              | NSOL | 0.00     | 0.68       | 5.79        |
| Parlibellus cruciculoides             | PCRL | 5.77     | 1.93       | 0.00        |
| Tryblionella apiculata Gregory        | TAPI | 1.01     | 5.67       | 4.34        |
Despite the differences between *N. pargemina* and *N. maiorpargemina* described here, we verified certain similarities between the two taxa. That is, valves were found in pairs even after the oxidation process with one in valvar view and the other in girdle view (i.e., Fig. 35) for *N. maiorpargemina* and Figs. 38-42, 44-47 for *N. pargemina*); asymmetrical axial central area but smaller in *N. maiorpargemina*.

In *N. pargemina* (Underwood and Yallop, 1994), Figs. 11-12, the central area is wider than in *N. maiorpargemina* sp. nov. (Figs. 49-51). Hymens were not found in *N. maiorpargemina* sp. nov., as described in *N. pargemina*, and the number of lineolae was 60-70 for the new species instead of 100 counted in *N. pargemina*. 
Discussion

Our work addressed the variation of diatom communities from pond sediments under different electric conductivity. The study sites constitute part of a more extensive monitoring network with more than 50 ponds from Andalusia, since they represent more than 25% of ponds in this area (provided by the Regional Government of Andalusia). The analysis of the diatom assemblages in pond sediments indicated differences between lower EC groups (oligosaline and mesosaline) and higher (eusaline). This fact has also been observed in Oliva-Pego wetlands where diatom species characteristic of brackish and freshwaters were defined (Cantora-Uriza and Aboal 2008).

The cluster analysis characterizes more clearly the similarity among the ponds studied, confirming that electric conductivity plays a critical role in the distribution of periphytic diatoms, as observed in other studies (Veres et al. 1995; Potapova and Charles 2003; Tibby et al. 2007; Stenger-Kovács et al. 2014).

Balance between evaporation and precipitation, especially during periods of severe drought (e.g. summer months), influences the variability in EC values (Veres et al. 1995), especially in the shallowest and most saline ponds such as Zarracatín (Table 1). This trend is consistent with the changes noted in other ponds, such as Gosque or Ratosa, included in the eusaline group. Nevertheless, the maximum in this study did not reach the previously reported highest values with more than 100 mS cm$^{-1}$ in some years (Montes and González-Capitel 2002), this level pertaining to the hypersaline category. Mesosaline ponds such as Honda proved more variable, having periods with subsaline to hypersaline conditions. However, oligosaline ponds (e.g. Taraje, Pilón, Rincón, Zóñar) clearly had hydrological characteristics corresponding to those that Montes and González-Capitel (2002), categorized as subsaline ecosystems.

Although the genera of the most representative taxa found in the mesosaline to eusaline ponds from this study were represented mainly by *Amphora sensu lato* (which includes *Halamphora*), *Cocconeis*, *Navicula*, *Nitzschia*, *Planothidum*, and *Tryblionella*, the main genera were *Navicula* and *Nitzschia*, as reported by Stenger-Kovács et al. (2014) as more dominant in saline waters.

*Tryblionella pararostrata* (Lange-Bertalot) Clavero & Hernández-Marín (in Clavero 2009), which is usually found in marine or hypersaline environments (Schoeman 1972; Siqueiros-Beltrones et al. 1991; Clavero 2009), is one of the dominant species in the present study in eusaline ponds as well as *Halamphora cf. pertusa* Stepanek & Kociolek characteristic of waters with high conductivity (Stepanek and Kociolek 2015). *Parlibellus cruciculoides* (C. Brockmann) Witkowski, Lange-Bertalot & Metzeltin (Figs. 27-28), a marine species, was important in the eusaline ponds of this...
study and has also been reported in estuarine environments in Portugal (Ribeiro 2010) and is therefore considered a characteristic species of high-conductivity waters. *Halamphora* sp.1 is a small diatom that, together with *Cocconeis euglypta* Ehrenberg, filamentous algae, and carophytes such as *Lamprothamnium papulosum* (Wallroth) J. Groves was very abundant in the group of ponds with the highest conductivity (Gosque and Ratosa) and has frequently been reported in these ecosystems in Spain (Cantoral-Uriza and Aboal 2008).

Diatom species that characterized mesosaline ponds were *Nitzschia elegantula* Grunow in Van Heurck and *Planothidium delicatulum* (Kützing) Round & Bukhtiyarova 1996, found in Salada pond with more than 10 mS cm$^{-1}$. The species *Nitzschia elegantula* has been reported in other studies as halophilous and dominant in media with moderate electrolyte content (Della Bella et al. 2007; Solak et al. 2019). In Spain, *N. elegantula* has been reported as characteristic of brackish waters (Antón-Garrido et al. 2013).

The oligosaline group was characterized by the presence of *Pseudostaurosira brevistriata* (Grunow) D.M. Williams & Round 1988, which was the most abundant diatom species and apparently more sensitive to higher EC values (Tibby et al. 2007) although this species tolerates a wide range of conductivity (Antón-Garrido et al. 2013). *Nitzschia inconspicua*
| (References) | Navicula maiorpargemina Fernandez Moreno, Sanchez Castillo, C. Delgado, S.F.P. Almeida sp. nov. | N. pargemina Underwood and Yallop 1994 | N. abscondita Hustedt 1939 | N. dilucida Hustedt 1939 | N. consentanea Hustedt 1939 | Navicula groschopfii Hustedt 1939 |
|---|---|---|---|---|---|---|
| Valve length (µm) | 21.3-30 | 12-18 (Underwood and Yallop 1994); 15.0-19.3 (this study) | 18.0-40.0 | 15.0-29.0 | 12.0-20.0 | 15.0-30.0 |
| Valve width (µm) | 4.0-5.0 | 3.0-4.0 | 4.0-6.0 | 2.0-4.0 | 4.0-5.0 | 4.0-5.0 |
| Valve outline | Narrowly lanceolate to rhombic–lanceolate | Linear-lanceolate to lanceolate | Narrowly lanceolate | Lanceolate | Rhombic-lanceolate | |
| Valve apices | Acute apices | Acute apices | Fairly acute apices | Acutely rounded | Acutely rounded | Acutely rounded |
| Central area | Slightly asymmetrical and on one side developed as a narrow transversely rectangular fascia | Asymmetrical and on one side developed as a narrow transversely rectangular fascia | Small and circular | Narrow | Absent | Rhombic |
| Axial area | Unilaterally widened | Unilaterally widened | Very narrow | Very narrow. Linear barely widened | Absent | Narrow |
| Number of striae in 10 µm | 15-17 | 22-25 | 15 | 18-24 | 20-24 | 20 |
| Striae patterns | Slightly radiating at the centre to slightly convergent towards the apices | Very slightly radiating to parallel | Very slightly radiating in the middle | Slightly radiating in the middle thoroughly | Slightly radiate in the middle | Slightly radiating in the middle. Parallel close to apices |
| Raphe | Straight. external central endings close | Straight | Straight. external central endings approximate close | Straight. external central endings close | Straight. external central endings close | Straight. External central endings moderately distant |
| Ecology | Endorheic saline water | Brackish marine water | Silty sediments | Marine | Marine | Marine |
Grunow and *Navicula veneta* Kützing were also dominant in these ponds, especially the latter, which is considered by different authors as a “salt generalist” (Pienitz and Smol 1995).

Other taxa found in this study such as *Navicula cf. jakhalensis* Van Landingham, in Clavero et al. (2000), and *Caloneis permagna* (Bailey) Cleve, in Zarei-Darki (2011) and Resende et al. (2005) (Appendix 16), were reported as mesohalobian in estuarine habitats, respectively, and were also found in the present study in the eusaline ponds but with lower abundance compared to other taxa mentioned above. In Cantoral-Uriza and Aboal (2008) and Antón-Garrido et al. (2013), the species *Navicymbula pusilla* (Grunow) Krammer is reported as abundant in high-conductivity waters. In the present study, it appears in Consuegra pond (Appendix 16), which is in the mesosaline group, but it has not been identified in the eusaline group, which might represent the limit for conductivity tolerance of this species.

*Navicula maiorpargemina* sp. nov appeared in the group of ponds with the highest EC, registering a maximum relative abundance of 16.2% in Zarracatín pond (51.6 ms cm⁻¹), which had slightly alkaline water (pH = 8.0), and high temperature (35.2°C), with less than 1% in Gosque (38.7 ms cm⁻¹), alkaline water (pH = 9.1) and lower temperature (23.4°C) compared to the aforementioned pond, and in Ratosa with less than 3% relative abundance, high conductivity (32.3 ms cm⁻¹), slightly alkaline water (pH = 8.0), and high temperature (32.3°C).

According to the literature, the most similar species to *N. maiorpargemina* is *Navicula pargemina* (e.g., Underwood and Yallop 1994; Clavero et al. 2000; Ribeiro 2010). A taxon identified as *Navicula cf. pargemina* has been recorded in the Loire estuary by Ribeiro et al. (2019). The new taxon described here presents clear differences with respect to *Navicula pargemina*, such as larger size, a lower number of striae, and a more rhombic-lanceolate shape. The comparison between *Navicula maiorpargemina* sp. nov. and other similar taxa reveals a unique combination of characters, such as valve shape and an asymmetrical central axial area, whereas the valve pairs after oxidation are the most characteristic trait of this species, found in no other except in *N. pargemina*. Therefore, it is probable that *N. maiorpargemina* sp. nov. is more common in European estuaries (Ribeiro 2010; Ribeiro et al. 2019) and saline ponds than so far reported.

The environments with high conductivity are highly sensitive to climate change (Hammer 1990; Jeppesen et al. 2015), and diatom communities are affected by this global change (Reed 1998a, b). Detailed analyses of the long-term dynamics in ponds as well as key factors and interactions affecting water quality (Ventelä et al. 2016) are needed for better management, and conservation measures are enacted in these sensitive environments. More studies concerning the autoecology of diatom species in these wetland environments are necessary to establish the optimal and tolerance ranges of the different species.

### Appendix

#### Table 5

| Taxon name | Relative Abundance (> 5%) of taxa in ponds |
|------------|------------------------------------------|
| Amphipleura rutilans (Trentepohl) Cleve |     |     | 22.2 | - | - | 6.8 | 49.5 | - | - | - | - | - | - | - | - |
| Halamphora cf. pertusa |     |     |     |     |     | 6.8 | 49.5 | - | - | - | - | - | - | - | - |
| Amphora cf. tenuissima Hustedt | 9.6 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Amphora sp | 9.6 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Anomoeoneis aff. sphaerophora (Ehr.) Pfitzer |     |     |     |     |     | 24.3 | - | - | - | - | - | - | - | - | - |
| Caloneis permagna (J.W.Bailey) Cleve |     |     |     |     |     | 11.7 | - | - | - | - | - | - | - | - | - |
| Cocconeis euglypta Ehrenberg |     |     |     |     |     | 11.7 | - | - | - | - | - | - | - | - | - |
| Cocconeis placentula Ehrenberg |     |     |     |     |     | 11.8 | - | - | - | - | - | - | - | - | - |
| Craticula cf. halophilioides (Hustedt) Lange-Bertalot |     |     |     |     |     | 18.4 | - | - | - | - | - | - | - | - | - |

Wetlands (2022) 42: 14
Table 5 (continued)

| Taxon name                                      | Salada | Montelano | Tiscar | Zóñar | Rincon | Honda | Ratosa | Zarracatin | Calderon | Balkester | Consuegra | Gosque | Pikón | Taraje | Verde | Relative Abundance - Ponds |
|------------------------------------------------|--------|-----------|--------|-------|--------|-------|--------|-------------|-----------|-----------|------------|--------|-------|--------|-------|--------------------------|
| Denticula kuetzingii Grunow                    | -      | -         | -      | -     | 1.2    | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     | -                        |
| Dickeria sp.                                    | -      | -         | -      | -     | -      | -     | 7.3    | -           | -         | -         | -          | -      | -     | -      | -     | -                        |
| Hakomphos sp1                                   | -      | -         | -      | -     | -      | 1.7   | 56.8   | 6.4          | -         | -         | -          | 25.5   | -     | -      | -     | -                        |
| Hakomphos veneta (Kützing) Levkov              | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     | -                        |
| Haslea spicula (Hickie) Bukhtiyarova            | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     | -                        |
| Navicula aff. cryptothaloides Hustedt           | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     | -                        |
| Navicula cf. jalkalsensis Van.landingham       | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     | -                        |
| Navicula cryptocephaloides Hustedt              | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     | -                        |
| Navicula duerenbergiana Hustedt in Schmidt et al | -      | -         | -      | -     | -      | -     | 13.8   | -           | -         | -         | -          | -      | -     | -      | -     | -                        |
| Navicula salinarum Grunow in Cleve et          | -      | 7.1       | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     | 0.7                      |
| Navicula sp. nov. Fernandez-Moreno,             | -      | -         | -      | -     | -      | -     | 2.8    | 16.2        | -         | -         | -          | -      | -     | -      | -     | -                        |
| Sanchez-Castillo, C. Delgado & S.F.P. Almeida  |        |           |        |       |        |       |        |              |           |           |            |        |       |        |       |                           |
| Navicula veneta Kützing                         | 7.7    | 19.5      | -      | -     | -      | -     | -      | -           | -         | 37.5       | -          | 54.2   | 18.4 | 11.2  | -     |                           |
| Navicula pula (Grunow) Krammer                  | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     |                           |
| Nitzschia cf. desertorum Hustedt                | -      | 2.3       | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     |                           |
| Nitzschia cf. frutulum (Kützing) Grunow         | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     |                           |
| Nitzschia eleganta Grunow in Van Heurck         | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     | 78.0                      |
| Nitzschia inconspicua Grunow                    | 8.5    | -         | -      | -     | -      | -     | 9.3    | -           | -         | -         | -          | 9.9    | -     | 6.7   | -     |                           |
| Nitzschia pala (Kützing) W.Smith                | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | 11.8  | -     |                           |
| Nitzschia solto Hustedt                         | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | 16.1  | 10.0  |                           |
| Parälenus crenuloides (Brockmann) Witkowski     | -      | 28.9      | -      | -     | -      | -     | 9.7    | -           | -         | -         | -          | -      | -     | -      | -     |                           |
| Planothidium delicatum (Kütz.) Round et Bukht  | 58.6   | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     |                           |
| Pseudostaurosira irvistriata (Grun.in Van       | -      | -         | 7.9    | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     |                           |
| Heurck) Williams & Round                        |        |           |        |       |        |       |        |              |           |           |            |        |       |        |       |                           |
| Pseudostaurosira subulata (Hustedt) Morales     | -      | -         | 7.4    | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     |                           |
| Sertella poissoni Pantocsek                     | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     |                           |
| Tryblionella apiculata Gregory                  | 2.3    | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | 21.4   | -     | -      | -     |                           |
| Tryblionella gracilis W. Smith                  | -      | -         | -      | -     | 21.9   | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     |                           |
| Tryblionella hungarica (Grunow) D.G. Mann       | -      | -         | -      | -     | -      | -     | -      | -           | -         | -         | -          | 31.7   | -     | -      | -     |                           |
| Tryblionella paranostrata (Lange-Bertalot)      | -      | 12.2      | -      | -     | -      | -     | -      | -           | -         | -         | -          | 88.6   | -     | -      | -     |                           |
| Clavero & Hernández-Marín in Clavero            |        |           |        |       |        |       |        |              |           |           |            |        |       |        |       |                           |
| Ulnaria acus (Kützing) Aboal in Aboal et al.    | -      | -         | -      | -     | 8.2    | -     | -      | -           | -         | -         | -          | -      | -     | -      | -     |                           |
Acknowledgements The authors are grateful to the General Directorate for the Environment of the Andalusian Government, which supported the first phase of the “Phycological Flora of Andalusia”. We also thank the Department of Biology and the Foundation of Science and Technology, Portugal, for the strategic project granted to Geobiotec (UID/GEO/04035/2019), of the Research Centre of the University of Aveiro for making their facilities available and providing funding.

The authors thank two anonymous reviewers who provided valuable feedback that improved this manuscript. Special thanks go to Saül Blanco and Irene Gallego, who provided helpful comments concerning several species or topics.

Authors’ Contributions SA and CD suggested the subject and the method of the manuscript and were the major contributors to the Results and Discussion sections; PS designed the research process, obtained the samples with DF. DF wrote the first draft and was the major contributor in writing the manuscript.

Funding General Directorate for the Environment of the Andalusian Government, which supported the first phase of the “Phycological Flora of Andalusia”, granted to Botany Department of the University of Granada (Spain). Also, the Department of Biology and the Foundation of Science and Technology, Portugal granted the strategic project to Geobiotec (UID/GEO/04035/2019), of the Research Centre of the University of Aveiro.

Data Availability Not applicable.

Code Availability Not applicable.

Declarations

Conflicts of Interest/Competing Interests the authors declare that they have no conflict of interest.

Ethics Approval Samples were taken with permission from the Andalusian Government (Spain) for the project “Phycological Flora of Andalusia”, granted to Botany Department of the University of Granada (Spain).

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Studies Involving Humans and/or Animals In this study any human or animal were involve.

References

Abdullahi AS, Underwood GJC, Gretz MR (2006) Extracellular matrix assembly in diatoms (Bacillariophyceae). V. Environmental effects on polysaccharide synthesis in the model diatom, Phaeodactylum tricornutum. Journal of Phycology 42:363–378. https://doi.org/10.1111/j.0022-1565.2006.0042.issue-2

Aboal M (1989) Aportaciones al conocimiento de las algas del SE de España. IV. Las diatomese (Bacillariophyceae). Acta Botánica Malacitana 14:13–40

Allan GG, Lewin J, Johnson PG (1972) Marine polymers. IV Diatom polysaccharides. Botanica Marina 15:102–108

Amores MJ, Verones F, Raptis C, Jurasek R, Pfister S, Stoesel F, Antón A, Castells F, Hellweg S (2013) Biodiversity impacts from salinity increase in a coastal wetland. Environmental Science & Technology 47(12):6384–6392

Antón-Garrido B, Romo S, Villena MJ (2013) Diatom species composition and indices for determining the ecological status of coastal Mediterranean Spanish lakes. Anales Del Jardín Botánico De Madrid 70(2):122–135. https://doi.org/10.3989/ajbm.2373

Armengol J, Sabater S, Vidal A, Margalef R, Planas D, Toja J, Vallespinós F (1975) Observaciones limnológicas en las lagunas de La Mancha. Boletín de la Estación Central de Ecología 4:11–27

Bate GC, Smailes PA, Adams JB (2013) Epitelic diatoms in the estuaries of South Africa. Water SA. 39:105–118

Beauger A, Allain E, Voldoire O, Wetzel CE, Ector L, Van de Vijver B (2020) Temporal evolution of diatoms in a temporary pond situated in the Massif du Sancy Mountains (Massif Central, France) and description of a new Pinnularia Species. Diversity 12(10):367. https://doi.org/10.3390/d12100367

Belando MD, Marín A, Aboal M (2012) Licochora species from a Mediterranean hypersaline coastal lagoon (Mar Menor, Murcia, SE Spain). Nova Hedwigia Beiheft 141:275–287

Blanco S, Ector L, Bécares E (2004) Epiphytic diatoms as water quality indicators in Spanish shallow lakes. Vie Milieu- Life and Environment 54:71–79

Blanco S, Álvarez-Blanco I, Cejudo-Figueiras C, Espejo JMR, Barrera CB, Bécares E, Del Olmo FD, Artigas RC (2013) The diatom flora in temporary ponds of Doñana National Park (southwest Spain): five new taxa. Nordic Journal of Botany 31(4):489–499

Blanco S, Olenici A, De Vicente I, Guerrero F (2019) Contribution to the inventory of Iberian diatoms: Encyonema nevadense S.Blanco & al. sp. nov. (Cymbellales, Gomphonemataceae), Anales del Jardín Botánico de Madrid 76(088):2. https://doi.org/10.3989/ajbm.2519

Buczko K, Ács É (1996–1997) Zonation of periphytic algae in two Hungarian shallow lakes (Lake Velence and Fertô). Acta Botanica Hungarica 40:21–34

Cantoral-Uriza EA, Aboal M (2008) Diatomese (Bacillariophyceae) del marjal Oliva-Pego, (Comunidad Valenciana, España). Anales Jardín Botánico de Madrid 65(1):111–128

Casamayor E, Triadó-Margarit X, Castañeda C (2013) Microbial biodiversity in saline shallow lakes of the Monegros Desert, Spain. FEMS Microbiol Ecology 85:503–518

Clarke KR, Gorley RN (2006) PRIMER V6: User Manual/Tutorial. PRIMER-E Ltd., Plymouth Marine Laboratory, Plymouth

Cantoral-Uriza EA, Aboal M (2008) Epiphytic diatoms as water quality indicators in Spanish shallow lakes. Vie Milieu- Life and Environment 54:71–79

Clavero E, Hernandez-Mariné M, Grimalt JO, Garcia-Pichet F (2000) Microbial biodiversity in saline shallow lakes of the Monegros Desert, Spain. FEMS Microbiol Ecology 32:475–486

Clavero E, Hernandez-Mariné M, Grimalt JO, Garcia-Pichet F (2000) Salinity tolerance of diatoms from Thalassic hypersaline environments. Journal of Phycology 36:1021–1034

Clavero E, Oms E (2009) Diatomese d’ambients hipsalins costaners: taxonomia, distribució i empremtes en el registre sedimentari. Institut d’Estudis Catalans. Barcelona, p 432

Consejería de Medio Ambiente (2005) Caracterización ambiental de humedales en Andalucía. Consejería de Medio Ambiente, Junta de Andalucía. Sevilla, 511 p

Consejería de Medio Ambiente (2020) Inventario de Humedales de Andalucía (IHA). http://www.juntadeandalucia.es/medioambiente/site/portalweb/menutem. Accessed 29 Dec 2020

Cowardin LM, Carter V, Golet FC, LaRoe ET (1979) Classification of wetlands and deepwater habitats of the United States, FWS/OBS-79/31, Reprinted 1992. U.S. Fish and Wildlife Service, Washington, DC

Cumming BF, Wilson SE, Hall RI, Smol JP (1995) Diatoms from British Columbia (Canada) Lakes and their relationship to salinity nutrients and other limnological variables. Bibliotheca Diatomologica 31:1–207

De Decker P (1988) Biological and sedimentary facies of Australian salt lakes. Palaeogeography Palaeoclimatology Palaeoecology 62:237–270
Della Bella V, Manzini L (2009) Freshwater diatom and macroinvertebrate diversity of coastal permanent ponds along a gradient of human impact in a Mediterranean eco-region. Hydrobiologia 634:25–41

Della Bella V, Puccinelli C, Marchegiani S, Mancini L (2007) Benthic diatom communities and their relationship to water variables in wetlands of central Italy. Annales de Limnologie/International Journal of Limnology 43(2):89–99

Elvan OD, Birben Ü (2021) Analysis of the Ramsar convention’s effectiveness on the Turkish legislation and judicial decisions. Wetlands 41:35. https://doi.org/10.1007/s13157-021-01435-4

Figler A, B-Béres V, Dobronoki D, Marton K, Nagy SA, Bácsi I (2019) Salt tolerance and desalination abilities of nine common green microalgal isolates. Water 11:2527. https://doi.org/10.3390/w1112527

Gasith A, Resh VH (1999) Streams in Mediterranean climate regions: abiotic influences and biotic responses to predictable seasonal events. Annual Review of Ecology and Systematics 30:51–81

Gasse F (1986) East African diatoms. Taxonomy, ecological distribution. Bibliotheca Diatomologica 11:1–202

Gasse F (1987) Diatoms for reconstructing palaeoenvironments and paleohydrology in tropical semi-arid zones. Hydrobiologia 154:127–163

Gottschalk S, Kahler M (2012) Shifts in taxonomic and guild composition of littoral diatom assemblages along environmental gradients. Hydrobiologia 694:41–56

Guerrero MC, de Wit R (1992) Microbial mats in the inland saline lakes of Spain. Limnetica 8:197–204

Hammer UT (1990) The effects of climatic change on the salinity, water levels and the biota of Canadian prairie saline lakes. Verhandlungen des Internationalen Verein Limnologie 24:321–326

Hustedt F (1930) Die Süßwasserflora Mitteleuropas. - In: A. PASCHER (ed): Bacillariophyta (Diatomeae), Heft 10, 2nd edn. - 466 pp., Verlag von Gustav Fischer

Jeppesen ES, Bruclt L, Naselli-Flores E, Papastergiadou K, Stefanidis T, Noges P, Noges JL, Attayde T, Zohary J, Coppins T, Bucak RF, Menezes FRS, Freitas M, Søndergaard M, Bekliog˘lu M (2015) Ecological impacts of global warming and water abstraction on lakes and reservoirs due to changes in water level and salinity. Hydrobiologia 753:201–227

Krammer K, Lange-Bertalot H (1985) Naviculacea. - 230 pp., Bibliotheca Diatomologica, vol 9. J. Cramer, Berlin-Stuttgart

Krammer K, Lange-Bertalot H (1986) Bacillariophyceae. Cen- trales, Fragilariales, Eunoticeae. Süßwasserflora von Mitteleuropa, vol 1. - 876 pp. Gustav Fischer Verlag, Stuttgart

Krammer K, Lange-Bertalot H (1988) Bacillariophyceae. Bacillariaceae, Epicladiaceae, Surirellaceae. Süßwasserflora von Mitteleuropa, vol 2. Gustav Fischer Verlag, Stuttgart, p 596

Krammer K, Lange- Bertalot H (1991a) Bacillariophyceae. Centrales, Fragilariales, Eunoticeae. Süßwasserflora von Mitteleuropa, vol 3. Gustav Fischer Verlag, Stuttgart, p 577

Krammer K, Lange-Bertalot H (1991b) Bacillariophyceae. Achnan- thaceae, Kristische Ergänzungen zu Navicula (Lineolatae) und Gomphonema Gesamtliteraturverzeichnis. Süßwasserflora von Mitteleuropa, vol 4. Gustav Fischer Verlag, Stuttgart, p 437

Lange-Bertalot H (2001) Naviculaceae, Kristische Ergänzungen zu Navicula sensu stritco. Frustulia. Diatoms of Europe 2:1–526

Lange-Bertalot H (2000-2002) Diatoms of Europe. Diatoms of Euro- pean inland waters and comparable habitats, vols. I-IV. (A.R.G. Gantner Verlag K.G.: Rugell.)

Lekov Z (2009) Amphora sensu lato. In: Lange-Bertalot, H. (Ed.) Diatoms of Europe. Diatoms of the European inlandwaters and comparable habitats 5. Ruggell, A.R.G. Gantner Verlag K.G., 916 pp

Linnaeus Cuesta JE (2003) Las diatomeas bentónicas de las lagunas del Parque Nacional de Sierra Nevada. Estudio comparado con las colecciones del Herbario de la Universidad de Granada. 324 pp. Tesis doctoral. Universidad de Granada

Lowenstein TK, Schubert BA, Timo feef MN (2011) Microbial communities in fluid inclusions and long-term survival in halite. GSA Today 21:4–9

Lucena-Moya L, Gómez-Rodríguez C, Pardo I (2012) Spatio-temporal variability in water chemistry of Mediterranean coastal ponds and its management implications. Ponds 32(6):1033–1045

Millán A, Velasco J, Gutiérrez-Cánovas C, Arribas P, Picazo F, Sánchez-Fernández D, Abellán P (2011) Mediterranean saline streams in southeast Spain: what do we know? Journal of Arid Environments 75:1352–1359

Montes C, Martino P (1987) Las lagunas salinas españolas. Bases cien tíficas para la protección de los humedales en España: 95-145. Real Academia de Ciencias de Madrid

Montes C, Gonzalez-Capitel E (2002) Plan Andaluz de Humedales. Consejería de Medio Ambiente (Junta de Andalucia), Sevilla. 253 pp

Martin G, Toja J, Sala SE, de los Reyes Fernández M, Reyes I, Adela Casco M (2010) Application of diatom biotic indices in the Gualdi quir River Basin, a Mediterranean basin. Which one is the most appropriated? Environmental Monitoring and Assessment 170(1–4):519–534

Montes C, González-Capitel E (2002) Plan Andaluz de Humedales. Consejería de Medio Ambiente (Junta de Andalucia), Sevilla. 253 pp.

Montoya H (2009) Algal and cyanobacterial saline biofilms of the grande coastal wetland Lima, Peru. Natural Resources and Envi ronmental Issues 15(23):127–134

Nagy L, Pêterfi LS, Stefan L (2008) Preliminary data on the diatom communities from “Lacul Sulfuros” (“Lake No. 6”) near Turda (Cluj, County, Romania). Contrib Bot 43:105–111

Negro AI, De Hoyos C (2005) Relationships between diatoms and the environment in Spanish reservoirs. Limnetica 24(1–2):133–144

Ntiamaa-Baidu Y (1991) Seasonal changes in the importance of coastal ponds in Ghana for wading birds. Biological Conservation 57:139–153

Oren A (2014) The ecology of Dunaliella in high-salt environments. Journal of Biological Research (Thessalon) 21(1):23

Pienitz R, Smol J, Birks H (1995) Assessment of Freshwater Diatoms as Quantitative Indicators of Past Climatic Change in the Yukon and Northwest Territories, Canada. Journal of Paleolimnology 13(1):21–49. https://doi.org/10.1007/BF00678109

Polge N, Sukatar A, Soylu EN, Gönülol A (2010) Epipelic Algal Flora of Paleolimnology 19:129–137

Potapova M, Charles DF (2003) Distribution of benthic diatoms in U.S. rivers in relation to conductivity and ionic composition. Freshwater Biology 48:1311–1328

Reed JM (1998a) A diatom–conductivity transfer function for Spanish salt lakes. Journal Paleolimnology 19:399–416

Reed JM (1998b) Diatom preservation in the recent sediment record of Spanish saline lakes: implications for palaeoclimatic study. Journal of Paleolimnology 19:129–137

Reed JM, Mesquita-Joanes F, Griffiths HI (2012) Multi-indicator conduc tivity transfer functions for Quaternary palaeoclimate reconstruction. Journal of Paleolimnology 47:251–275
Ribeiro L (2010) Intertidal benthic diatoms of the Tagus estuary: taxonomic composition and spatial-temporal variation. PhD thesis, Universidade de Lisboa. Faculdade de Ciências, Lisboa

Ribeiro L, Hernández-Fariñas T, Laurent B (2019) Diatom atlas of the intertidal mudflats of the Loire estuary. University of Nantes deliverable for the French Agency Biodiversity, p 161. https://doi.org/10.5281/Zenodo3560055

Rivera-Rondón CA, Catalan J (2017) Diatom diversity in the lakes of the Pyrenees: An iconographic reference. Limnetica 36:127–395

Resende P, Azeiteiro U, Pereira MJ (2005) Diatom ecological preferences in a shallow temperate estuary (Ria de Aveiro, Western Portugal). Hydrobiologia 544:77–88

Round FE (1953) An investigation of two benthic algal communities in Malharm Tarn, Yorkshire. Journal of Ecology 41:97–174

Sánchez Castillo PM (1993) *Amphora margalefii* Tomas var. *lacustris* P. Sanchez var. nova, a new brackish water diatom. Hydrobiologia 269/270:81-86

Schoeman FR (1972) A further contribution to the diatom flora of sewage enriched water in southern Africa. Phycologia 11(3/4):239–245

Schubert BA, Timofeeff MN, Lowenstein TK, Polle JEW (2010) Dunaliella cells in fluid inclusions in halite: significance for long-term survival of prokaryotes. Geomicrobiology Journal 27:61–75

Siqueiros-Beltrones DAS, Ibarra-Obando E, Poumiñán-Tapia M (1991) Composición y estructura de las asociaciones de diatomeas bentónicas del estero de Punta Banda en otoño de 1983-1986. Ciencias Marinas 17(1):119–138

Shi H, Lee B, Wu SJ, Zhu JK (2002) Overexpression of a plasma membrane Na+/H+ antiporter gene improves salt tolerance in Arabidopsis thaliana. Nature Biotechnology 20:81–85

Solak C, Alakananda B, Kulikovskiy M (2019) Distribution of nitzschioïd diatoms in Kütahya waters. Oceanological and Hydrobiological Studies 48(2):140-164. Retrieved 3 Oct 2019, from https://doi.org/10.1515/ohs-2019-0014

Steele DJ, Franklin DJ, Underwood GJC (2014) Protection of cells from salinity stress by extracellular polymeric substances in diatom biofilms. Biofouling: The Journal of Bioadhesion and Biofilm Research 30(8):987–998

Stener-Kovács Cs, Lengyel E, Buczko K, Tóth FM, Crossetti LO, Pellinger A, Zámbo Doma ZS, Padišák J (2014) Vanishing world: alkaline, saline lakes in Central Europe and their diatom assemblages. Inland Waters 4:383–396

Stepanek JG, Kociolek JP (2015) Three new species of the diatom genus *Halamphora* (Bacillariophyta) from the prairie pothole lakes region of North Dakota, USA. Phytotaxa 197(1):27–36

Stevenson RJ (1996) An introduction to algal ecology in freshwater benthic habitats. In: Stevenson RJ, Bothwell ML, Lowe RL (eds) Algal ecology: freshwater benthic ecosystems. Academic Press, Inc., Cambridge, pp 3–30

Tibby J, Gell PA, Fluin J, Sluiter IR (2007) Diatom–salinity relationships in wetlands: assessing the influence of salinity variability on the development of inference models. Hydrobiologia 591(1):207–218

Underwood GJC, Yallop ML (1994) *Navicula pargemina* sp. nov. - a small epipelic species from the Severn Estuary. U K Diatom Research 9:473–478

Ubierna León MA, Sánchez-Castillo PM (1992) Diatomoflora de varias lagunas de aguas mineralizadas de las provincias de Málaga y Granada. Anales del Jardín Botánico de Madrid 49:171–185

Ventelä A, Amsinck SL, Kauppila T, Johansson LS, Jeppesen E, Kirkkala. T, Søndergaard J, Sarvala J (2016) Ecosystem change in the large and shallow lake Säkylän Pyhäjärvi (Finland) during the past ~400 years: Implications for management. Hydrobiologia 778(1):273–294

Veres AJ, Pienitz R, Smol JP (1995) Lake water salinity and periphytic diatom succession in three subarctic lakes, Yukon Territory, Canada. Arctic 48:63–70

Waisel MJ, Robarts RD (2009) Saline Inland Waters. In: Likens GE (ed) Encyclopedia of Inland Waters, vol 2, Elsevier, Oxford, pp 634-644

Witkowski A, Lange-Bertalot H, Metzeltin D (2000a) Diatom flora of marine Coasts I. Iconographia Diatomologica 7:1–925

Woodward J (2009) The physical geography of the Mediterranean. Oxford regional environments series. Oxford University Press, Oxford, p 663

Zarei-Darki B (2011) Species composition and ecology of the diatoms in the Gavkhuni wetland (Iran) / B. Zarei-Darki // Вісник Харківського національного аграрного університету. Серія: Біологія. - 2011. - Вип. 1. - С. 110-117

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.