Micro-scale distribution of algae in a Pyrenean peat-bog, Spain

Distribución en microescala de las algas de una turbera de los Pirineos, España

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ABSTRACT

We studied the small-scale distribution of algae in the Bassa Nera peat-bog (Pyrenees, NE Spain). A total of 110 algal taxa were identified, some of which are rarely recorded in Spain: *Cystodinium cornifax, Euastrum insigne* and *Desmidium swartzii*. Three algal assemblages were distinguished along the studied gradient. Data on the flora and structure of the algal communities, as well on conservation interest are given.

Key words: Algae, Cyanoprokaryota, diversity, peat-bog, Pyrenees.

RESUMEN

Se estudió la distribución de las algas a lo largo de un microgradiente en una turbera de los Pirineos. En total se identificaron 110 taxones, algunos de los cuales se encontran raramente en España como *Cystodinium cornifax, Euastrum insigne* y *Desmidium swartzii*. Se diferenciaron tres comunidades a lo largo del gradiente. Datos sobre la flora, estructura de la comunidad y estado de conservación de la comunidad son aportados.

Palabras clave: Algae, Cyanoprokaryota, diversidad, gradiente, turbera.

INTRODUCTION

Peat-bogs are ecosystems with a high degree of organization, which leads to spatial heterogeneity and characteristic structures consisting of water pools alternating with hummocks of *Sphagnum (Margalef*). The nutrient input to these ecosystems is limited and consists essentially of minerals dissolved in rainwater. In general, peat-bogs are characterized by low primary production, but have considerable accumulation of organic matter. Nevertheless, this accumulation of elements is not passive, because the considerable circulation and redistribution of water in peat-bogs usually create diverse micro-gradients.

Peat-bogs are highly suitable habitats for algal flora and assemblages (Bunt, 1954; Ettl, 1968, 1970; Hickman & Vitt, 1973; Kitner et al., 2004; Neustupa et al., 2009; Nováková & Poulíčková, 2004; Skuja, 1948, 1956, 1964; Šťastný, 2009). These studies focused on flora and ecological gradients, too (Poulíčková et al., 2003).

Various aspects of the aquatic systems in the Pyrenees mountains have been tackled, mainly by studies of lakes (Bartumeus et al., 2006; Catalán, 1987; Catalán et al., 1993, 2006; Felip et al., 1995, 1999; Gacia et al., 1994; Pla, 1999, 2001; Sanz et al., 2002; Vilaseca, 1978), but also of springs and rivers (Sabater & Roca, 1990, 1992).

In addition to lakes and rivers, *Sphagnum* peat-bogs form another widespread Pyrenean freshwater ecosystem. Interest in *Sphagnum* vegetation is readily explained by the fact that this group of mosses is the most ecologically dominant and economically important worldwide (Andrus, 1986).

In the Spanish Pyrenees, *Sphagnum* peat–bogs are usually restricted to, lake shores or wet soils situated between 1,800 and 2,200 m a.s.l. (Casas *et al.,* 1994). These peat-bogs cover only small areas. In general, they are ecologically important and are sometimes considered vulnerable ecosystems. This vulnerability is especially relevant in the Pyrenees because there are few bogs and these are exposed to persistent negative influences that can severely disturb or even destroy them (e.g. drought, tourist activities, draining, overgrazing by cows and sheep).

Several studies have examined the algal flora of Pyrenean peat-bogs (Allorge & Manguin, 1941; Cambra, 1998, 2010; Cambra & Roura, 1995; Cambra & Hindák, 1998; Carter, 1970; González-Guerrero, 1927; Massanell, 1966; Margalef, 1946, 1948, 1952, 1956). However, additional data on the biodiversity of these ecosystems are still required. *Sphagnum* peat-bogs host a wide variety of algae, which usually form highly diverse populations. *Sphagnum* mosses reduce the pH of a given site (Glime *et al.,* 1982) and may alter its environmental variables (Poulíčková *et al.,* 2004). This capacity explains why species distribution differs along environmental gradients, e.g. from wet to dry *Sphagnum* (Andrus, 1986). However, little attention has been paid to the distribution of *Sphagnum* in peat-bogs in the Pyrenees. Here, we studied algal communities along an ecological gradient in a peat-bog in the Bassa Nera lake.

MATERIALS AND METHODS

The study was carried out (summer 2010) at the Bassa Nera lake, located in the Aigüestortes National Park, NW Catalan Pyrenees (Fig. 1). This water body can be considered a relict lake with extended *Sphagnum* vegetation. The lake is located 1,890 m a.s.l., below the Gran Tuc de Colomers mountain (GPS 42º 38' N, 0º 55' E). The substrate is schist, the lake has an average depth of almost 4 m and its water is dark brown (Bassa Nera means 'Black Pond'). The catchment covers approximately 37 ha. The lake is oval (102 x 64 m), with a surface area of just over 4,500 m^2. A flat peat-bog in the littoral zone holds a massive layer of *Sphagnum* that has a thickness of 4 m and covers almost 7,000 m^2.

To study how the composition of algal assemblages changes over gradients, three parallel, linear transects were done from the open water into the *Sphagnum* peat-bog (Fig. 2). Each transect was 10 m long. Algal samples were collected every 2 m along each transect. A total of 12 samples were collected (4 samples per transect) from the lake shore of the *Sphagnum* zone (T1, T2, T3), from the dry-*Sphagnum* "hummock" zone (T4, T5, T6) and from the *Sphagnum* peat-bog zone surrounding the lake (T7 to T12). All samples were collected by squeezing a similar biomass of *Sphagnum* heads. Samples were then preserved in the field with formaldehyde to a final concentration of 4%. In addition, measu-

Figure 1. View of the Bassa Nera lake and *Sphagnum* peat–bog around.

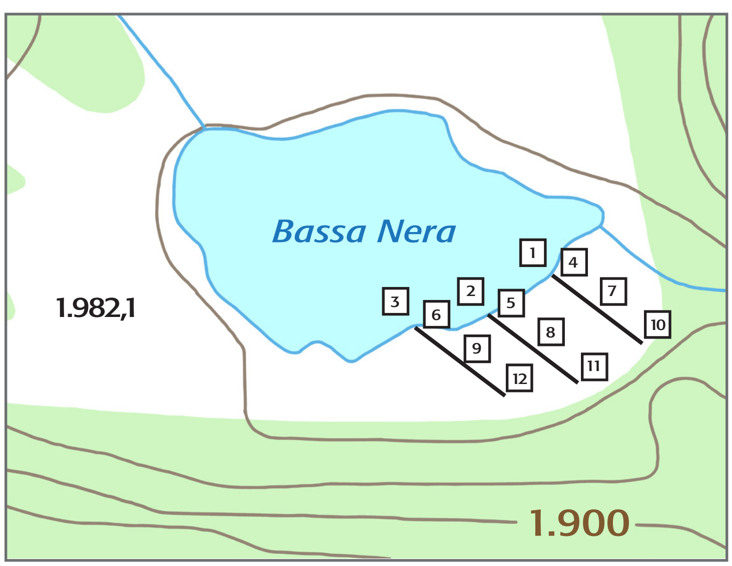


Figure 2. Way and sites where the algal samples were collected along the transect in Bassa Nera Lake, Spain.

rements for water temperature, pH (CRISON-pH), electrical conductivity (CRISON-Conductivimeter) and water content (% moisture out of *Sphagum* mass) were taken along the transects.

Algae were studied under an OLYMPUS BX–51 microscope. Each sample was homogenized before being pipetted onto previously prepared slide mounts. Diatoms were cleaned following Tomàs (1988) and mounted with naphrax. For taxonomic identification, several monographs were used Anagnostidis & Komárek, 1988; Bourrelly, 1968, 1970, 1972; Desikachary, 1959; Gonzalves, 1981; Komárek & Anagnostidis, 1990, 2000, 2005; Komárek & Fott, 1983; Krammer, 1997, 2002, 2003; Krammer & Lange-Bertalot, 1985, 1986, 1988, 1991a,b; Lange-Bertalot 1993, 1996, 1999a, b, 2001, 2002, 2003, 2004; Krieger, 1937; Lange-Bertalot & Krammer, 1989; Lenzenweger, 1996, 1997, 1999, 2003; Mrozińska, 1985; Popovský & Pfiester, 1990; Printz, 1964; Starmach, 1966, 1972).

Cells were counted in random microscopic fields until a total of 300-400 valves/cells were reached. The relative abundance of each taxon was then calculated. From these data, we calculated the Shannon & Weaver's diversity index (H') for each sample. In addition, a Canonical Correspondence Analysis (CCA) was performed with the PAST statistical package. This statistical analysis was done to identify algal assemblages along the gradient, as well as to check the relationship between certain physico-chemical parameters and the species.

RESULTS

The water temperature of the lake ranged between 21.3 and 27.4 ºC, while the water temperatures in the *Sphagnum* peat-bog were narrower, ranging between 26 and 27.4 ºC (Table 1). The pH of the lake was between 3.7 and 5.62, while in the *Sphagnum* peat-bog it was lower, between 3.7 and 4.02. The conductivity values in the water lake were 50-121 µS/cm, while in the *Sphagnum* peat-bog they were 67.2-121 µS/cm.

A total of 110 algal taxa were identified (Table 2), of which desmids (37.6%) and diatoms (33%) were the dominant groups. The algal flora in the Bassa Nera lake had ubiquitous algal taxa, e.g. *Achnanthidium minutissimum (Kützing) Czarnecki, Cocconeis placentula Ehrenberg* or *Pinnularia viridis (Nitzsch.) Ehrenberg.* We also observed numerous species which are considered acidophilous, e.g. *Chroococcus turgidus* (Kützing) Nägeli, *Cosmarium rectangulare* Grun. (Fig. 3F), *Desmidium swartzii Agardh* ex Ralfs (Fig. 3B,) *Euastrum insigne* Hassall ex Ralfs, *E. pulchellum Brébisson.* (Fig. 3C), *Netrium digitus* (Ehrenberg ex Ralfs) Itzigs. & Rothe, *Oocystis solitaria* Wittr., *Penium polymorphum* (Perty) Perty, *Xanthidium armatum* (Brébisson) Rabenh. ex Ralfs (Fig. 3E) and *Staurastrum striolatum* (Nägeli) Arch. (Fig. 3D). Several species are of particular interest, as they have rarely been recorded in Spain, such as *Cystodinium cornifax* (Schilling Klebs), *Euastrum crassum* Kützing, *Euastrum insigne* Hassall ex Ralfs (Fig. 3A), *Euglena mutabilis* Schmitz, *Gymnodinium fuscum* (Ehrenberg) Stein, *Monomastix pyrenigera* Skuja, *Sphaerocystis stellata* Her. and *Woloszynskia neglecta* (Schilling) Thompson.

Lake vegetation were, dominated by *Potamogeton alpinus, Myriophyllum alterniflorum*, *Utricularia* sp. and *Equisetum fluviatile*. The vegetation covered 3,900 m^2, which accounts for 85% of the lake's surface. The presence of other species on the *Sphagnum* peat-bog was

Table 1. Data of water temperature (ºC), pH, Conductivity (µS/cm), Shannon diversity (H') and water contents along the Bassa Nera transect.

	Temperature (ºC)	pH	Conductivity (µS/cm)	Shannon Diversity (H')	Water contents (%)
T1	21.3	5.62	50	2.37	98
T2	26	3.7	121	2.83	100
T3	27.4	3.7	94	2.39	99
T4	25.4	4.02	67.2	1.74	12
T5	26	3.7	121	1.98	10
T6	26	3.7	121	1.9	8
T7	27.4	3.7	94	1.94	37
T8	26.4	3.7	94	1.91	38
T9	27.4	3.7	94	2.04	34
T10	25.5	4.02	67.2	2.1	38
T11	25.6	4.02	67.2	1.71	35
T12	25.4	4.02	67.2	1.83	36

Table 2. List of algae and cyanoprokaryota taxa found in the Bassa Nera Lake at the Pyrenean peat-bog, Spain.

Cyanoprokaryota
Anabaena lapponica Borge
Anabaena solitaria Klebahn
Anabaena subcylindrica Borge
Aphanothece microscopica Nägeli
Calothrix braunii Bornet *et* Flahault
Chroococcus turgidus (Kützing) Nägeli
Cylindrospermum stagnale (Kütz) ex Bornet *et* Flahault
Eucapsis alpina Clements *et* Schantz
Gloeocapsa granosa (Berkeley) Kützing
Gloeothece distans Sitzenberger
Hapalosiphon fontinalis Bornet
Merismopedia punctata Meyen
Merismopedia tenuísima Lemmermann
Nostoc kihlmanii Lemmermann
Nostoc sphaericum Vaucher ex Bornet *et* Flahault
Synechococcus major Schrot.
Tolypothrix tenuis (Kützing) Schmidt
Bacillariophyta
Aulacoseira granulata (Ehrenberg) Simonsen
Achnanthidium minutissimum (Kützing) Czarnecki
Brachysira brebissonii Ross
Caloneis tenuis (Gregory) Krammer
Chamaepinnularia begerii (Krasske) Lange-Bertalot
Cocconeis placentula Ehrenberg
Cymatopleura elliptica (Brébisson) Smith

Table 2. (Continuation)

Cymbella cymbiformis Agardh
Diatoma mesodon (Ehrenberg) Kützing
Encyonema gracile Ehrenberg
Encyonema mesianum (Cholnoky) Mann
Encyonema minutum (Hilse) Mann
Epithemia sorex Kützing
Eunotia arcus Ehrenberg
Eunotia incisa Gregory
Eunotia lapponica Grunow
Eunotia naegelii Migula
Eunotia paludosa Grunow
Eunotia serra var*. tetraodon* (Ehrenberg) Nörpel
Pseudostaurosira brevistriata (Grunow) D.M. Williams
Frustulia crassinervia (Ehrenberg) Lange-Bertalot *et* Krammer
Gomphonema acumintaum Ehrenberg
Gomphonema gracile Ehrenberg
Gomphonema truncatum Ehrenberg
Hantszchia amphioxys Kützing
Kobayasiella subtilissima (Cleve) Lange-Bertalot
Navicula radiosa Kützing
Nitzschia paleaeformis Hustedt
Peronia fibula (Brébisson) Ross
Pinnularia maior (Kützing) Rabenh.
Pinnularia microstauron (Ehrenberg) Cleve
Pinnularia stomatophora (Grunow) Cleve
Pinnularia subcapitata Gregory
Pinnularia viridis (Nitzsch) Ehrenberg
Pseudostaurosira brevistriata (Grunow in Heurck) Williams *et* Round
Sellaphora pupula (Kützing) Mereschkovsky
Tabellaria flocculosa (Roth) Kützing

Chrysophyta
Ochromonas verrucosa Skuja

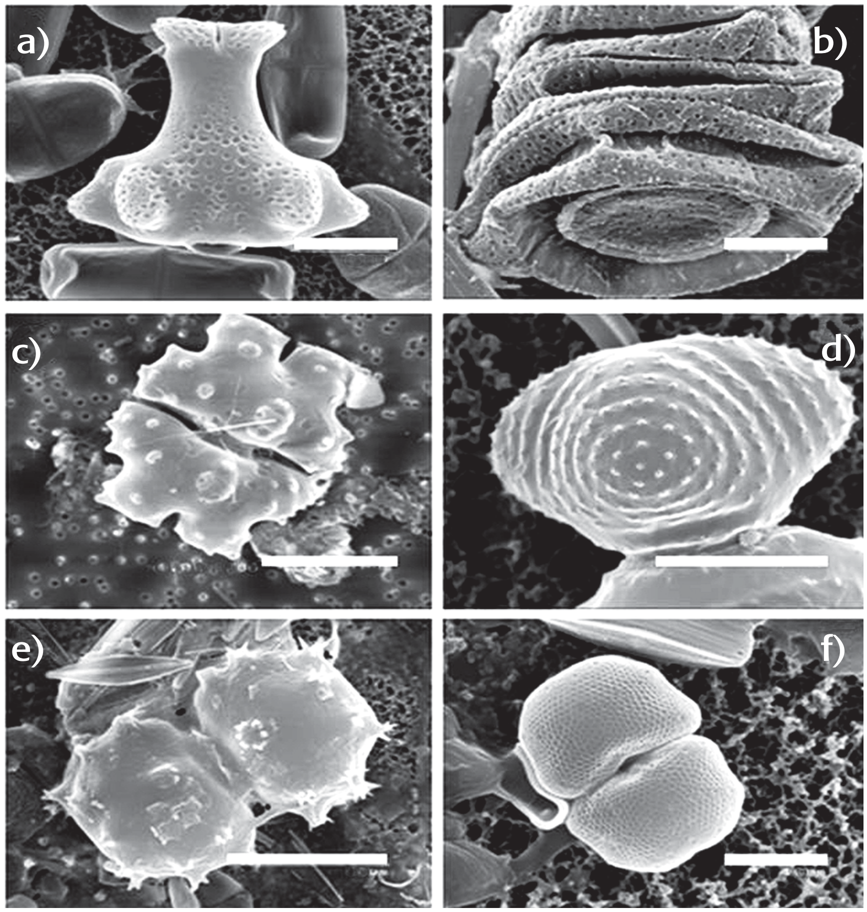
Dinophyta
Cystodinium cornifax (Schilling) Klebs
Gymnodinium fuscum (Ehrenberg) Stein
Hemidinium nasutum Stein
Woloszynskia neglecta (Schilling) Thompson

Xanthophyta
Chlorobotrys polychloris Pascher

Chlorophyceae
Monomastix pyrenigera Skuja
Oedogonium sp.
Oocystis solitaria Wittr.
Pandorina morum (O.F. Müller) Bory
Stichococcus minutus Grintz *et* Péterfi
Asterococcus superbus (Cienkowski) Scherffel
Sphaerellocystis stellata Ettl

Zygnematophyceae
Closterium attenuatum Ehrenberg
Closterium closterioides (Ralfs) Louis *et* Peeters
Closterium costatum Corda ex Ralfs
Closterium dianae Ehrenberg ex Ralfs
Closterium intermedium Ralfs
Closterium lunula Schmidle
Closterium striolatum Ehrenberg ex Ralfs
Cosmarium amoenum Brébissonin Ralfs
Cosmarium connatum (Brébisson) Ralfs
Cosmarium conspersum Ralfs
Cosmarium pachydermum Lund.
Cosmarium portianum Arch.
Cosmarium ralfsii Brébisson
Cosmarium rectangulare Grunow
Cylindrocystis brebissonii (Menegh. ex Ralfs) De Bary
Desmidium swartzii Agardh ex Ralfs
Eremosphaera viridis De Bary
Euastrum crassum Kützing
Euastrum insigne Hassall ex Ralfs
Euastrum insulare (Wittrock) Roy
Euastrum pulchellum Brébisson
Hyalotheca mucosa Ralfs
Mesotaenium sp.
Micrasterias pinnatifida (Kützing) Ralfs
Netrium digitus (Ehrenberg ex Ralfs) Itzigs *et* Rothe
Netrium oblongum (De Bary) Lütk.
Penium didymocarpum Lund.
Penium polymorphum (Perty) Perty
Penium spirostriolatum Barker
Pleurotaenium ehrenbergii (Brébisson) De Bary
Staurastrum brachiatum Ralfs
Staurastrum controversum Brébisson
Staurastrum cristatum (Nägeli) Archer
Staurastrum hirsutum Ehrenberg ex Ralfs
Staurastrum striolatum (Nägeli) Archer
Staurastrum teliferum Ralfs
Staurodesmus aristiferum (Ralfs) Thomson
Staurodesmus dejectus (Brébisson ex Ralfs) Teil
Teilingia granulata (Roy *et* Bisset) Bourrelli
Tetmemorus laevis (Kützing) Ralfs
Xanthidium armatum Brébisson ex Ralfs

Euglenophyta
Euglena mutabilis Schmitz



Figures 3a-f. Desmids of Bassa Nera at spanihs Pyrenees. a) *Euastrum insigne* Hassall ex Ralfs (Segment = 20 μm); b) *Desmidium swartzii* Agardh Ex Ralfs (Segment = 10 μm); c) *Euastrum insulare* (Wittr.) Roy (segment = 10 μm); d) *Staurastrum striolatum* (Nägeli) Arch. (Segment = 10 μm); e) *Xanthidium armatum* (Brébisson) Rabenh. ex Ralfs (Segment = 50 μm); f) *Cosmarium rectangulare* Grun. (Segment = 10 μm).

also notable (e.g. *Drosera rotundifolia, Drosera anglica, Eriophorum* sp., *Menyanthes trifoliata, Parnassia palustris* and *Potentilla palustris*).

The first two axes in the results from the CCA (Fig. 4) explained 83.93% of the data variability. The first CCA axis had more weight and we considered that it expresses a combined pH and moisture gradient (54.47% of the variability). The pH was lower at T4, T5, T6, T7-T12 and higher at T1, T2 and T3. For the second CCA axis, conductivity had more weight (29.46% of variability). Points T4, T5 and T6 had greater conductivity. Moreover, these sampling points were aerophytic environments. In contrast, points T7-T12 corresponded to the transition from an aquatic to a terrestrial environment and the largest expansion of *Sphagnum* biomass.

Three groups of algal communities were clearly differentiated along the gradient. Nevertheless, in spite of the spatial segregation of three environments in the peat-bog, some taxa were distributed throughout the whole transect, tolerating the small variations in pH, conductivity and temperature, e.g. *Frustulia crassinervia* (Ehrenberg) Lange-Bertalot & Krammer, *Navicula subtilissima* Cleve and *Tabellaria flocculosa* (Roth) Kützing.

Group I: The lake shore *Sphagnum* zone (T1, T2, T3) had relatively acidic water and the algal assemblage was dominated mainly by *Encyonema minutum* (Hilse) Mann, *Pinnularia maior* (Kützing) Rabenh., *Closterium costatum* Corda ex Ralfs, *Cosmarium conspersum* Ralfs and *Actinotaenium turgidum* (Brébisson ex Ralfs) Teiling. However, the quantitative data showed that, in terms of relative abundance, diatoms and flagellated dinophytes (especially *Woloszynskia neglecta* (Schilling) Thom.) were the dominant taxa in this zone. The species included in Group I corresponded to a mixture of taxa, a characteristic of peat-bogs, together with representatives of phytoplankton dystrophic lakes.

Group II: The dry *Sphagnum* "hummock" zone, with less water. This environment had subaerial conditions, which was the main ecological factor. In general, acidophilous taxa and aerophilous species were dominant, consisting mainly of *Eucapsis alpina* Clements *et* Schantz, *Oocystis solitaria* Wittr., *Gomphonema gracile* Ehrenberg, *Euastrum insulare* (Wittrock) Roy, *Cylindrocystis brebissonii* (Ralfs) de Bary, *Nostoc kihlmani* Lemmermann and *Euglena mutabilis* Schmitz, while the other algal groups were quantitatively irrelevant.

Group III: The *Sphagnum* peat-bog zone surrounding the lake (T6, T7, T8, T9, T10, T11, T12) had more acidic water and higher water

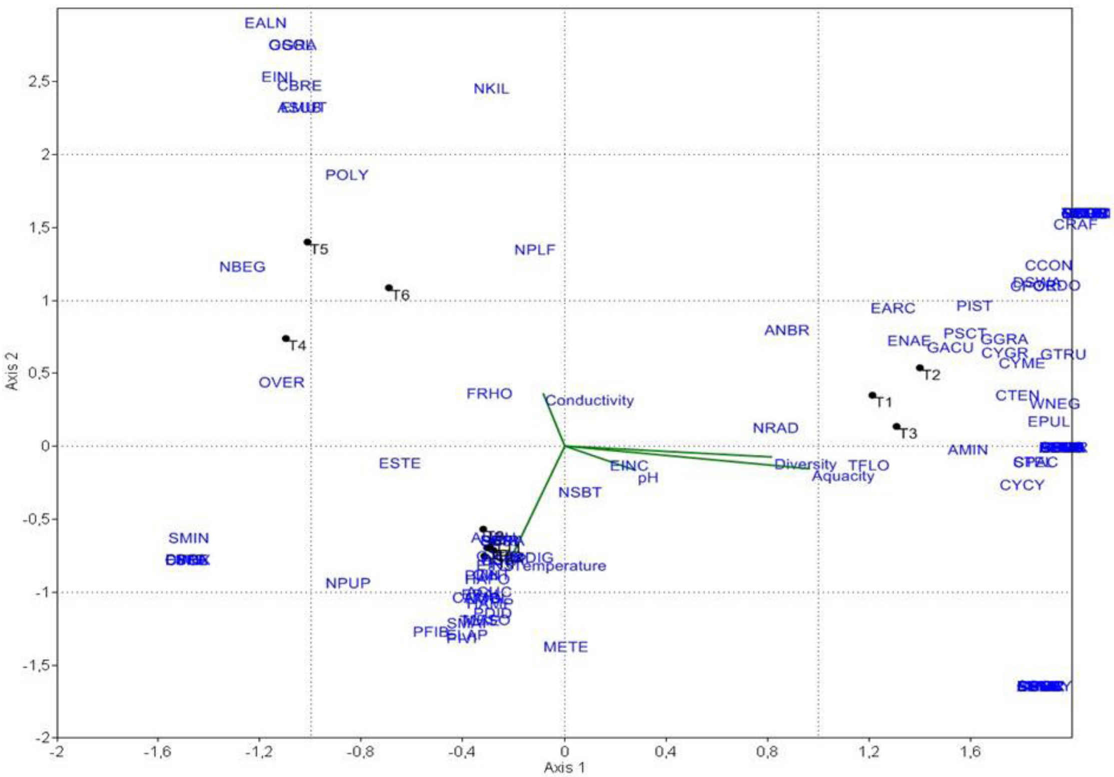


Figure 4. Correspondence Canonical Analysis (CCA) of the studied samples along the transect in Bassa Nera peat-bog at spanish Pyrenees.

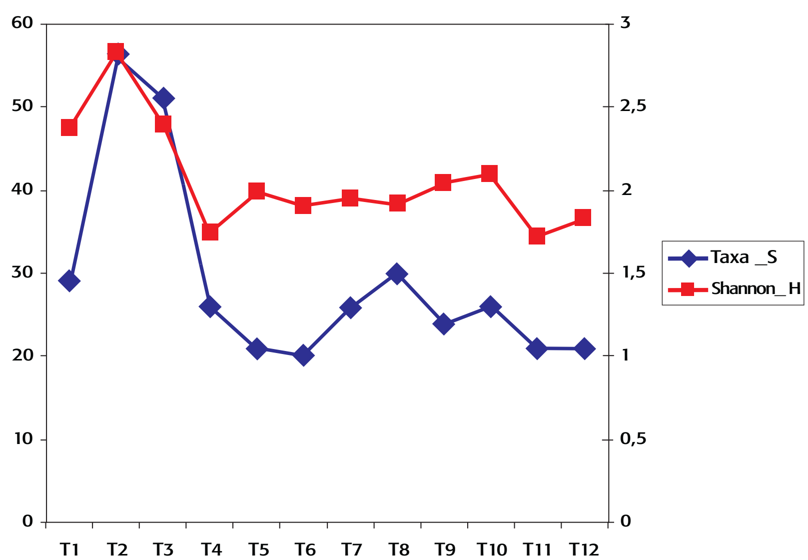


Figure 5. Diversity index (H') ans species richness (Taxa_S) variation along the transect in Bassa Nera peat-bog (Spain).

The *Sphagnum* peat-bog zone (Group III) was inhabited by typical bog algae, namely mainly desmids and diatoms. The zone's samples show affinities with *Micrasterieto jenneri-Euastretum insignis*, described by Margalef (1955) in Galicia (NW Spain). This finding greatly extends the known distribution area in Spain of this community, which is probably widespread in acidic peat-bogs of northern Spain, reaching the sub-alpine zone, as occurs in the Pyrenees. However, during our visits to more than one hundred peat-bogs in this mountain range over temperature. The *Sphagnum* peat-bog was dominated by the diatoms *Cymatopleura elliptica* (Brébisson) Smith, *Diatoma mesodon* (Ehrenberg) Kützing*, Epithemia sorex Kützing, Fragilaria brevistriata* Grun.*, Sellaphora pupula* (Kützing) Mereschkovsky, *Pinnularia microstauron* (Ehrenberg) Cleve and by other algae, such as *Cylindrospermum stagnale* (Kützing) ex Bornet & Flahault*, Hapalosiphon fontinale* (Agardh) Bornet *et* Flahault*, Euastrum insigne* Hassall ex Ralfs*, Closterium intermedium Ralfs* and *Actinotaenium cucurbita* (Brébisson) Teil. These algal groups were quantitatively and qualitatively dominant, but in this case the assemblage was formed by sphagnophilous species. Another relevant aspect was the increase (quantitatively and in species richness) in desmid taxa along the transect, reaching their highest relative abundance in this zone.

Species richness and diversity increased towards the water of the lake (Fig. 5). The diversity index (H') was between 1.71 and 2.83 along the transect. The lakeshore *Sphagnum* zone (T1, T2, T3) had higher diversity (H'=2.37-2.83 bits) than other points of the transect. In contrast, samples T4 to T12 showed slightly lower values (H'= 1.71-2.1 bits).

DISCUSSION

Peat-bog systems are characterized by low nutrient concentrations and substantial amounts of organic matter. In general, peat-bog algal assemblages consist of a mixture of acidophilous and sphagnophilous taxa, which are widespread along micro-gradients in these habitats (Cambra & Hindák, 1998; Borics et al.,1998; Kol, 1970).

The Bassa Nera lake is sheltered from the wind by terrestrial vegetation (mainly *Pinus uncinata*) and hydrophyte cover, thus reducing significant water turbulence. In these undisturbed lentic environments, organisms that do not show effective movement sink to the sediments (Borics *et al.,* 2003). This might explain why the dominant algae in the *Sphagnum* zone of the lakeshore were flagellated dinophytes like *Woloszynskia neglecta* while *Hemidinium nasutum* Stein or *Gymnodinium fuscum* (Ehrenberg) Stein were less abundant. Moreover, periphytic algae are relatively abundant in such habitats. In the Bassa Nera lake these algae were represented by *Achnanthidium minutissimum* (Kützing) Czarnecki, *Encyonema gracile* Ehrenberg, *Gomphonema gracile* Ehrenberg and *Oedogonium* sp.

As a result of the dryness of the *Sphagnum* "hummock" zone (Group II), the establishment of many desmid species was hindered, while the presence of diatoms was also limited because of the extremely low pH (Poulíčková *et al.,* 2004; Lederer,1999). This pattern was reported in peat-bogs in Hungary by Uherkovich (1984), who concluded that desmids are more sensitive to drying out than diatoms. Consequently, flora impoverishment starts with the disappearance of desmids. This is precisely what we observed for desmid species richness in the dry *Sphagnum* "hummock" zone. However, the relative abundance of desmids in Group II was higher than in the lakeshore *Sphagnum* zone. Thus, although Group II contained only a few desmid species, they were sometimes relatively abundant. On the basis of this observation, we believe that desmids, such as *Cylindrocystis brebissonii* (Menegh. ex Ralfs) de Bary, *Penium polymorphum* (Perty) Perty and *Euastrum insulare* (Wittrock) Roy, are relatively well adapted to dry peat-bog habitats. Our results are consistent with data reported by Poulíčková *et al.* (2004) and suggest that the poor algal diversity of Group II in *Sphagnum* hummocks is attributable to dry and acidic conditions.

several years, we did not detect this desmid community in any lake. Its presence in the Bassa Nera lake is highly relevant for the Aigüestortes National Park and allows it to be classified as a relict peat-lake.

With regard to the diversity index (H') of these communities, the greatest diversity was observed in Group I, thereby indicating that this algal community is diverse. However, in this case, this environment hosts not only algae that live among *Sphagnum* thalli, but also diverse forms of phytoplankton, some of which are possibly from the periphyton, which coexist with sphagnophilous species.

When dealing with small-scale gradients like the one addressed in this study, the spatial heterogeneity of algae must be examined to check for small changes over very short distances. Our results confirm those reported by Nováková (2002), in which the spatial heterogeneity of algal communities of particular microbiotopes varied more than between various localities (peat-bogs). Moreover, we observed that species dominance increased with decreasing moisture, results that are consistent with the findings reported by Poulíčková *et al.* (2003) and Krenková (2001).

Our results confirm the high algal biodiversity in *Sphagnum* peat-bogs (even in southern European countries). The recent decrease in species diversity in European peat-bogs reflects the long dry period that started in the early eighties (Borics *et al.,* 2003). On the basis of these considerations and our results, we conclude that peat-bog algal assemblages could serve as indicators of anthropogenic disturbances at local levels, as well as climate changes on a global scale.

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REFERENCES

Allorge, P. & E. Manguin. 1941. Algues d'eau douce des Pyrénées basques. *Bulletin Société Botanique de France* 88: 159-191.

Anagnostidis, K. & J. Komárek. 1988. Modern approach to the classification system of cyanophytes *Oscillatoriales*. *Archiv für Hydrobiologie* 50-53: 327-472.

Anagnostidis, K. & J. Komárek. 1990. Modern approach to the classification system of cyanophytes *Stigonematales*. *Arch. Hydrobiol.* 59: 1-73.

Andrus, R. E. 1986. Some aspects of *Sphagnum* ecology. Canadian Journal of Botany. 64: 416-426

Borics, G., J. Padisák, I. Grigorszky, I. Oldal, I. Péterfi. & L. Momeu. 1998. Green algal flora of the acidic bog-lake, Balátá-tó SW Hungary. *Biologia. Bratislava* 53: 457-465.

Borics, G., B. T´hmérész, I. Grigorszky, J. Padisák, G. Várbíró. & S. Szabo. 2003. Algal assamblage types of bog-lakes in Hungary and their relation to water chemistry, hydrological conditions and habitat diversity. *Hydrobiologia* 502: 145-155.

Bourrelly, P. 1968. Les algues d'eau douce. Algues jaunes et brunes. N. Boubée & Cie., Paris. 438 p.

Bourrelly, P. 1970. Les algues d'eau douce. Initiation à la systématique. Tome 3: les algues bleues et rouges. Les Eugléniens, Peridiens et Cryptomonadines. N. Boubée & Cie., Paris. 252 p.

Bourrelly, P. 1972. Les algues d'eau douce. Initiation à la systématique. Tome 1: les algues vertes. N. Boubée & Cie., Paris. 517 p.

Bunt, J. S. 1954. A comparative account of the terrestrial diatoms of Macquarie Island. *Proceedings of the Linnean Society of London* 79: 34-57.

Cambra, J. 1998. Observacions sobre la biodiversitat de desmidiàcides Cloròfits a Catalunya. *Acta botánica barcinonensia* 45: 115-132.

Cambra, J. 2010. Chrysophytes from some lakes and peat-bogs in the eastern Pyrenees, Catalonia Spain. *Biologia* 65: 577-586

Cambra, J. & F. Hindák. 1998. Green algae from mountain peat–bogs in the Eastern Pyrenees Catalonia, Spain. *Biologia* 34: 467-480.

Cambra, J. & M. T. Roura. 1995. Contribució al coneixement de les desmidiàcies *Chlorophyta* de les torberes dels Pirineus, pp. 91-107. *In*: Aniz, M. (Ed.), III Jornades de Recerca del Parc Nacional d'Aigüestortes, Boí, Spain.

Carter, J. R. 1970. Diatoms from Andorra. *Nova Hedwigia* 31: 605-652.

Casas, C., M. Brugués & R. M. Cros. 1994. Els esfagnes de les mulleres del Parc Nacional d'Aigüestortes i estany de Sant Maurici. *In*: Aniz, M. Ed.: III Jornades de Recerca del Parc Nacional d'Aigüestortes, Boí, Spain. 81-90 p.

Catalán, J. 1987. Limnologia de l'estany Redó Pirineu central. Doctoral Thesis, Univ. Barcelona, Barcelona. 229 pp.

Catalán, J., E. Ballesteros, E. Gacia, A. Palau & Ll. Camarero. 1993. Chemical composition of disturbed and undisturbed high-mountain lakes in the Pyrenees: a reference for acidified sites. *Water research* 271: 133-141.

Catalán, J., L. Camarero, M. Felip, S. Pla, M. Ventura, T. Buchaca. F. Bartumeus, G. de Mendoza, A. Miró, E. O. Casamayor, J. M. Medina-Sánchez, M. Bacardi, M. Altuna, M. Bartrons & D. Díaz de Quijano. 2006. High mountain lakes: extreme habitats and witnesses of environmental changes. *Limnetica* 251-2: 551-584.

Desikachary, T. V. 1959: *Cyanophyta*. ICAR, N. Delhi. India. 685 p.

Ettl, H. 1968. Ein Beitrag zur Kenntnis der Algenflora Tirols. *Berichte des naturwissenschaftlich-medizinischen Vereins in Innsbruck* 56: 177–354.

Ettl, H. 1970. Ein Beitrag zur Kenntnis der Algenflora Tirols II. *Berichte des naturwissenschaftlich-medizinischen Vereins in Innsbruck* 58: 89-124.

Felip, M., B. Sattler, R. Psenner. & J. Catalán. 1995. Highly active microbial communities in the ice and snow cover of high mountain lakes. *Applied & Environmental Microbiology* 61: 2394-2401.

Felip, M., L. Camarero. & J. Catalán. 1999. Temporal changes of microbial assemblages in the ice and snow cover of a high mountain lake. *Limnology Oceanography* 44: 973-987.

Gacía, E., E. Ballesteros, Ll. Camarero, O. Delgado, A. Palau, J. Riera & J. Catalán. 1994. Macrophytes from the Easter Pyrenean lakes: composition and ordination in relation to environmental factors. *Freshwater Biology:* 73-81.

Glime, J. M., R. G. Wetzel. & B. J. Kennedy. 1982. The effects of bryophytes on succession from alkaline marsh to sphagnum bog. *American Midely Naturalist* 108: 209-223.

González-Guerrero, P. 1927. Contribución al conocimiento ficológico del Pirineo español. *Boletín Real Sociedad Española Historia Natural* 27: 434-346.

Gonzalves, E. A. 1981. *Oedogoniales*. I.C.A.R., New Delhi. 757 p.

Hickman, M. & D. H. Vitt. 1973. The aerial epiphytic diatom flora of moss species from subantarctic Campbell Island. *Nova Hedwigia* 24: 443-458.

Kitner, M., A. Poulnicková, R. Novotny. & M. Hájek. 2004. Desmids *Zygnematophyceae* of the spring fens of a part of West Carpathians. *Czech Phycology* 4: 43-61.

Kol, E. 1970. Algological and hydrobiological investigations of the bog of Grajka–streamlet, Vas-county. *Savaria* 4: 9-29.

Komárek, J. & B. Fott. 1983. *Chlorophyceae* Grünalgen, Ordnung C*hlorococcales*. In: Huber–Pestalozzi, G. (Ed.), Das Phytoplankton des Süsswassers, Die Binnengewässer 16, 7/1, Schweizerbart Verlag, Stuttgart. 1044 p.

Komárek, J. & K. Anagnostidis. 2000. Cyanoprokaryota I. Chroococcales. pp.548 In: *Chlorophyta* VI *Oedogoniophyceae*: *Oedogoniales*. *In*: Ettl, H., Gärtner, G., Heying, H. & Mollenhauer, D. (Eds.). Süsswasserflora von Mitteleuropa vol. 19/1. G. Fischer Verlag, Stuttgart. 624 p.

Komárek, J. & K. Anagnostidis. 2008. Cyanoprokaryota II. Oscillatoriales. In: *Chlorophyta* VI *Oedogoniophyceae*: *Oedogoniales*. pp. 624 In: Büdel, B., Gärtner, G., Krienitz, L. & Schagerl, M. (eds.), Süsswasserflora von Mitteleuropa vol. 19/2. G. Fischer Verlag, Stuttgart. 759 p.

Krammer, K. 1997. *Die cymbelloiden Diatomeen.* Bibliotheca Diatomologica. Band 36, J. Cramer, Berlin. 382 p.

Krammer, K. 2002. Diatoms of Europe. Diatoms of the European Inland Waters and Comparable Habitats. *Cymbella*. *In*: Lange–Bertalot, H. (Ed.). *Diatoms of Europe: Diatoms of the European Inland Waters and Comparable Habitats* 3. A. R. G. Gantner Verlag K. G., Ruggell. 584 p.

Krammer, K. 2003. *Cymbopleura, Delicata, Navicymbula, Gomphocymbellopsis, Afrocymbella* Supplements to cymbelloid taxa. In: Lange–Bertalot, H. (Ed.). Diatoms of the European Inland Waters and Comparable Habitats Elsewhere. Vol. 4, A. R. G. Gantner Verlag K. G., Ruggell. 530 p.

Krammer, K. & H. Lage-Bertalot. 1985. *Naviculaceae*. *Bibliotheca Diatomologica* 9: 1-389.

Krammer K. & H. Lange-Bertalot. 1986: *Bacillariophyceae* 1. *Naviculaceae*. *In*: Ettl, H., J. Gerloff, H. Heynig & Mollenhauer, D. (Eds.). *Süβwasserflora von Mitteleuropa*, Volume 2/1. G. Fischer Verlag, Jena. 876 p.

Krammer K. & H. Lange-Bertalot. 1988 *Bacillariophyceae* 2. *Bacillariaceae*, *Epithemiaceae, Surirellaceae*. *In*: H. Ettl, J. Gerloff, H. Heynig

& Mollenhauer, D. (Eds.), *Süβwasserflora von Mitteleuropa*, Volume 2/2. G. Fischer Verlag, Jena. 596 p.

Krammer K. & H. Lange-Bertalot. 1991a. *Bacillariophyceae* 3. *Centrales*, *Fragilariaceae*, *Eunotiaceae*. *In*: Ettl, H., J. Gerloff, H. Heynig & Mollenhauer, D. (Eds.), *Süβwasserflora von Mitteleuropa*, Volume 2/3. G. Fischer Verlag, Jena. 599 p.

Krammer K. & H. Lange-Bertalot. 1991b. *Bacillariophyceae*. 4. *Achnanthaceae*. Kritische Ergänzungen zu *Navicula Lineolatae* und *Gomphonema*. *In*: Ettl, H., J. Gerloff, H. Heynig & Mollenhauer, D. (Eds.). *Süβwasserflora von Mitteleuropa*, Volume 2/4. G. Fischer Verlag, Jena. 437 p.

Krenková, P. 2001. *Distribuce řas v mechorostech na vybraných svahoých prameništích moravsko–slovenského pomezí*. Diplomová práce PřF UP Olomouc, katedra ekologie, 52 p.

Krieger, W. 1937. Conjugata. Die Desmidiacen. *In*: Kolwitz, K. (Ed.). *Krytogamenflora von Deutschland, Österreich und der Schweiz.* Ak. Verlagsgesellschaft, Leipzig. 449 p.

Lange-Bertalot, H. 1993. 85 Neue Taxa und über 100 weitere neu definierte Taxa ergänzend zur Süβwasserflora von Mitteleuropa Vol. 2/1–4. Bibliotheca *Diatomologica* 27: 1-454.

Lange-Bertalot, H. 1996. *Iconographia Diatomologica. Annotated Diatom Micrographs. Vol. 2.* Koeltz Scientific Books, Frankfurt. 389 p.

Lange-Bertalot, H. 1999a. *Iconographia Diatomologica. Annotated Diatom Micrographs. Vol. 6*. Koeltz Scientific Books, Frankfurt. 304 p.

Lange-Bertalot, H. 1999b. I*conographia Diatomologica. Annotated Diatom Micrographs. Vol. 8.* Koeltz Scientific Books, Frankfurt. 203 p.

Lange-Bertalot, H. 2001. *Diatoms of Europe. Diatoms of the European Inland Waters and Comparable Habitats.* Navicula sensu stricto, 10 genera separated from Navicula sensu lato, Frustulia. Koeltz Scientific Books, Frankfurt. 526 p.

Lange-Bertalot, H. 2002. *Iconographia Diatomologica. Annotated Diatom Micrographs. Vol. 11*. A.R.G. Gantner Verlag K.G., Berlin. 286 p.

Lange-Bertalot, H. 2003. *Iconographia Diatomologica. Annotated Diatom Micrographs. Vol. 12*. Biogeography-Ecology-Taxonomy. A.R.G. Gantner Verlag K.G., Berlin. 438 p.

Lange-Bertalot, H. 2004. *Iconographia Diatomologica. Annotated Diatom Micrographs. Vol. 13.* Ecology-Hydrogeoloy-Taxonomy. A.R.G. Gantner Verlag K.G., Berlin. 417 p.

Lange-Bertalot H & Krammer, K. 1989. *Achnanthes* eine Monographie der Gattung. *Bibliotheca Diatomologica* 18: 1-393.

Lederer, F. 1999. Algal flora of the Červené blato peat bog Třeboň Basin, Czech Republic. *Preslia* 70: 303-311.

Lenzenweger, R. 1996 Desmidiaceenflora von Österreich, Teil 1. *Bibliotheca Phycologica* 101: 1-162.

Lenzenweger, R. 1997. Die Desmidiaceenflora von Österreich. Teil 2. *Bibliotheca Phycologica* 102: 1-216.

Lenzenweger, R. 1999. Desmidiaceenflora von Österreich, Teil 3. *Bibliotheca Phycologica* 104: 1-218.

Lenzenweger, R. 2003. Desmidiaceenflora von Österreich, Teil 4. *Bibliotheca Phycologica* 111: 1-87.

Margalef, R. 1946. Contribución al conocimiento hidrobiológico del país vasco-navarro Sierra de Aralar. *In: Aportación al estudio de la flora y fauna vasco-navarras. Instituto de Estudios Pirenaicos, CSIC, Zaragoza.* Pp. 7-44.

Margalef, R. 1948. *Flora, fauna y comunidades bióticas de las aguas del Pirineo de la Cerdaña.* Instituto de Estudios Pirenaicos. CSIC. Zaragoza. 226 p.

Margalef, R. 1952. La vida en las aguas dulces de Andorra. Actas I Congreso Internacional de Estudios Pirenaicos, Jaca.107 p.

Margalef, R. 1955. Comunidades bióticas de las aguas dulces del noroeste de España. Publ. *Publicaciones del Instituto de Biología Aplicada* 21: 5-85.

Margalef, R. 1956: Estudios hidrobiológicos en los valles de Bohí Pirineo de Lérida. In: Actas II Congreso Internacional de Estudios Pirenaicos, Jaca. pp. 87-108

Margalef, R. 1983. *Limnología*. Omega, Barcelona. 1010 p.

Massanell, M. A. 1966. *Algues aquàtiques del Parc d'Aigüestortes.* – Institut Estudis Catalans 31: 1-44.

Mrozińska, T. 1985: *Chlorophyta* VI *Oedogoniophyceae*: *Oedogoniales*. *In*: Ettl, H., Gerloff, J., Heying, H. & Mollenhauer, D. (Eds.), Süsswasserflora von Mitteleuropa vol. 14. G. Fischer Verlag, Stuttgart. 624 p.

Neustupa, J., K. Černá. & J. ŠtAstný. 2009. Diversity and morphological disparity of desmid assemblages in Central European peatlands. *Hydrobiologia* 630: 243-256

Nováková, S. 2002. Algal flora of subalpine peat bog pools in the Krkonoše Mts. *Preslia* 74: 45-56.

Nováková, J. & Poulíčková, A. 2004. Moss diatom *Bacillariophyceae* flora of the Nature Reserve Adrspašsko–Teplické Rocks, Czech Republic. *Czech Phycology* 4: 75-86.

Pla, S. 1999. The chrysophycean cysts from the Pyrenees and their applicability as palaeoenvironmental indicators. Doctoral Thesis, Univ. Barcelona, Barcelona. 277 p.

Pla, S. 2001 Chrysophycean cysts from the Pyrenees. *Biblioheca Phycologica* 109. J. Cramer, Berlin. 179 p.

Popovský, J. & L. A. Pfiester. 1990. *Dinophyceae Dinoflagellida*. *In*: Ettl, H., Gerloff, J., Heying, H. & Mollenhauer, D. (Eds.). Süsswasserflora *von Mitteleuropa, Bd. 6.* G. Fischer Verlag. Jena - Stuttgart. 272 p.

Poulíčková, A., J. Nováková. & P. Krásová. 2003. Vertical distribution of epiphytic algae on the mosses and their relation to moisture. *Czech Phycology* 3: 119-124.

Poulíčková, A., P. Hájková, P. Krenková. & M. Hájek. 2004. Distribution of diatoms and bryophytes on linear transects through spring fens. *Nova Hedwigia* 78: 411-424.

Printz, H. 1964. Die Chaetophoralen der Binnengewässer. *Hydrobiology* 24: 1-376.

Sabater, S. & J. R. Roca. 1990. Some factors affecting distribution of diatom assemblages in Pyrenean springs. *Freshwater Biology* 24: 493-507.

Sabater, S. & J. R. Roca. 1992 Ecological and biogeographical aspects of diatom distribution in Pyrenean springs. *British Phycological Journal* 27: 203-213.

Sanz, O., J. Cambra, M. Menéndez, E. Velasco. & H. Szymanska. 2002. Epiphytic macroalgae in high mountain lakes Pyrenees, Spain. pp. 161-167, *In*: Aniz, M. (Ed.). IV Jornades de Recerca del Parc Nacional d'Aigüestortes, Barruera.

Skuja, H. 1948. Taxonomie des Phytoplanktons einiger Seen in Uppland, Schweden. *Symb. Bot. Upsaliensis* 9: 5-399.

Skuja, H. 1956. Taxonomische und biologische Studien über das Phytoplankton schwedischer Binnengewässer. *Nova Acta Regiae Societatis Scientiarum Upsaliensi* 16: 1-404.

Skuja, H. 1964. Grundzüge der Algenflora und Algenvegetation der Fjeldgegenden um Abisko in Schwedisch Lappland. *Nova Acta Regiae Societatis Scientiarum Upsaliensis* 18: 1-465.

Starmach, K. 1966. *Cyanophyta, Glaucophyta. Flora słodkowodna Polski Vol. 2.* Polska Akad. Nauk, Warszawa & Krakow. 808 p.

Starmach, K. 1972. *Chlorophyta* III. Zielenice nitkowate. *Flora słodkowodna Polski Vol. 10.* Polska Akad. Nauk, Warszawa & Krakow. 750 p.

Stastny, J. 2009. The desmids of the Peat–bog Nature Reserve North Bohemia, Czech Republic and a small neighbouring bog: species composition and ecological condition of both sites. *Fottea* 91: 135-148.

Tomàs, X. 1988. Diatomeas de las aguas epicontinentals saladas del litoral mediterráneo de la península Ibérica. Ph. Doctoral Thesis. Univ. Barcelona, Spain. 687 p.

Uherkovich, G. 1984 Microvegetation of the bog–lake Vad–tó. *Folia Musei Historico–naturalis Bakonyiensis* 3: 43-56.

Vilaseca, J. M. 1978 Fitoplancton de los lagos pirenaicos. Graduate Thesis, Univ. Barcelona, Barcelona, Spain. 102 p.

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