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Variability of sediment diatom assemblages of Lake Pont-de-Salars on the Viaur River (France)

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Keywords : diatoms, sediment, lake, relative abundance, biostratigraphy, Correspondence Analysis.

Limnological surveys from the pelagic zone of Lake Pont-de-Salars were undertaken during the 1993-1996 period, which included the emptying of the whole-lake in summer 1995 and the first post year refilling. This reservoir was warm and monomictic and was determined to vary between oligo- and meso-eutrophic status from year to year. Three sediment cores were collected from the deepest zone and frozen *in situ* during the short drying period, just after the emptying and before the refilling of the reservoir. Analysis of the relative abundance and vertical distribution of diatom taxa was undertaken. The diatom vertical distribution, evident by visual biostratigraphy, is confirmed by the correspondence analysis (CA) despite of absence of sediment dating.

Variabilité de l'assemblage de la flore diatomique des sédiments du Lac de Pont-de-Salars sur la rivière Viaur (France)

Mots-clés : diatomées, sédiments, lac, abondance relative, biostratigraphie, Analyse de Correspondance.

Quelques facteurs abiotiques et biotiques de la zone pélagique du lac de Pont-de-Salars ont été étudiés de 1993 à 1996, période incluant la vidange du réservoir (été 1995) et sa remise en eau. Ce réservoir est de type monomictique chaud et son statut trophique varie de oligotrophe à méso-eutrophe suivant l'année. Lors de la mise à sec, trois carottes de sédiment ont été effectuées dans une zone correspondant à la partie la plus profonde du lac et congelés «*in situ*». L'analyse de la répartition verticale des diatomées et de l'abondance relative des espèces a été effectuée. Les assemblages de diatomées mis en évidence par l'analyse biostratigraphique sont confirmés par une analyse de correspondance, malgré l'absence de datation du sédiment.

1. Introduction

Diatom assemblages preserved in lake sediments can directly reflect the diatom flora in the water column and can indirectly indicate lake water quality due to short generation times and sensitivity to their environment (Barttarbee 1986, Leavitt et al. 1994, Zeeb et al. 1994, Wessels et al. 1999). It is generally used in paleolimnology to reflect or reconstruct environmental changes despite the absence of past water chemistry data (Anderson 1989, Anderson 1990, Anderson et al. 1995, Smol 1990).

Initially the aim of this study was to observe the vertical variability of diatom assemblages in the recently accumulated sediments, which was supposed to reflect environmental conditions of the pelagic zone at that time (Feuillade et al. 1995). If there were some changes, it would be used to compare with diatoms in the pelagic zone before and after the emptying of the reservoir in order to observe the role of sediment diatoms in the recolonization of the water column (McQuoid & Hobson 1995).

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2. Study site

Lake Pont-de-Salars is relatively large (200 ha) with a maximum depth of ca. 35 m, a mean depth of ca. 11 m, and a short water residence time of 66 days. It is located on the Viaur River and in the southwest of the Massif Central (Aveyron 44°16'N and 2°45'E) in France at an altitude of 718 m (normal retention level). The lake's morphometric characteristics are presented in Table 1.

This non-hydropower reservoir built by Electricité de France (EDF) in the 1950's is upstream and is directly connected to the pumping station of Lake Bage downstream. The surface of Lake Pont-de-Salars is relatively well sheltered from wind because of the elevated (ca.720-804 m) and forested (mainly oak, pine and bushes) surrounding terrain.

The water body is long, narrow and slightly dendritic (Fig.1). The geological nature of the lake basin is mica schist and gneiss. Due to the geographical location, the climate has oceanic (spring and autumn), mediterranean (summer), and continental (winter) influences.

The major land use pattern of the sparsely populated (ca. 14 inhab./km^2) surroundings (> 70 %) is livestock breeding (bovine, ovine, porcine,...) and agriculture (cereals, feed grains and grasses). The reservoir is known for leisure activities (bathing, fishing, water sports and camping) in which untreated wastewater flows directly into the reservoir, in addition to the agricultural and dairy farm wastewaters and runoffs.

Since the construction of the reservoir in 1952, two whole-lake emptyings were performed : firstly in 1972 without monitoring and secondly during this study period of August 21-September 1, 1995.

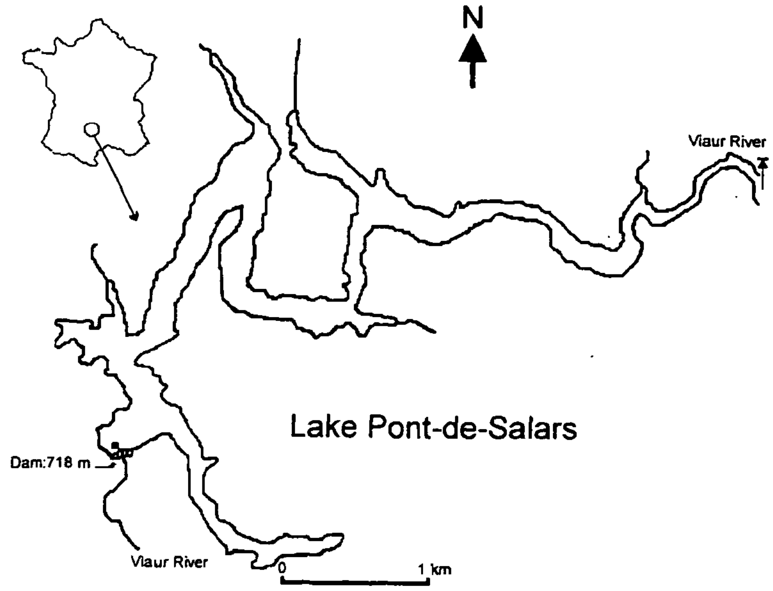

Fig. 1. Map of Lake Pont-de-Salars and the sediment sampling point.

Fig. 1. Situation géographique du Lac de Pont-de-Salars et localisation de l'échantillonnage des carottes de sédiment.

According to the sediment cores study of Lake Pareloup (Dagnac 1994), near to Lake Pont-de-Salars, yearly sediment accumulation thickness was estimated at 0.5 cm of dry deposits, and sediment laminae were well distinguished. However, once they were dried, sediment samples stayed intact, and could not be remoistened (Dagnac 1994). Moreover, according to the analyses of two sediment cores from the pelagic zone of Lake Pont-de-Salars (David 1998), the sediment was mainly composed of fine particles such as clay and silt (90 %) and contained about 81 % of water, 12 to 17 % of organic materials including 8 % of organic carbon and C : N ratio of 12, which indicated the importance of resistant plants from the watershed and 1.7 ‰ of to-

Table 1. Morphometric characteristics of Lake Pont-de-Salars (Southwest, France).

Tableau 1. Caractéristiques morphométriques du Lac de Pont-de-Salars (Sud-Ouest, France).

Altitude	718 m	Reservoir volume	20.6 * 10^6 m^3
Shore length	50 km	Drainage area	182 km^2
Surface area	200 ha	Maximum depth	34.7 m
Theoretical hydraulic residence time	65.5 days*	Mean depth	11.3 m

* Period 1985-1994

tal phosphorus (TP) which was higher than that of Lake Pareloup (David 1998). Suspended solids (SS) analyses at the time of emptying showed similar features, compared with those of the sediments, also a lot of accumulated organic materials of the sediments were supposed to be removed at this time as well (David 1998).

A summary of physical and chemical features of the pelagic zone in the whole water column before the emptying is presented in Table 2. The data characterize Lake Pont-de-Salars as unlimited (nutrients), mesotrophic (in particular, TP), modestly loaded ions (conductivity), crystalline (alkalinity), and usually neutral to slightly alkaline in the upper layer (down to metalimnion) in summer due to photosynthetic activities (pH). Suspended solids concentrations varied widely from 0 to 37800 $\mu g\ l^{-1}$. Secchi disc transparency was always above 3 m (< 3 m) which means that there was never an observed clear water phase before emptying. Chlorophyll *a* concentrations reached a maximum in summer and varied widely (undetectable-46 $\mu g\ l^{-1}$). The results seemed to reflect the influences of surrounding land use patterns and geological nature.

A trophic status of the reservoir was studied using the TP model (Vollenweider 1976), water residence time, chlorophyll *a* and Secchi transparency (Fabre 1982) and some limnological studies (i.e., reservoir limnology, impact of inflow, biomanipulation, and phytoplankton dynamics...) were carried out during the 1993-1996 period (submitted & in preparation).

3. Material and methods

To avoid the problems of representatives from using only one or two cores (Anderson 1989,1990), three short sediment cores (16.5-18 cm) from the pelagic zone were collected using hand handling PVC corers (inner diameter of 7 cm and 35 cm long) and were frozen *in situ* in September 1995. In the absence of undulations in laminae contrary to that of Lake Pareloup (Dagnac 1994), frozen sediments were continuously sectioned 0.5 cm in accordance with approximately supposed annual increments (Dagnac 1994) from 0 to 2.5 cm : A lamina at 10-10.5 cm was also sectioned, and each last lamina of 0.5 cm was sectioned from the end which varied from 16.5 to 18 cm. The same depth laminae from each core were well mixed in order to

Table 2. Some physical and chemical characteristics of the water of Lake Pont-de-Salars before the emptying.

Tableau 2. Quelques paramètres physico-chimiques de l'eau du Lac de Pont-de-Salars avant le vidange.

	Jul./Aug. 1993-Aug. 1995 Mean (min-max) ; $\mu g\ l^{-1}$
pH	7.3 (6.64-9.4)
Alkalinity ($CaCO_3$ mg l^{-1})	24.6 (11-80)
Conductivity ($\mu S\ cm^{-1}$)	91 (43-111)
Suspended solids (SS)	2368 (0-37800)
Dissolved in organic nitrogen (DIN)	2024 (588-4175)
Total phosphorus (TP)	30 (5-808)
Silicate (Si)	7869 (200-10950)
Secchi disc transparency (SD : m)	1.97 (1.3-2.85)
Chlorophyll *a* (Chl *a*)	5.3 (undetectable-46)

avoid heterogeneity (patchness) and were conserved in the cold room. Subsamples of 0.3 g per depth were prepared according to Barttarbee (1986). Cleaned and dried samples were embedded in Naphrax mounting medium. For each slide, at least 500 valves were counted using Nachet NS 400 light microscope (L.M. : oil immersion with 1200 times magnification). For further systematic identifications, the scanning electron microscopy (SEM) samples were prepared according to Le Cohu & Coste (1995) and examined with a Cambridge Stereoscan 250 MK3 the scanning electron microscope. The species or taxa were generally identified using Germain (1981), Krammer (1992), and Krammer & Lange-Bertalot (1986, 1988, 1991a &1991b). For taxonomic purposes and problems with small centrals such as *Stephanodiscus, Cyclostephanos*, and *Cyclotella,* we identified them according to published articles by Klee & Schmidt (1987), Klee & Houk (1996), Klee & Casper (1997) and by personal communication with Klee in addition to precedent works of others (Chang 1991, Genkal & Hakansson 1990, Hakansson & Kling 1990).

For data analysis and presentation, we used percentage counting (relative abundance), biostratigraphy, and correspondence analysis which was used to summarize the variability of core biostratigraphy (Barttarbee 1986, Anderson 1989, 1990). Correspondence analysis was carried out using STATISTICA (StatSoft 2000).

4. Results

4.1. Relative abundances and biostratigraphy

All observed diatom taxa and relative abundance rating for the seven sediment laminae is presented in Table 3. 121 taxa were identified that belonged to 28 genera. 13 taxa were determined to genus only. 14 species have minimum relative abundances at more than 2 % at least in one depth. 68-89 % of the diatom assemblages belonged to the centrales (*Cyclotella, Cyclostephanos, Stephanodiscus, Aulacoseira, Melosira*) and Fragilariaceae (*Asterionella, Diatoma, Fragilaria, Meridion, Tabellaria*).

Fragilaria crotonensis was dominant (> 20 % of relative abundances), accompanied by either dominant or abundant (> 5 % of relative abundances) species such as *Cyclotella radiosa, Stephanodiscus minutulus*, and *Asterionella formosa* down to 2-2.5 cm. For *Cyclotella stelligeroides* which was abundant in the top layer, it included blurred individuals which were very difficult to identify to species such as *Cyclotella pseudostelligera, Cyclotella stelligera*, and *Cyclotella woltereckii*. In the sediment samples of the 10-10.5 cm, *Asterionella formosa* and *Stephanodiscus minutulus* were dominant accompanied by abundant *Cyclotella stelligera* and *Aulacoseira subarctica* which was also abundant at the 2-2.5 cm lamina. For the last layer (16.5-18 cm), *Cyclotella stelligera* was dominant, accompanied by abundant *Tabellaria flocculosa, Achnanthes minutissima*, and *Fragilaria capucina* which were never abundant above the laminae.

Vertical variability of mostly representative taxa was presented as a biostratigraphy in figure 2 which included the modestly recorded taxa occurring almost throughout the depths such as *Gomphonema parvulum, Aulacoseira ambigua, Aulacoseira distans*, and *Navicula cryptocephala*. The biostratigraphy summarized well the changes of the sediment depths and was in accordance with the rating of relative abundances (Table 3).

4.2. Correspondence analysis

For the CA ordination, 15 taxa were selected. 14 taxa were rated 'frequent' (> 2 % relative abundances at least in one layer) and *Cyclotella pseudostelligera* (relative abundance > 1.5 %) which could be confused with *Cyclotella stelligeroides* for the top layer (Fig. 3). Ordination of CA showed well distinguished vertical variabilities in four groups (about 89 % of inertia mainly by X-axis of 72 %) to indicate the diatom assemblages in relation to sediment depths (L0-LL) as well as in accordance with relative abundances and biostratigraphy (Table 3 and Fig. 2). The top layer (L0-0.5 cm) was characterized by *Stephanodiscus minutulus* (SMi), *Cyclotella pseudostelligera* (CPs), *Cyclotella stelligeroides* (CSd), *Asterionella formosa* (AsF), and *Aulacoseira subarctica* (ASu). The following 4 layers (L0.5-1 cm, L1-1.5cm, L1.5-2 cm, and L2-2.5 cm) showed a very similar pattern associated with *Cyclotella radiosa* (CRa), *Fragilaria crotonensis* (FCr), and *Cyclotella woltereckii* (CWo) but they shared with the top layer *Stephanodiscus minutulus* (SMi), *Aulacoseira subarctica* (ASu), and *Asterionella formosa* (AsF). The 10-10.5 cm layer (L10) was well distinguished with respect to *Aulacoseira ambigua* (AAm), which had a high relative abundance value(> 2 %) and thus was rated 'frequent' (Table 3) in this layer only, and shared with the top layer for *Stephanodiscus minutulus* (SMi), *Cyclotella stelligera* (CSt), *Asterionella formosa* (AsF), and *Aulacoseira subarctica* (ASu) and with the last layer, *Achnanthes minutissima* (AMi). The mixed last layer (LL) showed a sparsely dispersed pattern but was represented by *Tabellaria flocculosa* (TFl), *Fragilaria*

Table 3. Diatom taxa list and relative abundance «rating» for the seven survey sediment layers : dominant (D > 20 %), abundant (A > 5 %), frequent (F > 2 %), occasional (O > 0,5 %), present (P), absent (-).

Tableau 3. Liste des espèces de diatomées et les classes d'abondance relative pour les sept couches de sédiment étudiées : dominante (D > 20 %), abondante (A > 5 %), fréquente (F > 2 %), occasionnelle (O > 5 %), présente (P), absente (-).

Taxa name \ sediment depth (cm)	**L0**-0.5	**L0.5**-1	**L1**-1.5	**L1.5**-2	**L2**-2.5	**L10**-10.5	**LLast**
Cyclotella glabriuscula (Grunow) Hakansson	-	-	-	-	P	-	-
Cyclotella meneghiniana Kützing	P	-	P	O	-	P	P
Cyclotella pseudostelligera Hustedt	O	P	-	-	-	-	P
Cyclotella radiosa (Grunow) Lemmermann	A	A	D	A	A	P	P
Cyclotella stelligera Cleve & Grunow	O	O	O	O	O	A	D
Cyclotella woltereckii Hustedt	F	A	F	F	F	O	P
Cyclotella stelligeroides (*Cyc.pseudostelligera, stelligera,* and *woltereckii*)	A	-	P	-	-	P	P
Cyclostephanos invisitatus (Hohn & Hel.) Ther., Stoerm. & Hak.	O	-	-	-	-	O	P
Stephanodiscus hantzschii Grunow	O	O	O	O	O	O	-
Stephanodiscus minutulus (Kützing) Cleve & Möller	D	A	A	A	A	D	P
Aulacoseira ambigua (Grunow) Simonsen	P	P	P	P	P	F	O
Aulacoseira distans (Ehrenberg) Simonsen	F	O	-	P	P	-	F
Aulacoseira subarctica (O.Müller) Haworth	F	F	F	F	A	A	O
Melosira varians Agardh	-	-	-	P	-	-	-
Asterionella formosa Hassall	A	A	A	A	A	D	F
Diatoma sp.	-	-	-	-	-	-	P
Fragilaria arcus (Ehrenberg) Cleve	-	-	-	-	-	-	O
Fragilaria capucina Desmazières	P	P	P	P	P	O	A
Fragilaria crotonensis Kitton	D	D	D	D	D	F	O
Fragilaria delicatissima (W.Smith) Lange-Bertalot	-	-	-	-	-	O	P
Fragilaria parasitica(W.Smith) Grunow var.*subconstricta* Grunow	-	-	-	-	P	-	-
Fragilaria pinnata Ehrenberg	-	P	-	-	P	P	P
Fragilaria ulna (Nitzsch) Lange-Bertalot	P	P	P	P	P	P	P
Fragilaria ulna var. *acus* (Kützing) Lange-Bertalot "Sippen" *angustissima*	-	P	P	P	P	P	P
Meridion circulare (Greville) Agardh	-	P	-	-	P	P	P
Tabellaria flocculosa (Roth) Kützing	P	-	P	P	P	O	A
Achnanthes biasolettiana Grunow	-	P	-	-	-	-	-
Achnanthes biasolettiana Grunow var.*subatomus* Lange-Bertalot	-	-	-	-	-	P	-
Achnanthes bioretii Germain	P	-	P	P	P	P	O
Achnanthes clevei Grunow	-	P	P	-	-	-	-
Achnanthes coarctata (Brébisson) Grunow	-	-	-	-	-	-	P
Achnanthes daonensis Lange-Bertalot	-	P	-	-	-	-	-
Achnanthes lanceolata (Brébisson) Grunow	P	P	P	P	O	O	O
Achnanthes minutissima Kützing	F	F	F	F	F	F	A
Achnanthes oblongella Oestrup	-	-	-	-	-	P	-
Achnanthes sp.	O	-	P	-	-	-	O
Amphora pediculus Kützing	P	P	P	-	P	-	P
Caloneis bacillum (Grunow) Cleve	-	-	-	-	-	-	P
Caloneis silicula (Ehrenberg) Cleve	-	-	P	P	-	P	-
Cocconeis placentura Ehrenberg	-	-	-	-	-	P	P
Cocconeis placentura Ehrenberg var. *euglypta* (Ehrenberg) Grunow	-	P	-	P	-	-	-
Cymbella affinis Kützing	-	P	-	P	O	P	P
Cymbella amphicephala Naegeli	-	-	-	-	-	-	P
Cymbella cymbiformis Agardh	P	-	-	-	-	-	-
Cymbella minuta Hilse	O	P	P	O	O	O	O
Cymbella sinuata Gregory	P	O	O	P	P	P	O
Cymbella triangulum (Ehrenberg) Cleve	P	O	P	P	P	-	-
Cymbella sp.	-	-	P	-	-	-	-
Denticula elegans Kützing	-	P	P	O	O	-	-
Denticula spp.	O	P	-	P	P	-	-
Diploneis elliptica (Kützing) Cleve	-	P	-	P	O	-	-
Diploneis parma Cleve	-	-	-	-	-	-	P
Diploneis petersenii Hustedt	-	-	-	-	-	-	P
Entomoneis ornata (Bailey) Reimer	P	-	-	-	P	P	-
Eunotia bilunaris (Ehrenberg) Mills	-	-	-	P	-	-	O
Eunotia implicata Nörpel et al.	-	-	-	P	-	-	-
Eunotia paludosa Grunow	-	-	-	-	P	-	-
Eunotia veneris (Kützing) De Toni	-	-	-	-	-	-	P

Table. 3. Continued.
Tableau. 3. Suite.

Eunotia spp.	P	-	P	-	P	P	P
Frustulia rhomboides (Ehrenberg) De Toni var. *crassinervia* (Brébisson) Ross	-	-	-	-	-	-	P
Gomphonema acuminatum Ehrenberg	-	-	-	P	-	P	P
Gomphonema angustum Agardh	-	-	P	-	-	-	-
Gomphonema constrictum Ehrenberg	-	-	-	-	-	P	-
Gomphonema olivaceum (Hornemann) Brébisson	-	P	-	-	-	-	-
Gomphonema parvulum Kützing	P	-	P	P	P	O	F
Gyrosigma sp.	-	P	-	-	-	-	-
Navicula accomoda Hustedt	-	-	-	-	P	-	-
Navicula angustata W.Smith	P	-	-	-	-	-	-
Navicula atomus (Kützing) Grunow	P	-	-	P	-	-	-
Navicula bacillum Ehrenberg	-	-	-	P	-	-	-
Navicula capitata Ehrenberg	-	P	P	-	-	P	-
Navicula cocconeiformis Gregory	P	-	-	-	-	-	-
Navicula cryptocephala Kützing	O	P	O	O	O	O	O
Navicula elginensis (Gregory) Ralfs	-	-	-	-	P	-	-
Navicula globulifera Hustedt	P	-	-	-	-	-	-
Navicula gregaria Donkin	P	O	O	O	P	-	P
Navicula krasskei Hustedt	-	-	P	-	-	-	-
Navicula lanceolata (Agardh) Ehrenberg	-	P	P	-	P	P	O
Navicula mutica Kützing	-	-	-	-	-	-	P
Navicula pupula Kützing var. *pupula*	P	-	-	-	-	-	-
Navicula radiosa Kützing	-	-	-	P	P	-	-
Navicula rhynchocephala Kützing	P	P	P	-	-	P	O
Navicula similis Krasseke	-	-	-	-	-	-	P
Navicula subrhynchocephala Hustedt	P	-	-	-	-	-	-
Navicula trivialis Lange-Bertalot	P	-	-	-	-	-	-
Navicula sp.	-	-	-	-	-	-	P
Neidium affine var. *longiceps* (Gregory) Cleve	-	-	-	-	-	P	P
Nitzschia acicularis (Kützing) W.Smith	P	-	-	-	-	-	-
Nitzschia amphibia Grunow	P	O	O	O	P	-	-
Nitzschia bergii Cleve-Euler	P	-	-	-	P	-	-
Nitzschia capitellata Hustedt	-	P	-	-	-	-	P
Nitschia dissipata (Kützing) Grunow	-	P	P	P	-	-	-
Nitzschia fonticola Grunow	P	-	P	-	-	-	-
Nitzschia fruticosa Hustedt	-	P	-	-	-	-	-
Nitzschia hantzschiana Rabenhorst	-	-	-	-	-	P	O
Nitzschia heufleuriana Grunow	-	-	-	-	-	-	P
Nitzschia holsatica Hustedt	P	-	-	-	-	-	-
Nitzschia palea (Kützing) W.Smith	O	P	-	P	-	P	-
Nitschia aff.*paleacea* Grunow	-	P	-	-	-	-	-
Nitzschia pellucida Grunow	-	-	-	-	P	-	-
Nitzschia aff.*pseudofonticola* Hustedt	-	-	-	P	-	-	-
Nitzschia aff.*sublinearis* Hustedt	-	-	-	-	-	P	-
Nitzschia tubicola Lange-Bertalot	-	-	-	-	-	P	-
Nitzschia sp.1	P	P	O	P	P	P	P
Nitzschia sp.2	P	P	P	P	P	P	P
Nitzschia sp.3	P	-	P	-	-	-	P
Pinnularia accuminata W.Smith	-	-	-	-	P	-	P
Pinnularia borealis Ehrenberg	P	-	-	-	-	-	P
Pinnularia interrupta W.Smith	-	-	-	-	-	P	-
Pinnularia lundii Hustedt	-	-	-	-	-	P	P
Pinnularia microstauron (Ehrenberg) Cleve	P	P	P	-	P	O	P
Pinnularia obscura Krasske	-	P	-	P	-	-	P
Pinnularia viridis (Nitzsch) Ehrenberg	-	P	-	-	-	P	P
Pinnularia spp.	P	-	P	P	P	-	P
Stauroneis phoenicenteron (Nitzsch) Ehrenberg	-	-	-	-	-	P	-
Surirella angusta Kützing	P	P	P	-	-	P	-
Surirella ovalis Brébisson	-	P	-	-	-	-	-
Surirella roba Leclercq	-	-	-	-	-	-	P
Surirella splendida (Ehrenberg) Kützing	-	-	-	-	P	-	-
Surirella spp.	P	-	-	P	-	-	-

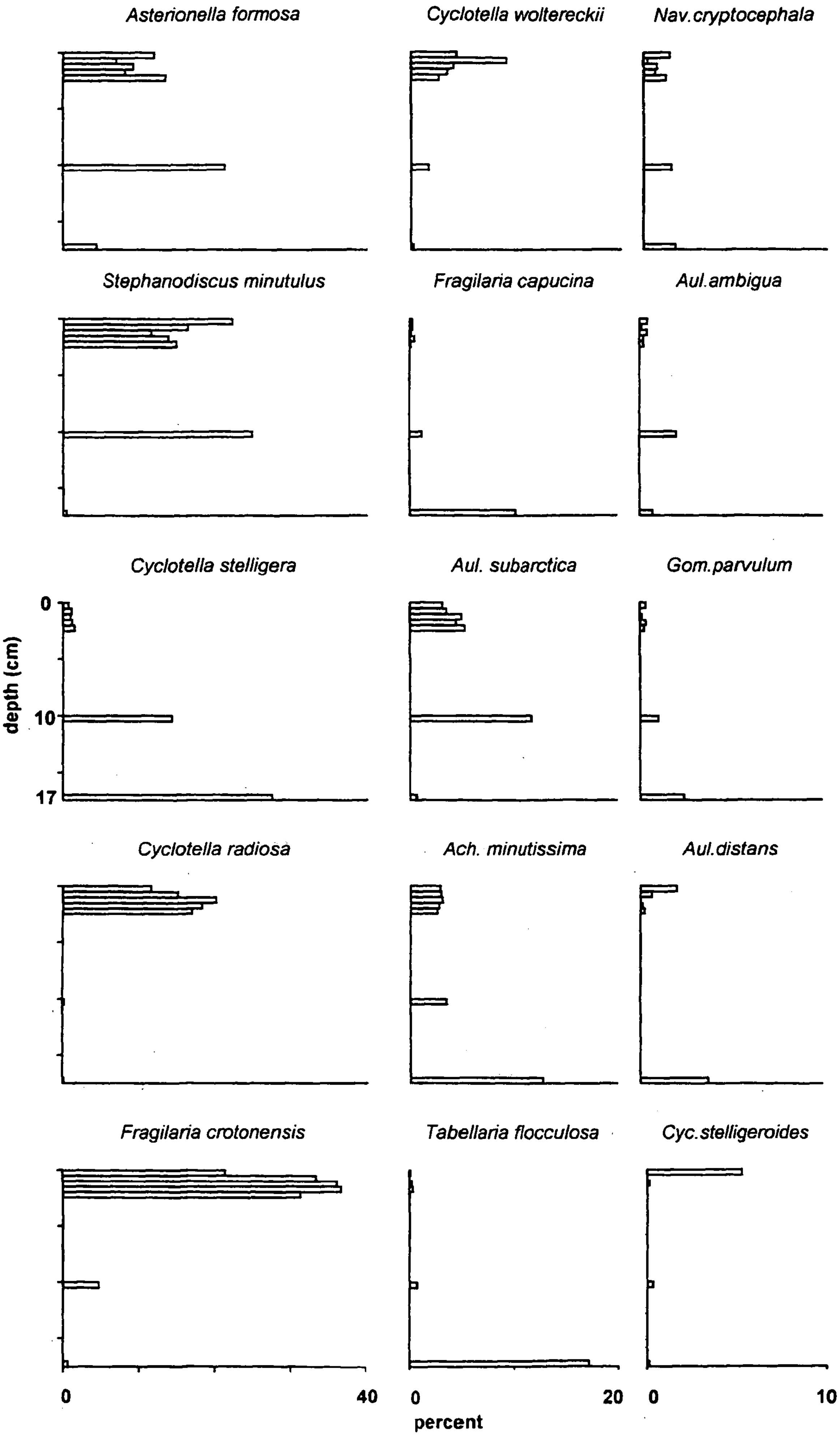

Fig. 2. Summary of diatom biostratigraphy for 15 representative taxa.
Fig. 2. Répartition verticale de 15 espèces représentatives.

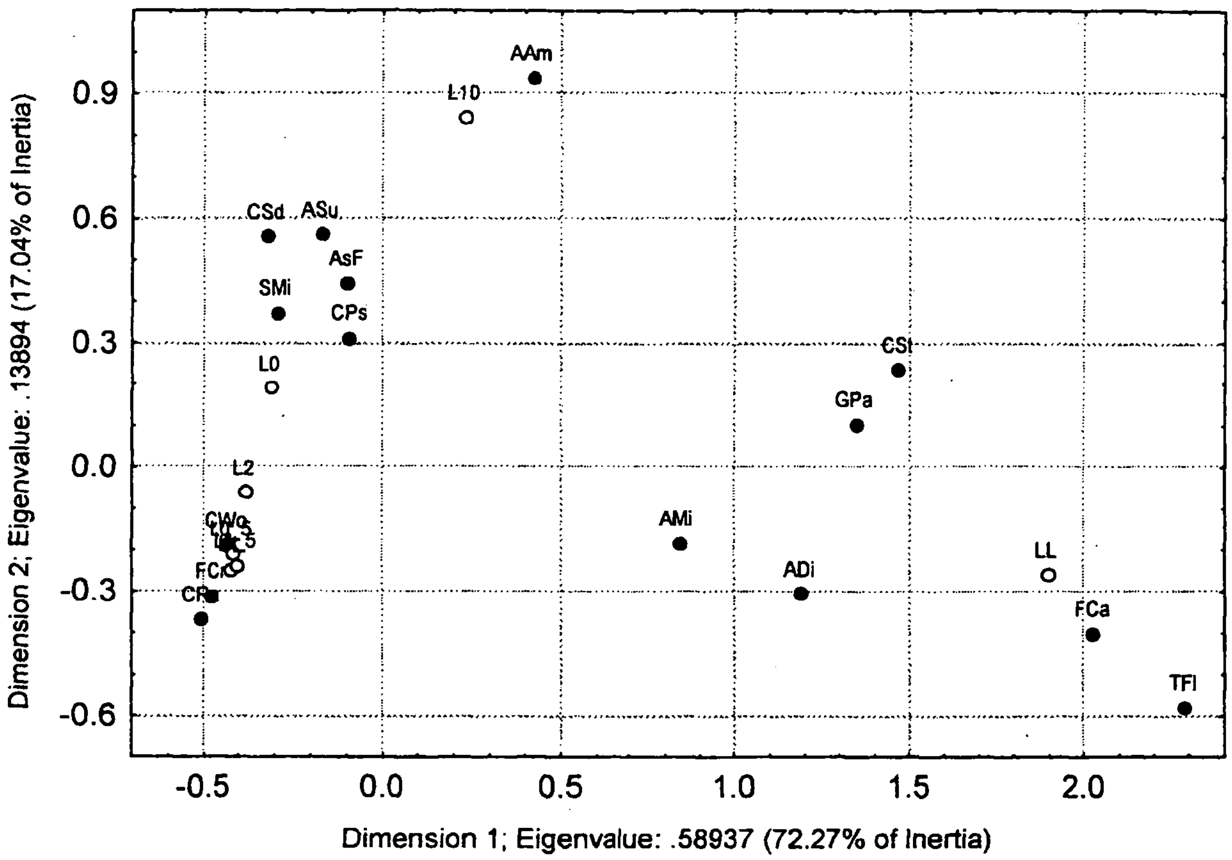

Fig. 3. CA ordination for 15 representative taxa in relation to the layer : L0-0.5 cm, L0.5-1 cm, L1-1.5 cm, L1.5-2 cm, L2-2.5 cm, L10-10.5 cm, and LL ; the three mixed last laminae of 16.5-18 cm. *Stephanodiscus minutulus* (SMi), *Cyclotella pseudostelligera* (CPs), *Cyclotella stelligeroides* (CSd), *Asterionella formosa* (AsF), *Aulacoseira subarctica* (ASu), *Cyclotella radiosa* (CRa), *Fragilaria crotonensis* (FCr), *Cyclotella woltereckii* (CWo), *Aulacoseira ambigua* (AAm), *Cyclotella stelligera* (CSt), *Achnanthes minutissima* (AMi), *Tabellaria flocculosa* (TFl), *Fragilaria capucina* (FCa), *Aulacoseira distans* (ADi), and *Gomphonema parvulum* (GPa).

Fig. 3. Ordination de l'analyse de correspondance pour 15 taxons représentatifs en fonction des couches : L0-0.5 cm, L0.5-1 cm, L1-1.5 cm, L1.5-2 cm, L2-2.5 cm, L10-10.5 cm, and LL ; les trois dernières laminae mélangées de 16.5-18 cm.

capucina (FCa), *Achnanthes minutissima* (AMi), *Aulacoseira distans* (ADi), *Gomphonema parvulum* (GPa), and *Cyclotella stelligera* (CSt) which were distinguished by highest relative abundances in this layer only.

5. Discussion and conclusion

5.1. Diatom assemblage changes

Vertical variability of diatom assemblages indicated little change between the top layer (L0) and the (supposed) recently accumulated sediments (L0.5-L2) which showed the same type of diatom assemblages using relative abundances, thereafter illustrated by the biostratigraphy, and finally by the correspondence analysis. However, the discontinuities or changes of diatom assemblages with sediment depths were clearly observed in the L10 and LL layers which were discontinuously sliced from the top layers. The sparsely dispersed pattern of the last layer may reflect the heterogeneity of the sediment preparation due to different depths among the three cores (16.5-18 cm).

The taxa rating such as dominant, abundant, and frequent (Table 3) in the supposed recently accumulated sediments (0-2.5 cm) were generally observed with relatively important proportions in the pelagic zone before the emptying (in preparation). The importance of centrales (*Cyclotella, Cyclostephanos, Stephanodiscus, Aulacoseira*, and *Melosira*) and Fragilariaceae (*Asterionella, Diatoma, Fragilaria, Meridion*, and *Tabellaria*) was in accordance with Wessels et al. (1999) in Lake Constance, in particular.

5.2. Trophic status changes in relation to diatom assemblages

We would try to speculate or reconstruct the nutrient levels in the pelagic zone for the diatom assemblages from the sediment depths (i.e., Bennion et al. 2000, Lange-Bertalot & Steindorf 1996, Feuillade et al. 1995), despite the absence of both sediment dating, which is used to determine the time of sediment accumulations, and sediment analyses (Anderson 1989, Anderson 1990, Barttarbee 1986, Dixit & Evans 1986, Feuillade et al. 1995, Wessels et al. 1999).

In general, dominant, abundant, and frequent taxa of all the observed layers (Table 3) were generally characterized in the category of 'eutrophic' and/or 'tolerant' which means they widely occured from oligo- to eutrophic status such as well known *Asterionella formosa* and *Fragilaria crotonensis* (Lange-Bertalot & Steindorf 1996, Feuillade et al. 1995).

The replacement of relatively important taxa from the last layer (*Cyclotella stelligera, Tabellaria flocculosa, Fragilaria capucina*, and *Achnanthes minutissima*) to 10-10.5 cm layer by *Stephanodiscus minutulus, Asterionella formosa, Aulacoseira subarctica* and the diminution of importance of *Cyclotella stelligera* (from 28 to 14 %) indicated a nutrient level shift from relatively low to moderate from the time of the last layer to the moment of 10-10.5 cm layer (Bennion et al. 2000). The relative abundance of *Stephanodiscus minutulus, Asterionella formosa*, and *Aulacoseira subarctica* were highest at the layer of 10-10.5 cm among the layers. For *Cyclotella radiosa* and *Fragilaria crotonensis* which occurred firstly, there are remarkable amounts and then persistent abundances or dominances (Table 3) up to the top layer from the 2-2.5 cm layer. Otherwise, it means pronounced species shifts from the 10-10.5 cm layer to this layer but their trophic status varied widely from oligo- to eutrophic by these assemblages (Bennion et al. 2000, Lange-Bertalot & Steindorf 1996, Feuillade et al. 1995). We already have discussed the similarity of species assemblages in the four adjacent layers from 2.5 cm to 0.5 cm above. Little change of species assemblages were noted due to a modest increase of *Stephanodiscus minutulus* from these layers to the top layer of 0-0.5 cm.

5.3. Case of *Cymbella triangulum* (Ehrenberg) Cleve

Recently noted as an invading and expanding species in France and Europe (Bertrand & Coste 1994), *Cymbella triangulum* only occurred modestly (Table 3) down to 2.5 cm in the sediment cores which seemed in accordance with this hypothesis.

In summary, despite the absence of sediment dating and sediment analyses, the diatom assemblages of the sediment cores showed vertical variability with the depths using relative abundances, biostratigraphy, and correspondence analysis from the pelagic zone of Lake Pont-de-Salars.

First, each layer was represented by four or five dominant or abundant taxa composed mainly by centrales (*Cyclotella, Cyclostephanos, Stephanodiscus, Aulacoseira, Melosira*) and Fragilariaceae (*Asterionella, Diatoma, Fragilaria, Meridion, Tabellaria*).

Secondly, four distinguished diatom groups with sediment depths were observed by the CA in accordance with relative abundances ; the top layer (L0), the next following four layers (L0.5-L2), the 10-10.5 cm layer (L10), and the last layer (LL). From the last layer to the top layer, diatom assemblages reflected moderately and continuously nutrient enriched conditions. However, it showed little environmental change between the top layer and the four following layers. The occurrence of *Cymbella triangulum* down to 2.5 cm only seemed to indicate that the first layers (L0-L2.5) were recently accumulated. Diatom assemblages of the 10-10.5 cm and the last layer showed differences compared with the top layers. The last layer showed a very distinctive and dispersed pattern, with characteristic diatom taxa (*Cyclotella stelligera, Tabellaria flocculosa, Fragilaria capucina, Achnanthes minutissima*) which indicated indirectly both a shift of environmental conditions and the heterogeneity of sample preparations.

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