

SPATIO-TEMPORAL DISTRIBUTION AND CHARACTERISATION OF PHYTOPLANKTON POPULATIONS COUPLED WITH ABIOTIC AND BIOTIC CHANGES IN LANDFILL LEACHATE TREATMENT BASINS (ETUFFONT, BELFORT, FRANCE)

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Abstract. The quantitative distribution of dominant phytoplankton species was carried out in the stabilisation ponds of Etueffont landfill leachate (Belfort, France) from May 1998 to May 1999. The results showed maximum phytoplankton abundance in the last lagooning basin during summer 1998, that coincided with an increase in temperature and better leachate quality. In addition, the phytoplankton was dominated by Euglenophytes species *Phacus* sp. and *Euglena* sp. known to resist constraints induced by the highly polluted aquatic environments. An improve in water quality of the last basins translated into a shift in species composition with the substitution of the Bacillariophyceae (*Stephanodiscus dubius*) by the Chlorophyceae (*Coelastrum* sp.).

Keywords: leachates, lagooning, phytoplankton

1. Introduction

The household waste accumulating in industrialized societies pose a potential hazard. In France, the whole annual average of these wastes reached 20 millions tonnes (400 kg per capita) (ADEME, 1997). In this respect, landfilling which is still the most popular way for solid wastes treatment in the world, is of major concern since it may pollute the surrounding environment. The leachate produced from landfill contains large quantities of organic and inorganic matters and heavy metals (Kjeldsen *et al.*, 2002; Schwarzbauer *et al.*, 2002; Baun *et al.*, 2004). Moreover, Vrijheid *et al.* (2002) reported a 33% increase in the risk of congenital anomalies among residents near hazardous waste landfill sites in a european collaborative study (EUROHAZCON). Also, several studies have reported excesses of bladder, lung, and stomach cancer and leukaemia in populations living near waste landfill sites (Vrijheid, 2000). To reach european standards (ISO 14000) of the domestic waste treatments, the SICTOM (domestic waste treatment agency) constructed four stabilisation ponds in the landfill of Etuffont city (Belfort, France). Nevertheless, landfill leachate generated by the biodegradation of solid wastes have been shown to migrate away from a landfill and may pollute groundwaters as well as surface

waters (Baun *et al.*, 2004; Christensen *et al.*, 2000; Silva *et al.*, 2004). As a result, contaminated water is injected into tributaries that are otherwise most often loaded with high amounts of nitrogen and phosphorus. These inputs enter lakes and reservoirs to induce intense spectacular phytoplankton proliferations (Aleya *et al.*, 1994; Nayar *et al.*, 2004; Arhonditsis *et al.*, 2004). From both ecological and economical points of view, this eutrophication is of much concern with respect to bodies of water that are used for recreational activities and/or for sources of drinking water in temperate and semi arid regions (Aleya and Devaux, 1989; Alaoui *et al.*, 1993; Pinel-Alloul *et al.*, 2004).

The waste stabilisation ponds are widely used for the treatment of domestic and agro-industrial wastes (Saqqar and Pescod, 1991; Shelef and Azov, 1996; Cauchie *et al.*, 2002), and the performance of the landfill leachate treatment depends on the efficiency of bacteria to degrade the organic matter. Furthermore, while an extensive literature dealing with the methods of landfill treatments is now available (Kettunen, 1997; Welander *et al.*, 1998; Hoilijoki *et al.*, 2000), little is known on the dynamics of the phytoplankton communities that develop in these ecosystems and the role of algal species in the basin functioning.

This work aimed at studying the annual distribution of the phytoplankton abundance and biomass, the biochemical composition of the particulate matter together with the zooplankton dynamics and several physical chemical parameters in the four basins of the Etuefont landfill.

2. Materials and Methods

2.1. STUDY SITE

The domestic landfill treatment station studied is located in Etuefont (Belfort, France, (Figure 1). It covers a total surface area of 2.2 hectares and from 1974 to 2000 had been operating in open air by crushing the waste before disposal. In 1999, the landfill had been filled with 200 000 tonnes of refuse (Figure 2). The leachates were treated by four natural lagooning basins whose characteristics are summarized in Table I.

2.2. SAMPLINGS AND ANALYSIS PROCEDURES

Water samples for chemistry and phytoplankton were taken in the deepest part of each basin (1m) monthly using a Van-Dorn bottle between May 1998 and May 1999. The temperature (T), pH and dissolved oxygen (O₂), were measured *in situ* with a WTW multiparameter probe (Multiline P3 PH/LF-SET). Biological oxygen demand (BOD) was determined photometrically using a WTW spectrophotometer (Photalab Spektral). The phytoplankton species were collected monthly (May 1998

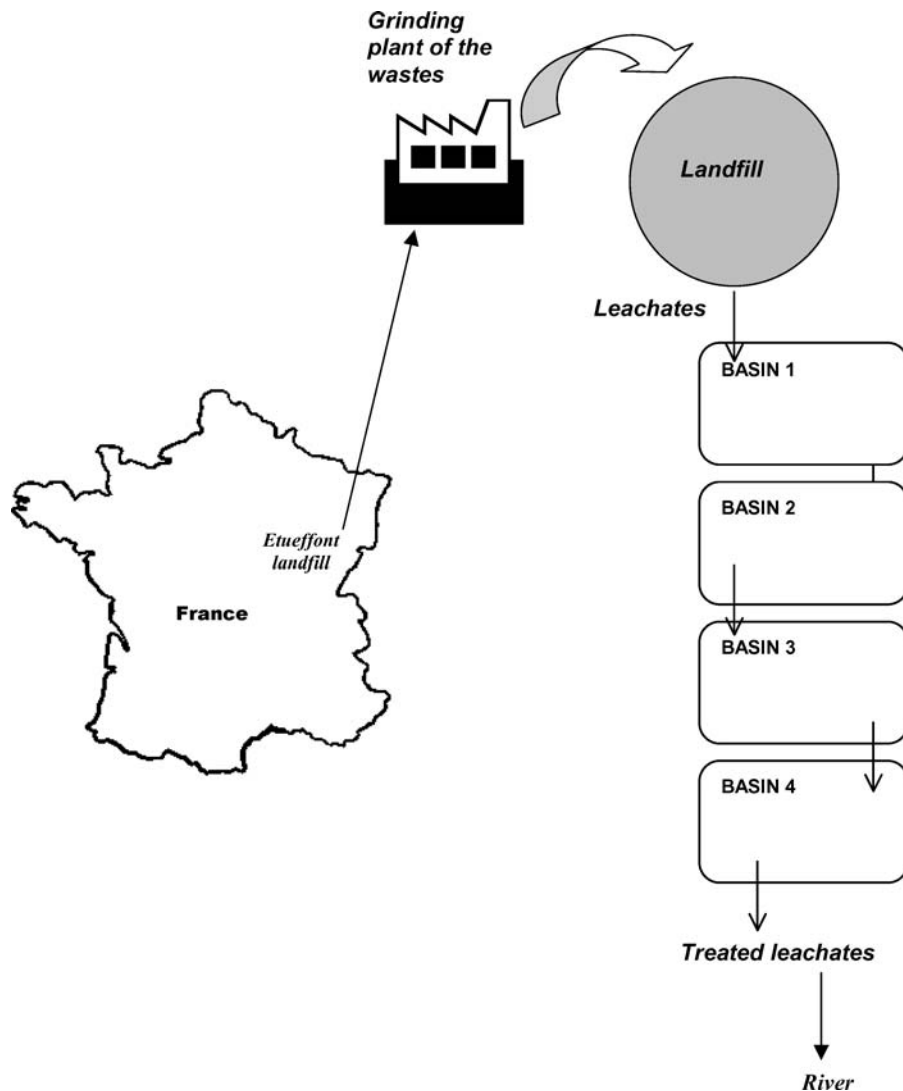


Figure 1. Study site.

to May 1999). Identification of species was made on live cells to prevent cell destruction. Phytoplankton countings were achieved with an inverted microscope by Uthermöl's method (1958) modified by Legendre and Whatt (1971–1972) after fixation with a Lugol's (4%) iodine solution (Bourrelly, 1985). The phytoplankton abundance was calculated using the following formula:

$$N = X/n * Rs * 1/v$$

TABLE I
Morphometric characteristics of the 4 basins

Basins	Basin 1	Basin 2	Basin 3	Basin 4
<i>Length (m)</i>	78	46	66	48
<i>Width (m)</i>	5	43	28	23.5
<i>Depth (m)</i>	0.8	1	1	1
<i>Thickness of sludge (m)</i>	0.09	0.07	0.07	0.05
<i>Surface (m²)</i>	390	1934	1848	1128
<i>Volume (m³)</i>	312	1934	1848	1128
<i>Average flow rate (m³.s⁻¹)</i>	0.001	0.001	0.001	0.001
<i>Residence time of water (j)</i>	5	32	31	19

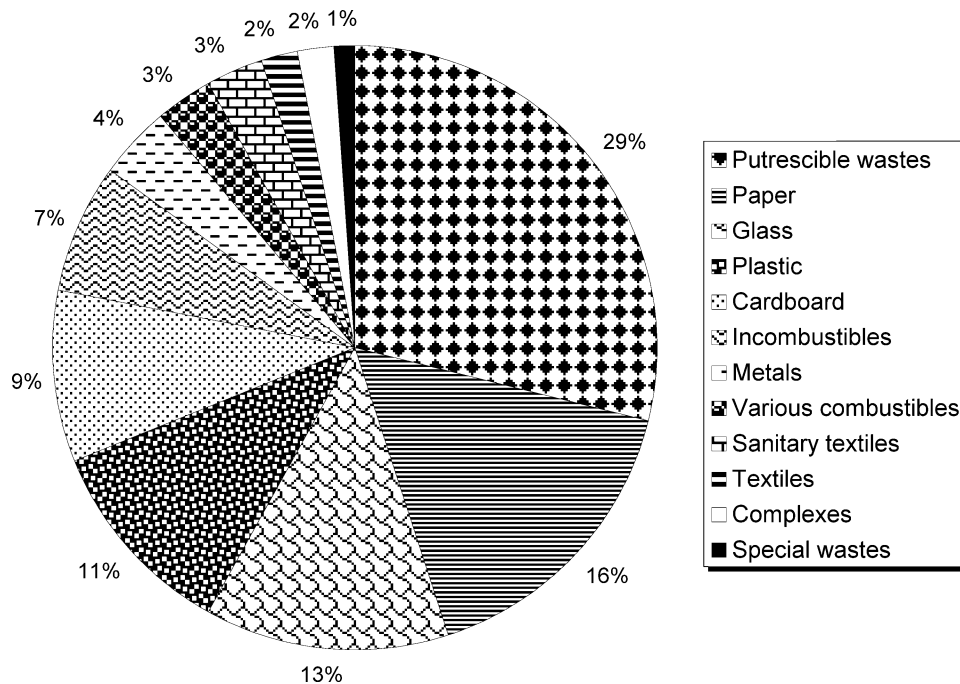


Figure 2. Composition of Etueffont landfill.

where, N : is the number of cells per ml of sample, X : is the total number of cells counted, n : is the number of optical fields, R_s : represents the ration of the surface area of the sediment chamber to the surface area of the optical field, and v : represents the volume of sedimented water. Biovolumes were estimated from cell dimensions according to Lohman (1908) and converted to carbon biomass with the conversion factor $1 \mu \text{m}^3 = 0.12 \cdot 10^{-6} \mu\text{gC}$. The biochemical composition

of particulates was estimated after a gentle filtration (vacuum pressure <100 mm Hg) of samples on precombusted (550 °C, over 6 hours) Whatman GF/C filters. The mixture of carbohydrates present which are mainly structural components of the cell wall, were hydrolyzed with concentrated sulphuric acid (97 wt.%). The phenol-sulphuric acid method of Dubois *et al.* (1956), modified by Moal *et al.* (1985) was used to determine the carbohydrate concentration. D-Glucose was used as the standard. Protein concentrations were determined by the method of Lowry (1951) with a bovine serum albumin (BSA) standard. Zooplankton was sampled in the four basins by a 75 µm pore size net.

3. Results

3.1. TEMPERATURE

The temperature values of the leachate observed in the 4 Etueffont basins varied from 3.7 to 26.2 °C ($m \pm \sigma = 14.5 \pm 7.15$ °C) in B1, 1.7 to 26.2 °C ($m \pm \sigma = 13.4 \pm 8$ °C) in B2, 0.9 to 23 °C ($m \pm \sigma = 12.5 \pm 8$ °C) in B3 and 0 to 23.7 °C ($m \pm \sigma = 12, 8 \pm 8, 3$ °C) in B4 (Figure 3a). These results provide evidence of similar seasonal evolutions of temperature in the 4 basins with warmer leachates observed in summer than in winter.

3.2. DISSOLVED OXYGEN

The dissolved oxygen concentrations measured in the 4 basins ranged between 0.17 and 12.5 mg. l⁻¹ ($m \pm \sigma = 3.56 \pm 3.8$ mg. l⁻¹) in B1, 0.25 and 13.6 mg. l⁻¹ ($m \pm \sigma = 5.4 \pm 3.6$ mg. l⁻¹) in B2, 1.5 and 17.1 mg. l⁻¹ ($m \pm \sigma = 6.1 \pm 4.3$ mg. l⁻¹) in B3 and 1.5 to 16.1 mg. l⁻¹ ($m \pm \sigma = 7.9 \pm 4.5$ mg. l⁻¹) in B4 (Figure 3b). The distribution of dissolved oxygen concentrations pointed out two peaks, in summer and later in winter. The lowest values of dissolved oxygen concentrations were recorded in the first basin.

3.3. pH

pH values recorded in the 4 basins varied between 4.02 to 8.08 ($m \pm \sigma = 6.91 \pm 1.24$) in B1, 4.62 to 8.21 ($m \pm \sigma = 6.88 \pm 1.27$) in B2, 4.74 to 8.39 ($m \pm \sigma = 7.23 \pm 1.47$) in B3 and 4.55 to 8.86 ($m \pm \sigma = 7.23 \pm 1.47$) in B4 (Figure 3c). The distribution of pH value showed a clear seasonal variability with alkaline pH in summer and more acidic values in winter and spring.

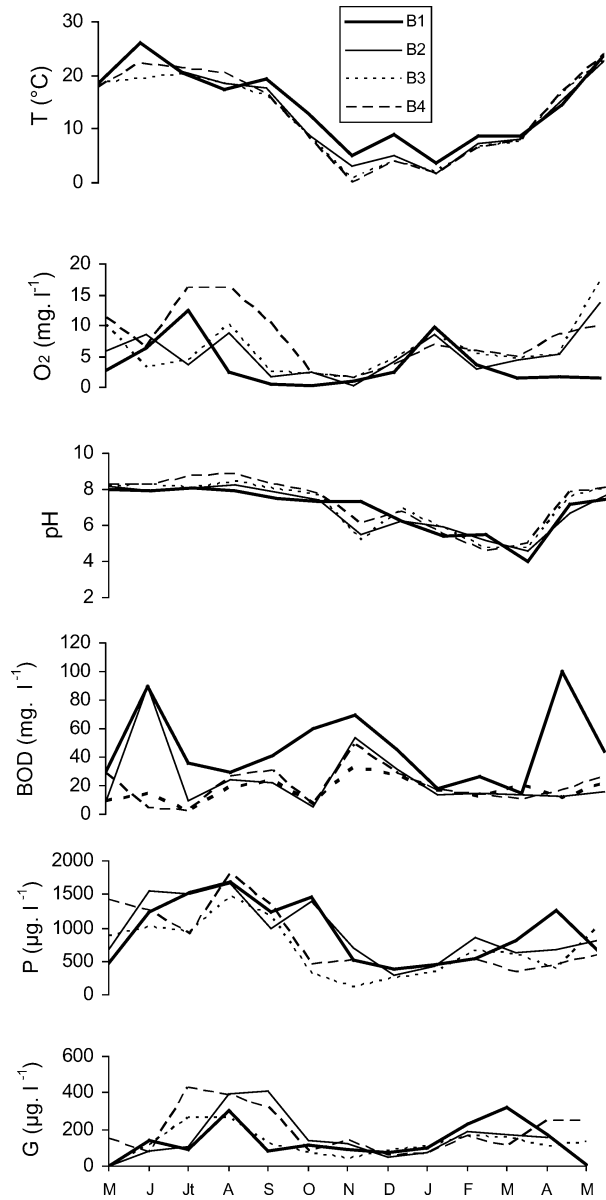


Figure 3. Spatio-temporal evolution of pH, temperature, dissolved oxygen (mg. l^{-1}), biochemical composition of particulate matter ($\mu\text{g. l}^{-1}$) and BOD (mg. l^{-1}) in the 4 basins.

3.4. BOD

BOD values varied from 14 to $100 \text{ mg. l}^{-1}\text{O}_2$ ($m \pm \sigma = 26 \pm 46 \text{ mg. l}^{-1}\text{O}_2$) in B1, 5 to $90 \text{ mg. l}^{-1}\text{O}_2$ ($m \pm \sigma = 24 \pm 23 \text{ mg. l}^{-1}\text{O}_2$) in B2, 2 to $34 \text{ mg. l}^{-1}\text{O}_2$

($m \pm \sigma = 17 \pm 8 \text{ mg. l}^{-1}\text{O}_2$) in B3 and 2 to 50 $\text{mg. l}^{-1}\text{O}_2$ ($m \pm \sigma = 20 \pm 13 \text{ mg. l}^{-1}\text{O}_2$) in B4 (Figure 3d). These results pointed out both spatial and temporal decreases in organic content respectively from B1 to B2 and from summer to winter.

3.5. SYSTEMATIC INVENTORY OF SPECIES FOUND IN THE 4 BASINS

The inventory of taxa present in the basins (no inventory has been made before our work) showed a weak species richness. These results went along with the phytoplankton population inventories reported in the literature (Drakides, 1987; Belbahri, 1989) from domestic water treatment basins (Figure 4). Obviously, these findings underlined the strong environmental constraints in which algal species evolved.

3.6. DISTRIBUTION OF PHYTOPLANKTON ABUNDANCE AND BIOMASS

Basin 1: Phytoplankton density fluctuated between 0.016×10^6 and 2.9×10^6 cells l^{-1} , ($m \pm \sigma = 0.5 \times 10^6 \pm 0.8 \times 10^6$ cells l^{-1}) (Figure 5) that corresponded to biomasses ranging between 2 and 1308 $\mu\text{g C. l}^{-1}$ ($m \pm \sigma = 172 \pm 386 \mu\text{gC. l}^{-1}$). The calculated annual phytoplankton biomass was up to 4.6 mgC. l^{-1} , with maximum values registered in the summer of 1998 (i.e. May to August). The peak algal biomass (1.3 mgC. l^{-1}) recorded in August 1998 was chiefly associated with the development of *Chlamydomonas* sp..

Basin 2: The Phytoplankton abundance measured in B2 ranged between 0.031×10^6 and 4.5×10^6 cells l^{-1} ($m \pm \sigma = 0.8 \times 10^6 \pm 1.3 \times 10^6$ cells l^{-1}) (Figure 5), with an annual biomass of 5.9 mgC. l^{-1} . The phytoplankton biomass varied from 15 to 3769 $\mu\text{gC. l}^{-1}$ ($m \pm \sigma = 456 \pm 1052 \mu\text{g C l}^{-1}$), with a maximal value of 3.76 mgC. l^{-1} recorded in August 1998; that coincided with the development of *Phacus* sp.

Basin 3: The phytoplankton numbers estimated in B3 varied between 0.032×10^6 and 14.5×10^6 cells l^{-1} , ($m \pm \sigma = 1.6 \times 10^6 \pm 4 \times 10^6$ cells l^{-1}) (Figure 5) and biomass ranged between 3.47 to 5558 $\mu\text{gC. l}^{-1}$ ($m \pm \sigma = 791.8 \pm 1777 \mu\text{gC. l}^{-1}$) with an annual calculated phytoplankton biomass reaching 10.29 mg C l^{-1} . The maximum biomass of 5.56 mgC. l^{-1} (May 1999) was attributed to the *Coelastrum* sp. development (49 % of the total biomass).

Basin 4: the phytoplankton density ranged between 0.048×10^6 to 29×10^6 cells l^{-1} , ($m \pm \sigma = 5.1 \times 10^6 \pm 10.2 \times 10^6$ cells l^{-1}) (Figure 5). This translated into phytoplankton biomasses ranging between 9 to 20685 $\mu\text{gC. l}^{-1}$ ($m \pm \sigma = 3244 \pm 6936 \mu\text{gC. l}^{-1}$). The calculated annual phytoplankton biomass was up to 42 mgC. l^{-1} . The maximal algal development was registered in May 1998 and correlated with the blooms of *Coelastrum* sp. and *Euglena* sp.

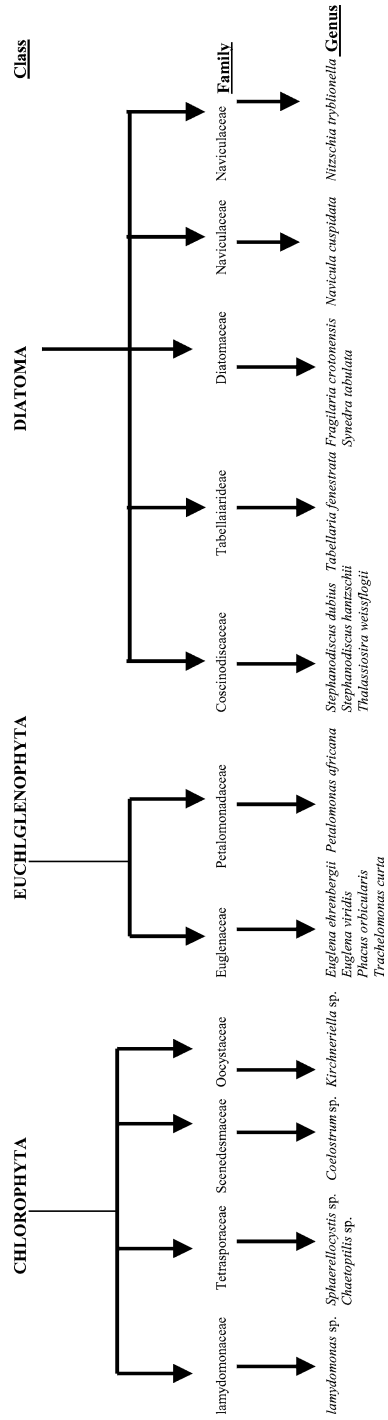


Figure 4. Systematic inventory of algal species found in the 4 basins.

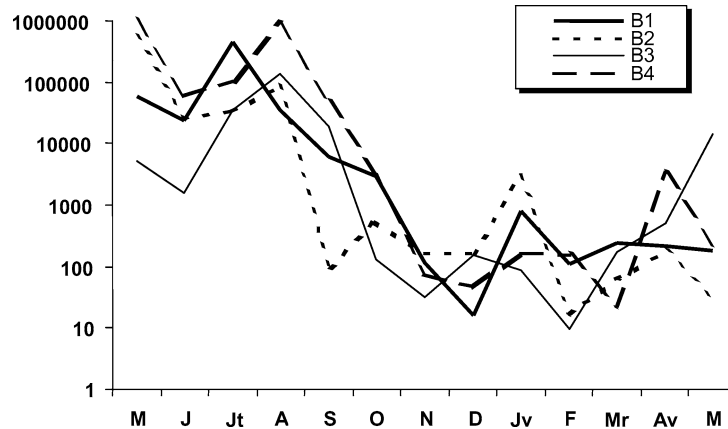


Figure 5. Spatio-temporal evolution of the algal abundance in the 4 basins (cells. l⁻¹).

3.7. BIOCHEMICAL COMPOSITION OF THE PARTICULATE MATTER

The particulate protein content of the leachate varied from 391 to 1680 $\mu\text{g. l}^{-1}$ ($m \pm \sigma = 946 \pm 467 \mu\text{g. l}^{-1}$) in B1, 284 to 1669 $\mu\text{g. l}^{-1}$ ($m \pm \sigma = 935 \pm 452 \mu\text{g. l}^{-1}$) in B2, 109 to 1468 $\mu\text{g. l}^{-1}$ ($m \pm \sigma = 701 \pm 413 \mu\text{g. l}^{-1}$) in B3 and 330 to 1804 $\mu\text{g. l}^{-1}$ ($m \pm \sigma = 797 \pm 493 \mu\text{g. l}^{-1}$) in B4 (Figure 3e). The temporal distribution in protein contents showed high levels particularly in summer, that coincided with increased phytoplankton density. The particulate carbohydrate content of the leachate ranged between 8 to 324 $\mu\text{g. l}^{-1}$ ($m \pm \sigma = 133 \pm 100 \mu\text{g. l}^{-1}$) in B1, 50 to 412 $\mu\text{g. l}^{-1}$ ($m \pm \sigma = 160 \pm 126 \mu\text{g. l}^{-1}$) in B2, 37 to 265 $\mu\text{g. l}^{-1}$ ($m \pm \sigma = 125 \pm 37 \mu\text{g. l}^{-1}$) in B3 and 60 to 425 $\mu\text{g. l}^{-1}$ ($m \pm \sigma = 190 \pm 125 \mu\text{g. l}^{-1}$) in B4 (Figure 3f). The distribution pattern of carbohydrate concentrations showed a clear decrease in winter concomitantly to that of proteins.

3.8. SPATIO-TEMPORAL DISTRIBUTION OF THE CLADOCERAN COMMUNITY

The Cladocera population decreased from 30.000 individuals $\cdot \text{l}^{-1}$ in the first basin to 800 individuals $\cdot \text{l}^{-1}$ in the last basin (Table II). These metazoan communities were present only in summer and dominated by *Moina* sp. which is reputed to develop in rich organic matter leachate (Loedolf, 1965; Angeli, 1979). The decrease of individual numbers from the first basin to the last correlated with the increase in Rotifera and phytoplankton (*Stephanodiscus* sp. and colonial *Coelastrum* sp.) numbers. All these species have been shown to be poorly edible preys for *Moina* sp. (Angeli, 1979; Benider *et al.*, 1998).

TABLE II
Abundance of *Moina* sp. individuals in the 4 basins

		M-98	J	Jt	A	S	O	N	D	Jv	F	Mr	A	M-99
B1	<i>M.macropa</i>	16400	5000	0	0	0	0	0	0	0	0	0	0	0
	<i>M.brachiata</i>	30000	2000	0	0	0	0	0	0	0	0	0	0	400
B2	<i>M.macropa</i>	0	800	25000	0	0	0	0	0	0	0	0	0	0
	<i>M.brachiata</i>	400	1200	18000	0	0	0	0	0	0	0	0	0	200
B3	<i>M.macropa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>M.brachiata</i>	1600	0	800	0	0	0	0	0	0	0	0	0	0
B4	<i>M.macropa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0
	<i>M.brachiata</i>	800	0	0	0	0	0	0	0	0	0	0	0	0

4. Discussion

4.1. PHYSICO-CHEMICAL ENVIRONMENT

The water temperature is an important and integral parameter in the functioning of aquatic ecosystems, and depends on the period of sunshine and exchanges with the atmosphere. Temperatures in the 4 basins were similar and varied between 18 to 25 °C in summer and 0 to 8 °C in winter (Figure 3a) with the basins freezing in November 1998. The temperature of the leachate in basin B1 was the highest as this basin was immediately influenced by the inputs from the raw leachate and also shallower than basins B2, B3 and B4. We did not observe a clear thermal water stratification since the highest difference in temperature between the bottom and superficial layers did not exceed 6 °C.

The dissolved oxygen concentrations points out a spatial (between basins and from the bottom to the surface layers) and temporal (seasonal variation). The annual cycle appears to show 2 sequence of events. Firstly, elevated values varying from 3 to 12 mg l⁻¹ are observed in summer in the euphotic zone. Secondly, in winter lower values ranging between 0 and 4 mg l⁻¹ were closely related to cold temperatures, plant respiration, animals, microorganisms and oxidation of dead organisms and their subsequent decomposition by heterotrophic bacteria. However, during January 1999, we observed high levels of oxygen in the middle of the basins, most likely due to the winter algal bloom and wind-inducing oxygen water enrichment. The oxygen concentrations. In summer, oxygen concentrations were higher at the surface than in the bottom due to spring primary production.

pH is highly dependent on biological and chemical mechanisms. Among the factors which may influence pH, we will discuss temperature, photosynthetic activity and salinity. In summer, we observed an elevation in pH of (up to 8), with values decreasing in winter to reach 4. These values resulted in part from the collapse of the algal photosynthetic activity in the basins (consumption of H⁺) and the supply

of acidic leachates. The vertical evolution of pH did not appear to be influenced by water depth. However, the annual changes in the pH did not exceed 1 between the surface and the bottom of all sampling points. BOD values recorded in this work showed a progressive decrease from B1 to B4. This is most likely due to both sedimentation and degradation (oxidation) of organic matter by microorganisms that colonized the leachate.

The distribution of protein and carbohydrate contents of the leachate showed increasing concentrations from B1 to B4, and from winter to summer that were associated to patterns of phytoplankton seasonal succession. Indeed, both proteins and carbohydrate concentrations peaked in summer when phytoplankton proliferated. The same results have already been reported by others but, to our knowledge, only from lacustrine environments (Ganf *et al.*, 1986; Bourdier, 1998; Aleya, 1991; Michard *et al.*, 1996). In basin 1, the increase in carbohydrate content resulted from supply via the protein and carbohydrate rich discharge originating from outside the basin. The protein to carbohydrate (P/C) ratios ranged between 2.34 and 123.72 in B1, 2.4 and 309.23 in B2, 2.92 and 522.12 in B3, and 1.84 and 17.29 in B4. In summer, the coupling of high supplies from very active leachate discharge and light levels had both favoured accumulation of carbohydrates whose production greatly exceeded protein synthesis. The same observations have been made by others from lab- experiments and aquatic freshwater and marine ecosystems (Morris and Skea, 1978; Ganf *et al.*, 1986; Aleya, 1992; Mykkestad, 2000; Nagata, 2000).

4.2. BIOLOGICAL ENVIRONMENT

Study of phytoplankton populations is highly informative and contribute to approach the community structures and allows to determine how communities are organized and which strategy they adopt, i.e. pioneer or mature development (Frontier, 1977; Reynolds, 1988; Aleya 1991). The presence of *Stephanodiscus* sp. and *Coelastrum* sp. in the basins, has also been reported from hypereutrophic lakes and reservoirs (Reynolds, 1984; Aleya *et al.*, 1994). In Etuefont landfill, the Euchlorophyceae represented approximately 10% of the algal population in B1, 13% in B2, 39% in B3 and 19% in B4. Euglenophyceae were more abundant representing 60% of the total algal population in B1, 77% in B2, 58% in B3, and 76% in B4. The Bacillariophyceae accounted for 30% of the total algal population in B1, 10% in B2, 3% in B3, and 5% in B4 (Figure 6).

In basin 1, the phytoplankton biomass showed a fluctuating trend all the sampling year round, most likely due to the interaction of a number of factors, (i) variations in temperature and day length; (ii) the leachate composition and input into the basins, that may supply the basin with organic and mineral nutrients able to induce phytoplankton proliferation; (iii) the grazing pressure exerted by zooplankton on edible phytoplankton preys yielding the waning of algal biomass in surface layers (iii) different structural parameters of the 4 basins.

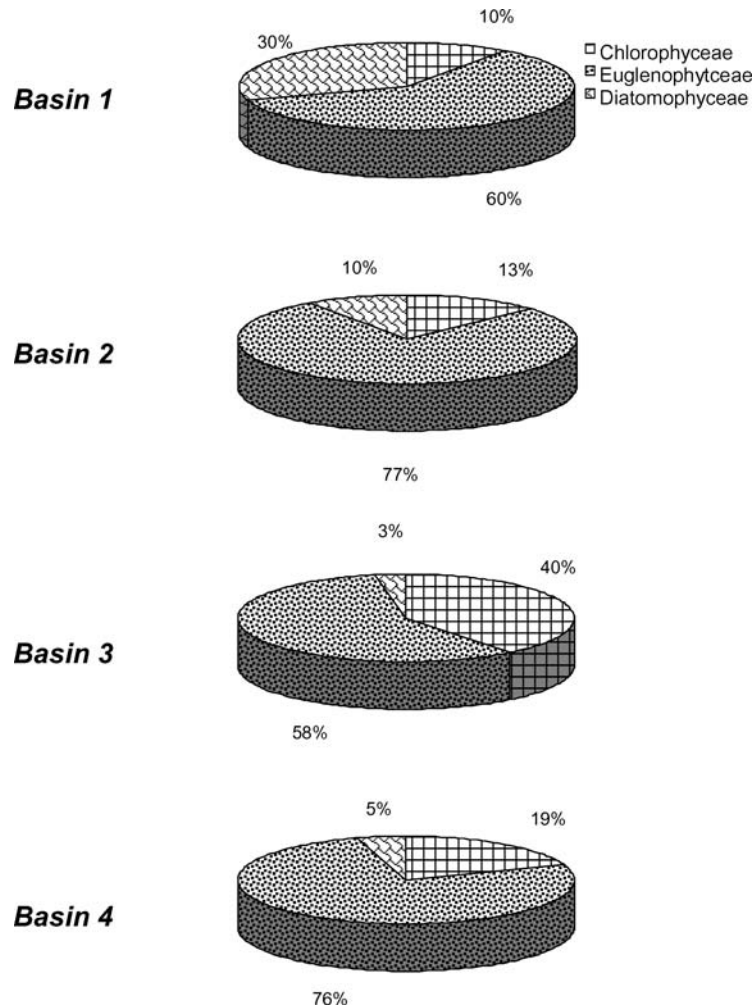


Figure 6. Relative abundance of the different algal groups in the 4 basins (%).

The ecosystem found in the Etueffont basins is very particular and entailed an unpredictably low production of phytoplankton biomass and is dominated by populations of pollutant-resistant species such as *Stephanodiscus dubius* and *Euglena* sp. Despite high nutrient supplies, the water transparency period observed in summer (May to July 1998) seemed to be an important feature in the basin1 functioning. While this behavioural pattern of prey-predator couples had been widely reported and modelled from lacustrine environments (Sommers *et al.*, 1986; Sterner, 1988; Aleya, 1991; Pinell-Alloul *et al.*, 2004), our study showed for the first time, to our knowledge this trend might occur in lagooning basins. The increase of phytoplankton biomass observed in winter 1999 (January 1999; $87.68 \mu\text{gC. l}^{-1}$) is

due to a decrease in mineral and organic contents (BOD decreased from 45 to 17 mg. l⁻¹) which originated from the rain-induced water dilution and the absence of zooplankton predators (Moinidae). Also, the phytoplankton community was monospecific (low diversity), and according to the theories of Margalef (1958, 1961), Odum (1960), Frontier (1977) and Sevrin-Ryessac (1998) who established a relationship between the specific diversity and degree of stability of a community, this trend corresponds to a pioneer strategy in species development. This leads to the break of system homeostasy and enhanced instability in the phytoplankton sequences of development yielding frequent algal invasions of surface layers.

The seasonal succession of phytoplankton in the other basins is characterised by two growth phases in summer and spring. In the summer of 1998, the increase in temperature, photoperiod, light intensity, and the presence of available nutrients, provided favourable conditions for the diverse algal species present to develop. However, this growth is downregulated by the prolific development of zooplankters (Rotifera and Moinidae) which actively exerted a significant grazing pressure on phytoplankton species. The collapse of zooplankton individuals linked to the drastic prey decline observed in August 1998 had induced new favourable conditions to phytoplankton species that underwent a valuable growth. In autumn, the fall in temperature, light intensity and the accumulation of both allochthonic and autochthonic organic matters, together with water overturn (which created homogenous temperature conditions, i.e. no stratification) induced the proliferation of the diatom *Stephanodiscus dubius*. This development went along with several reports pointing out a close relationship between *Stephanodiscus dubius* growth and the aforementioned conditions in lab experiments and field studies (Reynolds, 1990; Boumnick, 1992). During winter, an overall collapse of phytoplankton communities was observed except a short sequence of growth of primary producers in February 1999 correlating with an increase in both light intensity and water temperature and the decline in rotifer predators as reported by Sterner (1988) from limnic ecosystems. However, this episodic increase in phytoplankton biomass was not seen in basin4 due to rotifer *Keratella quadrata* grazing on algal species (Sommers *et al.*, 1986). In spring, the abiotic conditions improved and induced a shift in phytoplankton structure with the Chlorophyceae and Euglenophyceae, replacing the Bacillariophyceae. The decrease in algal density in May 1999 in the last basin was here again associated to the rotiferan grazing pressure.

4.3. DYNAMICS OF THE MOST ABUNDANT SPECIES

4.3.1. *Phacus Orbicularis*

The density of *Phacus orbicularis* decreased from the first to the last basin. This evolution correlated with an improve in leachate physico-chemical quality.

4.3.2. *Euglena* sp.

This species that have been shown (Devars *et al.*, 1998) to efficiently tolerating highly polluted leachates in particular those containing metals (e.g. Hg, Cd and Pb), was the most dominant Euglenophyte in the 4 basins. In Basin1, *Euglena* sp. showed a clear pioneer-like strategy with short but intense phases of proliferation in May 1998, November and March and April. In the second basin, and from summer to autumn, *Euglena* sp. showed two short growth peaks; the first in August 1998 and the second in November. Thereafter, *Euglena* sp. disappeared to reappear in March 1999 but with a lower cell density than in summer. In the third basin, we observed the same dynamics as seen in B2 with relatively constant numbers from August to October, with a peak in August 1998. Finally, in the last basin the development of *Euglena* was constant during the year (1998) with a brief absence of growth in autumn. Maximum growth was observed in August (Table III).

4.3.3. *Stephanodiscus Dubius*

Stephanodiscus dubius is the most abundant algal species in the 4 basins and has been shown to exhibit a high tolerance to highly polluted waters (Germain, 1981). *Stephanodiscus dubius* was present throughout the year, and absent only in July 1998 in B1. The abundance decreased in B2 and a total absence was observed over three months during the summer of 1999 (May, June and August). The maximum total number of this species was observed in January. In the third basin, *Stephanodiscus dubius* was present throughout the year but with lower numbers than in the first two basins (B1 and B2). The maximum density of *Stephanodiscus dubius* in basin 3 was observed in August 1998. In basin 4, *Stephanodiscus dubius* numbers decreased to be absent even in 1998. Two peak growths had been observed, in August and in April (Table III).

4.3.4. *Chlamydomonas* sp.

Chlamydomonas sp. is the only Euchlorophyceae specie that was commonly found in the 4 basins. This finding seemed obvious since *Chlamydomonas* sp. have been reported to develop in domestic treatment waters (Prat *et al.*, 1999). Nevertheless, observations of summer and spring growths in B1 showed a maximal growth in May 1998. In the other basins (B2, B3 and B4), *Chlamydomonas* sp. showed a slower rate of development compared to that observed in B1. In these last 3 basins, the dynamics of *Chlamydomonas* sp. were characterised by two growth phases, the first in May and June 1998 in B2, in May August and September 1998 in B3 and between June and August 1998 in B4. The second was observed in February and March (Table III).

4.3.5. *Chaetoptilis* sp.

This species was absent in B1 likely due to its commonly reported intolerance to highly polluted waters (Bourrelly, 1985). In the other basins, it developed sporadically (Table II).

TABLE III
 Spatio-temporal distribution of the total species abundance in Basins 1, 2, 3 and ($\times 10^4$ cells. l^{-1})

		Phacus sp.	Euglena sp.	Stephanod iscus sp.	Chlamydo monas sp.	Coelastru m sp.	Chaetoptili s sp.	Trachylom onas sp.
M-98	B1	10	48	99	58	Abs	Abs	Abs
	B2	Abs	1	Abs	3	Abs	Abs	42
	B3	2	Abs	1	11	11	Abs	Abs
	B4	13	Abs	6	Abs	2881	Abs	Abs
J	B1	Abs	Abs	Abs	Abs	Abs	Abs	Abs
	B2	39	Abs	Abs	3	Abs	Abs	13
	B3	2	Abs	56	Abs	Abs	Abs	8
	B4	11	Abs	Abs	2	64	Abs	Abs
Jt	B1	4.5	Abs	8	1	Abs	Abs	Abs
	B2	25	Abs	44	0	Abs	6	Abs
	B3	6	Abs	65	0	Abs	Abs	Abs
	B4	3	129	15	1	Abs	Abs	Abs
A	B1	Abs	Abs	54	41	Abs	Abs	Abs
	B2	88	48	Abs	Abs	317	Abs	Abs
	B3	9	111	6	31	249	8	Abs
	B4	8	352	0	3	1386	938	Abs
S	B1	Abs	2	14	Abs	Abs	Abs	Abs
	B2	Abs	Abs	11	Abs	Abs	Abs	Abs
	B3	Abs	48	Abs	4	Abs	Abs	Abs
	B4	4	94	29	Abs	Abs	Abs	Abs
O	B1	Abs	Abs	293	Abs	Abs	Abs	Abs
	B2	Abs	Abs	54	Abs	Abs	Abs	Abs
	B3	Abs	2	10	Abs	Abs	Abs	Abs
	B4	Abs	36	266	Abs	Abs	Abs	Abs
N	B1	Abs	2	9	Abs	Abs	Abs	Abs
	B2	2	1	15	Abs	Abs	Abs	Abs
	B3	Abs	Abs	3	Abs	Abs	Abs	Abs
	B4	Abs	Abs	7	Abs	Abs	Abs	Abs
D	B1	Abs	Abs	1.6	Abs	Abs	Abs	Abs
	B2	Abs	Abs	16	Abs	Abs	Abs	Abs
	B3	Abs	Abs	16	Abs	Abs	Abs	Abs
	B4	0.2	Abs	4	0.2	Abs	Abs	Abs
Jv	B1	Abs	Abs	81	Abs	Abs	Abs	Abs
	B2	Abs	Abs	296	Abs	Abs	Abs	Abs
	B3	Abs	Abs	8	Abs	Abs	Abs	Abs
	B4	Abs	Abs	16	Abs	Abs	Abs	Abs

(Continued on next page)

TABLE III
(Continued)

		Phacus sp.	Euglena sp.	Stephanod iscus sp.	Chlamydo monas sp.	Coelastru m sp.	Chaetoptili s sp.	Trachylom onas sp.
F	B1	Abs	2	9	0.5	Abs	Abs	Abs
	B2	2	1	6	2	Abs	Abs	Abs
	B3	0.5	2	6	2	Abs	Abs	Abs
	B4	1	2	5	3	Abs	Abs	Abs
Mr	B1	Abs	2	8	0.2	Abs	Abs	Abs
	B2	0.5	3	3	2	Abs	Abs	Abs
	B3	3	4	3	0.5	Abs	Abs	Abs
	B4	2	3	2	5	Abs	Abs	Abs
Ap	B1	Abs	Abs	22	Abs	Abs	Abs	Abs
	B2	Abs	2	15	Abs	Abs	Abs	Abs
	B3	10	1	38	2	Abs	Abs	Abs
	B4	0.8	4.8	315	Abs	Abs	Abs	Abs
M-99	B1	Abs	1	16.8	0.8	Abs	Abs	Abs
	B2	2	1	Abs	Abs	Abs	Abs	Abs
	B3	16	6	2	Abs	1430	Abs	Abs
	B4	Abs	13	0.6	Abs	10	Abs	Abs

4.3.6. *Coelastrum* sp.

Also, this species was absent in B1 but present in B2 only in July. It developed preferentially in least polluted waters of B3 and B4. (Table II).

4.3.7. *Kirchneriella* sp.

This species was not present in the last basin (Table II), going along with its preference to poor organic matter waters. The other phytoplankton populations were consistently present in low density.

5. Conclusion

The present study showed that the phytoplankton population in the Etueffont basins were dominated by pollutant-resistant species (*Stephanodiscus* sp. and *Euglena* sp). However, a sharp qualitative improve in the phytoplankton population was noted from the first to the last basin, characterised by the substitution of diatoms (abundant in the first basin) by the Chlorophyceae (*Coelastrum* sp.). This qualitative evolution provides evidence for the decrease in leachate treatment. The leachate quality and the presence of predatory are cues to the dynamic of phytoplankton populations in the Etueffont basins.

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