INVESTIGATION OF A WASTEWATER OXIDATION POND-SYSTEM PART II. BIOLOGICAL INVESTIGATIONS

by

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Introduction

To establish the efficiency of pond-systems with respect to sewage purifikation, in addition to chemical examinations we also investigated some biological processes in the ponds. We carried out continously plankton algae and zooplankton investigations for this purpose and observed the development of the submerged aquatic plants as well as the reed stands.

Plankton algal investigations

In such a pond-system the phytoplankton may play a definitive role in the optimal oxygen supply of the water and thereby in the final decomposition of organic matter. It binds the mineralized inorganic nutrients, it serves as food to numerous aquatic organisms. It may cause an increase in the secondary saprobity by its overmultiplication and thus it may pollute the River Tisza as the recipient. We tried to find an answer to all these problems in the course of our algal investigations.

The sampling was carried out parallel with the chemical sampling on the spots referred to in Part I of this paper (Kiss – Szabó 1978 – 79).

The quantitative investigations were carried out by the Utermöhl method. Qualitative investigations were done partly from settling sapmles, partly from samples filtered by a plankton-net.

Qualitative relations of the plankton algae

During the investigation period in 1975 – 1976 various algal communities appeared in the ponds that reached in some periods very large individual numbers. In some other periods they were scanty. On the basis of the species-list reported below we may state that the plankton algal stand of the ponds cannot be considered as particularly rich in species. This can be connected with frequently occurring extreme alterations in water quality.

The frequencies of occurrence are indicated by the following figures:

1 – rare, sporadic;
2 – moderately frequent;
3 – frequent;
4 – very frequent
5 frequent and at the same time occasionally abundant species (we used this term for organisms causing discoloration, blooming of the water [Table I]).

The following marks refer to the saprobiontic nature of the organisms:

oligo – oligosaprobiontic;
oligo-beta – oligo-beta mesosaprobiontic;
beta – beta mesosaprobiontic;
beta-alpha – beta-alpha mesosaprobiontic;
alpha – alpha mesosaprobiontic;
poly – polysaprobiontic.

In our investigations we determined 154 algal taxons:

Cyanophyta

Anabaena spiroides Kleb. – 1
Chroococcus turgidus (Kütz.) Naeg. – 1, oligo-beta
Coelosphaerium kützingianum Naeg. – 1, oligo-beta
Lyngbya limnetica Lemm. – 3
L. martensiana Menegh. – 1, beta
Merismopedia elegans A. Br. – 1, oligo-beta
M. glauca (Ehrbg.) Naeg. – 2
M. punctata Meyen – 1, beta-alfa
M. tenuissima Lemm. – 2, beta-alfa
Oscillatoria chlorina Kütz. – 1, poli (poli-alpha)
O. lauterbornii Schmidle – 1
Spirulina laxissima G. S. West – 2
S. subtilissima Kütz. – 1, (beta)

Euglenophyta

Euglena oxiuris Schmarda – 2, beta-alpha
E. proxima Daug. – 2, beta-alpha
Phacus acuminatus Stokes – 1, beta-alpha
Ph. caudatus Hübner – 1
Ph. longicauda (Ehrbg.) Duj. – 1, beta-alpha
Ph. pleuronectes (O. F. M.) Duj. – 1, beta-alpha
Strombomonas deflandrei var. *szolnokiensis* Uherkov. – 1
S. fluvatilis (Lemm.) Defl. – 1, beta
Trachelomonas oblonga Lemm. – 1

T. planctonica Swir. – 1, beta
T. scabra Playfair – 1
T. stokesiana Palmer – 1

Pyrrophyta

Chroomonas acuta Uterm. – 3 – 5
Cryptomonas erosa Ehr. – 3 – 5, alpha
C. marsonii Skuja – 3 – 5
C. ovata Ehr. – 3 – 5, oligo-beta

Chrysophyta
Chrysophyceae

Dinobryon divergens Huhof – 1, oligo-beta
Mallomonas elongata Reuvdin – 2

Xanthophyceae

Tribonema aequale Pascher – 1
T. vulgare Pascher – 1

Bacillariophyceae

Achnantes lanceolata f. *capitata* O. Müll. – 1, oligo
A. minutissima (Kütz.) Grun. – 2 oligo-beta
Amphora ovalis Kütz. – 1, oligo-beta
A. ovalis var. *pediculus* Kütz. – 1
A veneta (Kütz.) Hust. – 1
Cocconeis pediculus Ehrbg. – 3, oligo-beta
C. placentula var. *euglypta* (Ehrbg.) Grun. – 3, oligo-beta
Cyclotella comta (Ehrbg.) Kütz. – 3, beta
C. kützinghiana (Thwait.) Chauvin – 2
C. menenghiniana Kütz. – 3 – 5, beta-alpha
Cymatopleura solea (Bréb.) W. Smith – 1, beta-alpha
Cymbella ventricosa Kütz. – 1, oligo-beta
Diatoma elongatum (Lyngb.) Agh. – 2, oligo-beta
D. vulgare var. *lineare* Grun. – 2
Gomphonema angustatum Ehrbg. – 1, oligo-beta
G. olivaceum (Lyngb.) Kütz. – 2, beta-alpha
Gyrosigma acuminatum (Kütz.) Cleve. – 1, beta
G. kützingii (Grun.) Cleve. – 1
G. scalproides (Rabenh.) Cleve. – 1
Melosira granulata var. *angustissima* Müll. – 2, beta
M. varians Agh. – 1, beta (oligo-beta?)
Navicula cryptocephala Kütz. – 3, beta-alpha
Nitzschia acicularis W. Smith – 2, beta-alpha

N. actinastroides (Lemm.) v. Goor – 1
N. capitellata Hust. – 1
N. palea (Kütz.) W. Smith – 1 alpha
N. frustulum (Kütz.) Grun. – 1
N. sigmoidea (Ehrbg.) W. Smith – 1, beta-alpha
Rhoicosphaenia curvata (Kütz.) Grun. – 2, beta
Stephanodiscus hantzschii Grun. – 4
Surirella ovata Kütz. – 3, oligo-beta
S. patella Kütz. – 1
S. peisonis Pant. – 1
Synedra acus Kütz. – 2, beta
S. acus var. *radians* (Kütz.) Hust. – 2, beta
S. ulna (Nitzsch.) Ehrbg. – 1, beta-alpha
S. ulna var. *oxyrhynchus* (Kütz.) v. Heurck – 1

Chlorophyta
Chlorophyceae

Actinastrum hantzschii Lagerh. – 1, oligo-beta
Ankistrodesmus acicularis (A. Br.) Kors. – 3 – 5, beta-alpha
A. angustus Bern. – 3 – 5, beta
A. arcuatus Kors. – 2
A. longissimus var. *acicularis* (Chod.) Brunnt. – 2, beta
Ankyra ocellata (Kors.) Fott – 3
Characium ambiguum Hermann – 2
Chlamydomonas conferta Kors. – 3 – 5
Ch. reinhardii Dang. – 3 – 5, alpha (Figure 1/1)
Chodatella balatonica Scherfel – 1
Ch. longiseta Lemm. – 1, beta
Coelastrum cambricum Arch. – 1
C. microporum Neag. – 2, beta
C. sphaericum Naeg. – 2, oligo-beta?
Crucigenia apiculata Schmidle – 2, beta
C. quadrata Morren – 1, beta
C. rectangularis Gay – 1
Dictyosphaerium pulchellum Wood. – 1, beta
Didymocystis inconspicua Kors. – 1
D. planctonica Kors. – 3
D. tuberculata Kors. – 2
Franceia droescheri (Lemm.) Kors. – 1
Gloeoactinium limneticum G. M. Smith – 3 – 5 (Figure 1/3)
Hydrodictyon reticulatum (L.) Lagerh. – 1 – 5, oligo-beta
Kirchneriella contorta (Schmiddle) Bohl. – 2
K. lunaris (Kirch.) Moeb. – 3, beta
K. obesa (W. West) Schmidle – 2, beta
Lagerheimia genevensis Chod. – 1
Nephrocytium aghardianum Schroed. – 1

Oocystis borgei Snow. – 2, beta-alpha
Pediastrum boryanum (Turp.) Menegh. – 2, beta-alpha
P. duplex Meyen. – 1, beta-alpha
Pteromonas angulosa Lemm. – 1 (Figure 1/2)
Scenedesmus acuminatus (Lagerh.) Chod. – 2, beta-alpha
S. acutus Meyen. – 2, beta-alpha
S. acutus f. *alternans* Hortob. – 1
S. acutus f. *costulatus* (Chod.) Uherkov. – 1, beta-alpha
S. armatus var. *boglariensis* Hortob. – 1
S. armatus var. *boglariensis* f. *semicostatus* Hortob. – 1
S. carinatus (Lemm.) Chod. – 1
S. denticulatus Lagerh. – 1, beta
S. denticulatus var. *linearis* Hansg. – 1, beta
S. denticulatus var. *linearis* f. *granulatus* Hortob. – 1
S. dispar Bréb. – 1, (Figure 1/4)
S. ecornis var. *disciformis* Chod. – 1
S. intermedius Chod. – 1, beta
S. intermedius var. *bicaudatus* Hortob. – 1
S. opoliensis P. Richt. – 1
S. quadricauda Fritsch – 3
S. quadricauda var. *maximus* Uherkov. – 1
S. quadricauda var. *quadrispina* (Chod.) G. M. Smith – 1
S. spicatus W. et G. S. West – 1
S. spinosus Chod. – 3, oligo-beta
S. spinosus var. *bicaudatus* Hortob. – 3
S. spinosus Chod. forma (Figure 1/5 Cell-size $4.5-5\times10.5-11\mu m$. The cell-shape of the double-celled cenobium was found only on one occasion and the spinosity of one ("marginal") cell is in conformity with the typical form. But there is a remarkable difference in the spinosity of another cell (which is, with respect to its form, its localization, its symmetry, indentical with the intermediate second cell of a four-celled cenobium). On one apex of this cell there is one shorter, 2.5 μm, on the other apex one short, 1 μm and one long, 9 μm, spine. On the basis of the direction of bend of this long spine, which corresponds to the spine of similar position of the other cell, the specimen found shows a considerable similarity to *Scenedesmus quadricuada* var. *setosus* Kirch. To determine its proper systematical position it would be necessary to find and examine further individuals.
S. subspicatus Chod. – 1
S. subspicatus var. *brevicauda* (G. M. Smith) Chod. – 1, (Figure 1/6) Cell-size: $7.7-8\times2.3-2.5\ \mu m$. It differs from the variety in the robustness of the spines, which is apparent in first line on the marginal cells.
Schroederia robusta Kors. – 3
S. setigera (Schroed.) Lemm. – 3
Selenastrum minutum (Naeg.) Coll. – 2
S. gracile Reinsch. – 2
Siderocelis ornata Fott – 3

Siderocystopsis fusca (Kors.) Swale – 1
Tetraëdron arcus Kiss K. – 1
T. caudatum (Corda) Hansg. – 1, beta. The alga visible in Figure 1/7 the diameter of wich is 13–14 μm, length of its spines is 2–3 μm, differs from the typical form by the forking of one spine from its wide base. We may consider it as a teratologic form since the forking spine is not a hereditary mark. This is well observable on the regular spininess of the autospora developed within the mother-cell.
T. caudatum var. *incisum* Lagerh. – 1, beta
T. caudatum var. *inciso-punctatum* Kiss K. – 1
T. caudatum var. *inciso-punctatum* f. *flexocaudatum* (Hortob.) Kiss K. – 1 (Figure 1/8)
T. minimum (A. Br.) Hansg. – 1, beta
T. minimum var. *scrobiculatum* f. *polypapillatum* Hortob. – 1
T. minimum var. *tetralobatum* (Reinsch.) Claus – 1
T. muticum (A. Br.) Hansg. – 1
T. pentaëdricum W. et G. S. West – 1 (Figure 1/9)
T. triangulare Kors. – 1 (Figure 1/10). Cell-diameter 12 μm. The shape of the mother-cell is apparently grown round during autospora formation.
Tetrastrum glabrum (Roll.) Ahlstr. et Tiff. – 1
T. staurogeniaeforme (Schroed.) Lemm. – 1, beta
Treubaria triappendiculata Bern. – 2
Volvox aureus Ehrbg. – 3 – 5, oligo-beta
V. globator (L.) Ehrbg. – 3 – 5, oligo-beta

Conjugatophyceae

Closterium acutum Bréb. – 1
C. acutum var. *variabile* (Lemm.) Krieger – 2
C. leibleinii Kütz. – 1, beta-alpha
Cosmarium obtusatum Schmidle – 1, beta

Based on the above species-list we may establish that 59% of the algae found turned up only rarely, sporadically. Nearly 10% of them are thus abundant and at the same time of mass-like appearance. These are the following species: *Chroomonas acuta, Cryptomonas erosa, C. marsonii, C. ovata, Cyctotella meneghiniana, Stephanodiscus hantzschii, Ankistrodesmus angustus, Chlamydomonas conferta, Ch. reinhardii, Gloeoactinium limneticum, Hydrodictyon retudulatum, Volvox aureuas, V. globator.*

47% of the algae species found are saprobiontic indicator organisms. We may establish on the basis of frequency data and saprobiontic indicator values that the overwhelming plurality of the organisms indicate an oligo-beta mesosaprobic respectively beta-alpha mesosaprobic domain of pollution. Thus the water quality of the ponds cannot be objected from the point of view saprobiology even in the case of the algal mass-vegetations (Table I.) At the same time trophity problems arise. This is also indicated by the high a-chlorophyll content (Figure 2).

Table I

Distribution of algae by frequency and saprobiologic indicator-value

f−v \ s.i.v.	o	o−b	b	b−a	a	p	n.i.o.
1	1	9	15	11	1	1	48
2		3	7	8			16
3		3	2	1			6
4							1
5		4	1	2	1		5

s. i. v. = saprobiologic indicator-value, o = oligosaprobiontic, o − b = oligo-beta mesosaprobiontic, b − beta mesosaprobiontic b − a = beta-alpha mesosaprobiontic, a = alpha mesosaprobiontic, p = polysaprobiontic, n. i. o. = non-indicator organisms, f − v = frequency-value.

Quantitative alterations of the plankton algae

Concerning the expectable quantitative alterations of the plankton algae two hypotheses emerged already during the planning of the ponds. As one possibility it was postulated that a very rich algal vegetation will develop in the ponds that may eventually lead to water-blooms. This would disturb both the efficiency of the secondary treatment and the proper operation of the ponds. Another possibility was a scattered, poorish algal vegetation developing mainly in winter or as a result of strong pollution. This would lead to a failure of the efficiency of secondary treatment. In such cases one should establish the favorable plankton communities by inoculating laboratory algal cultures.

We carried out our first algal investigations in the initial period of the filling up of the pond-system. The investigations on April 23, 1975 have shown that the *Cryptomonas* and Chlorococcales species multiplied in large masses in the algal and fish ponds (Figure 3 and 4). In the algal ponds the species *Cryptomonas* (90 millions ind./liter), the *Ankistrodesmus angustus* (240 millions ind./liter) and a hardly indentifiable Chlorococcales species (730 millions ind./liter) exceeding the poly and hypertroph level appeared. [All the P and N values were above the polytroph level too as stated by Kiss-Szabó 1978 – 79.] The alga multiplication of great extent reaching the hypertroph level may have two reasons. On one hand, the ponds were built on a former agriculturally utilized territory from which the upper tilth layer rich in nutrient matter has not been removed. On the other hand, by a technological break more hundreds kilograms of trisodium phosphate got into the sewage in March. These two factors together may have caused such an increase of the trophity level (Felföldy 1974, Järnefelt 1952, Uherkovich 1971).

After the first measurements it was to be expected that the unusually rich phytoplankton communities developing in the ponds – although

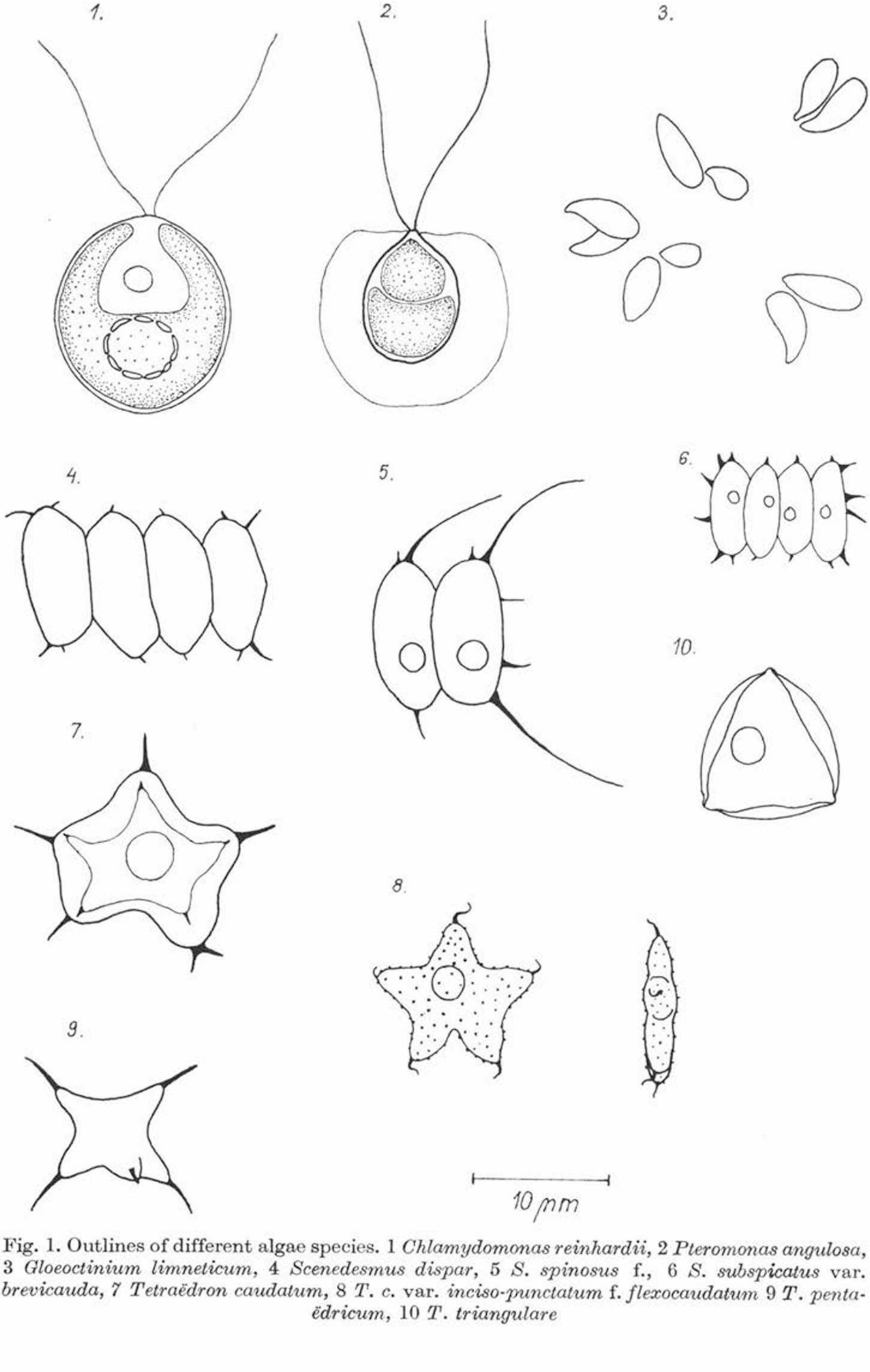

Fig. 1. Outlines of different algae species. 1 *Chlamydomonas reinhardii*, 2 *Pteromonas angulosa*, 3 *Gloeoctinium limneticum*, 4 *Scenedesmus dispar*, 5 *S. spinosus* f., 6 *S. subspicatus* var. *brevicauda*, 7 *Tetraëdron caudatum*, 8 *T. c.* var. *inciso-punctatum* f. *flexocaudatum* 9 *T. pentaëdricum*, 10 *T. triangulare*

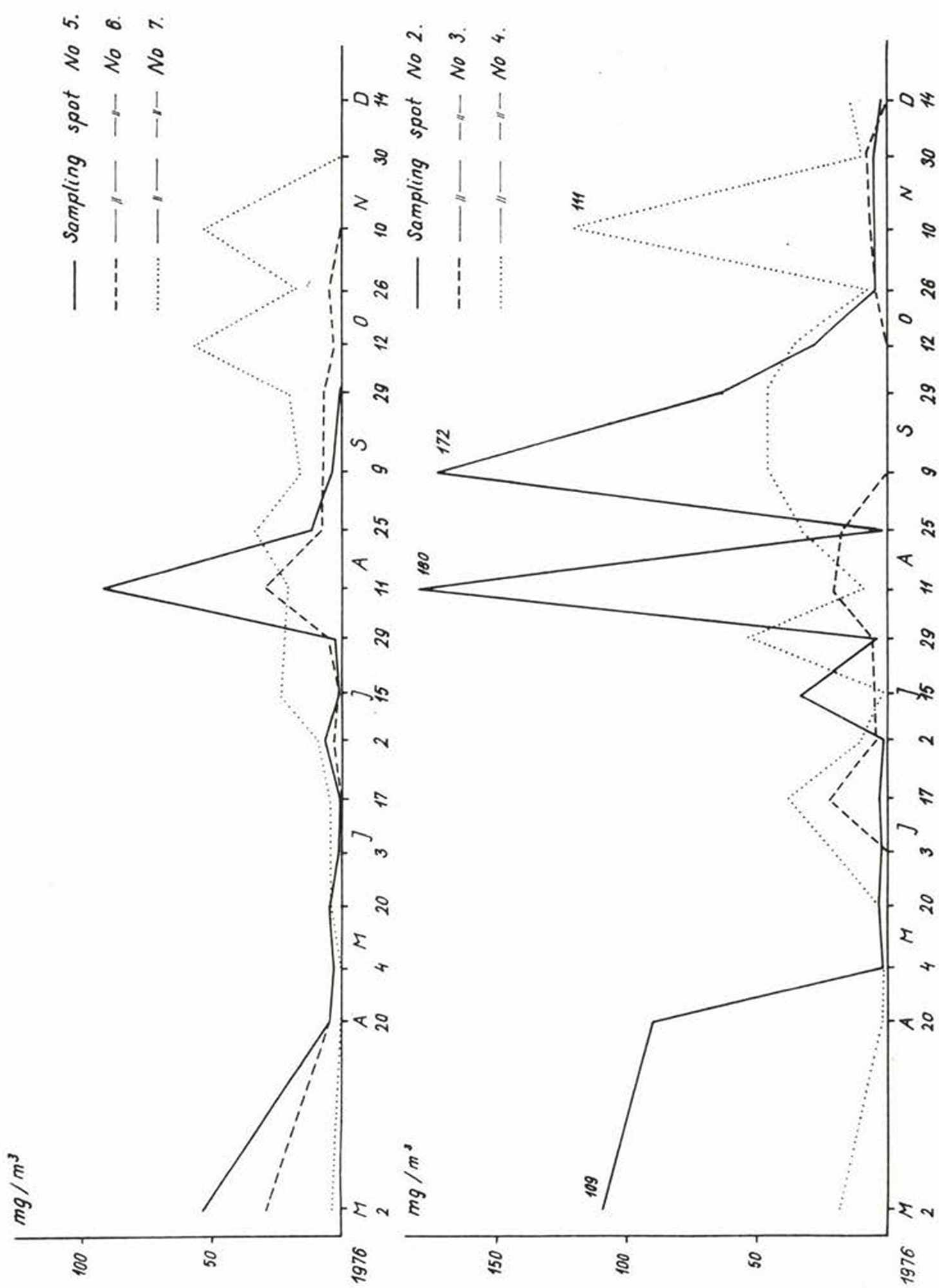

Fig. 2. Variation of a- clorophyll in 1976

they decrease the dissolved nutritive matter content and the pollution of the ponds by turning it into body matter, – will not settle in the ponds carrying a planktonic life. After the lift they will pollute the water of the River Tisza at least to such an extent as if the primarily treated water getting in the ponds would have been discharged in the recipient. Perhaps, there exists the danger that through further multiplication in the River Tisza they will provide the water with "inoculating matter" and will be the cause of the deterioration of the water quality in the Kisköre Reservoir.

The initial extensive multiplication of the plankton algae later stopped, then regressed, the cause of which were in first line the filamentous alga (*Cladophora fracta* Kütz.) grass-plots-forming, continually larger masses and the tangle (*Potamogeton pectinagus* L.) plots appearing on the bottom of the ponds. By their gaining ground they gradually outplaced the plankton algae first in the reedy ponds, later on in the algal and fish ponds (Figure 3 and 4). Thus by the end of August the phytoplankton stand became unusually poorish.

As long as winter has not set in, and the ponds have not frozen in, this image did not alter notably. But then in reedy pond No 3, in fish pond No 4 later on in the other ponds the plankton algae appeared in large masses. The *Cocconeis pediculus*, *Chroomonas acuta*, *Cryptomonas*, *Chlamydomonas*, *Cyclotella* species and the *Stephanodiscus hantzschii* reached an individual number of many millions. In Winter, in cold water, under unfavorable light conditions while ice- and snow-bound such an algal overmultiplication is a very rare event. This is rather characteristic of europhycated lakes (as for example the Keszthely Bay of Lake Balaton/Hungary), we observed a similar phenomenon on the River Tisza and primarily on the Keleti Főcsatorna/Hungary (= Eastern Principal Canal) (Kiss 1975).

After the melting of the ice the algal number further increased (Tables II and III) primarily in the two algal ponds and approached the 30–60 millions ind./liter values. To the end of May the quantity of algae decreased in every pond to the expected low value. Me say "to the expected low value" because we hoped that the *Cladophora* and *Potamogeton* communities will further multiply in large masses similar to the previous year, fixing in their bodies the dissolved nutrients and ousting the algae. However as will be described below, the filamentous algae and submerged macrophytes stands gradually became deterioriated and later on got entirely destructed.

Parallel to this latter event the algal number began to increase again, later on it became very fluctuationg as it is illustrated in Figures 2 and 3. The fluctuation and the differences, so apparent with ponds, have two essential causes. On the one hand the destruction of the *Cladophora* and *Potamogeton* vegetation and the increase in autosaprobity incidental to it proceeded not in every pond at the same time and not everywhere during the same period. On the other hand the destruction of the submerged vegetation was elicited by the overcharge of the inner sewage treatment system, i.e. water of unfavourable quality got to the ponds and this loaded

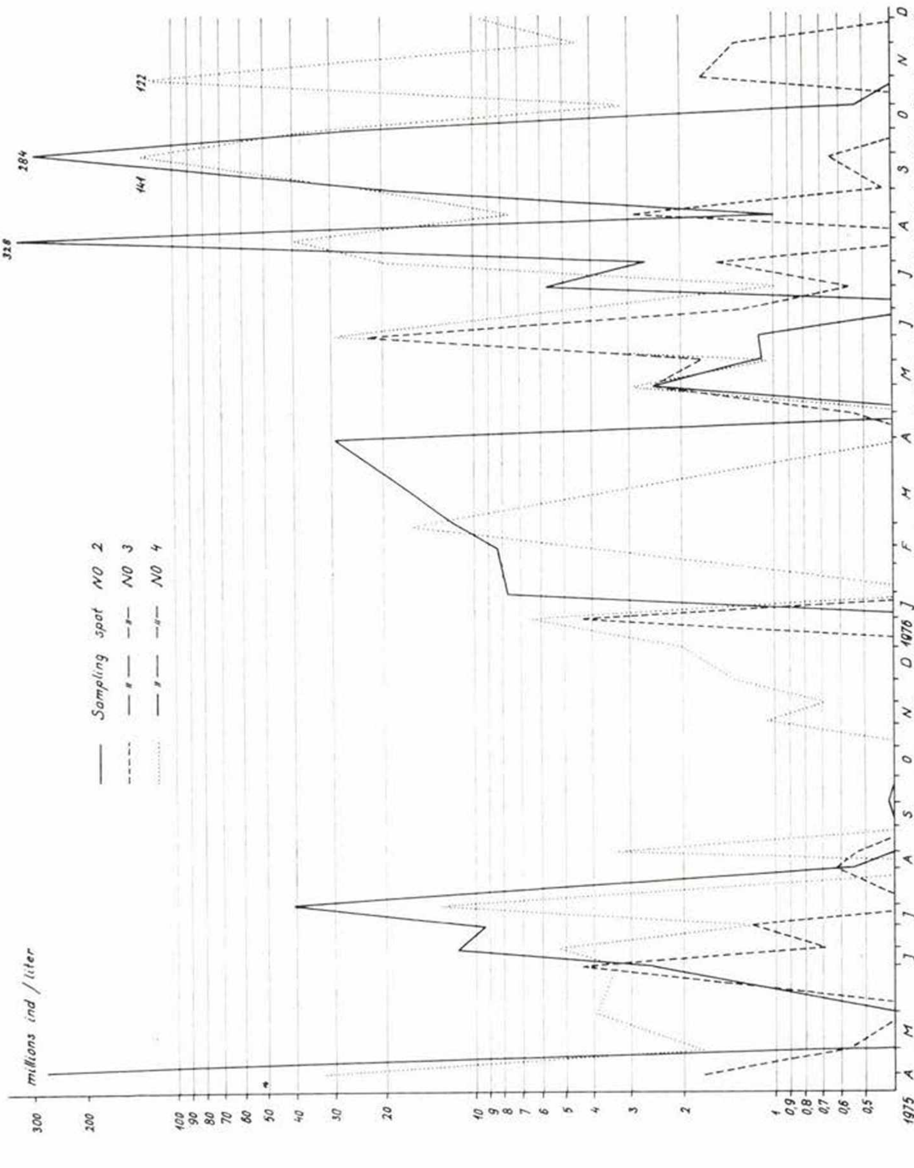

Fig. 3. Variation of the phytoplankton quantity in 1975 and 1976

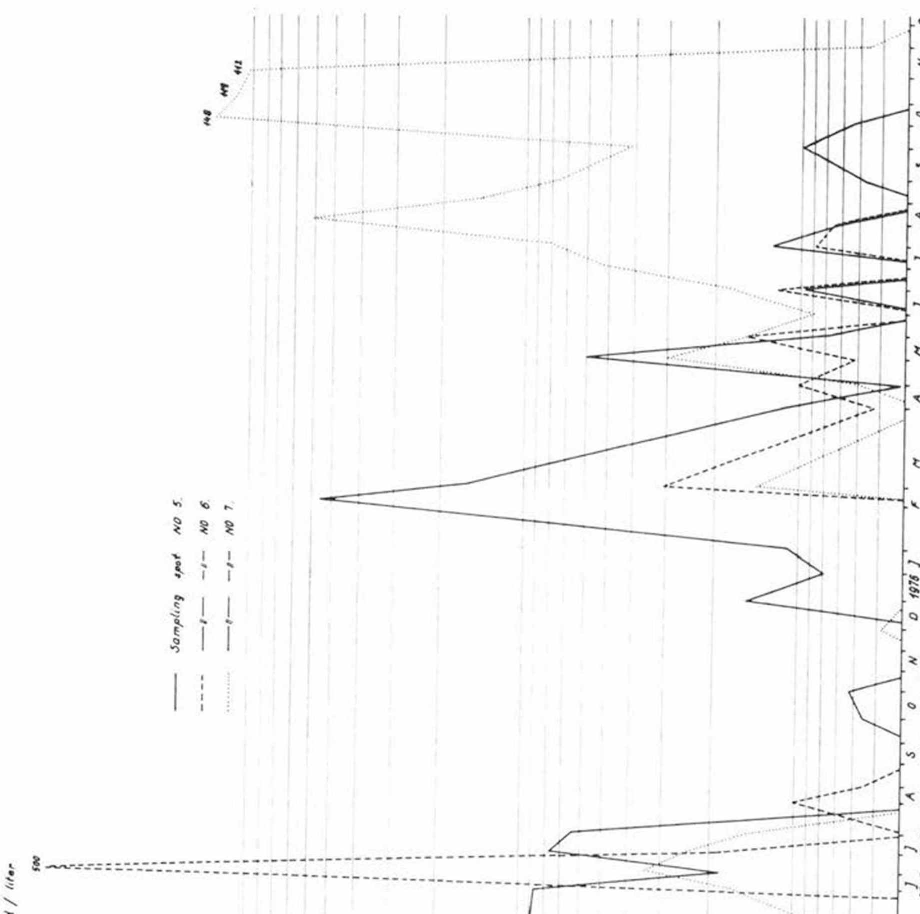

Fig. 4. Variation of the phytoplankton quantity in 1975 and 1976

Table II

A quantitative analysis of the plankton algae on March 2, 1976

Sampling spot	1	2	3	4	5	6	7
Achnantes minutissima	25	75		20	100		10
Cocconeis pediculus		50			25		
Cyclotella spp.				10 480	50		60
Gomphonema angustatum		50			25		
Navicula crytocephala	25	25					10
Surirella ovata							30
Other Pennales		775		1120	325		220
total Bacillariophyceae	50	975		11620	525		330
Ankistrodesmus angustus		25					
A. longissimus vae. *acicularis*		25	5		25		
Characium ambiguum		25			25		
Other Chlorococcales		100	15	60	75	50	
total Chlorococcales		175	20	60	125	50	
Lyngbya limnetica				10			
Spirulina laxissima			60	880		50	
Trachelomonas planctonica						25	
Chroomonas acuta		1950	20	70	5600	1450	370
Chryptomonas spp.		650		70	8800	1125	460
Dinobryon divergens		25					
Mallomonas sp.		600	5		75		
Chlamydomonas reinhardii	50	6600	105	2240	1000	200	220
other algae						25	
total algal number thousand ind./liter	100	10975	210	14950	16125	2925	1380

the different ponds to an unequal extent. The effect was less in algal pond No 2, and in fish ponds No 4 and 7. Consequently the plankton algae multiplied here better, improving this way the unstable and unfavorable water quality (Table IV). In algal pond No 5 and in reedy ponds No 3 and 6 the destruction of the submerged vegetation occurred explosionlike what was promoted by the degrading sewage water quality. Thus, in these ponds neither the plankton algae could reach a great individual number.

Table III

A quantitative analysis of the plankton algae on April 20, 1976

Sampling spot	1	2	3	4	5	6	7
Achnantes minutissima	38		5	35		15	10
Amphora ovalis var. *pediculus*				5			
Cocconeis pediculus				10			
C. placentula			5		12		
Cyclotella spp.		2800	10	25	250	15	10
Cymbella ventricosa			5				
Gomphonema olivaceum	13	25					
Stephanodiscus hantzschii		19600		5	750	95	
other Bacillariophycear	286	25	20	60	50	25	30
total Bacillariophyceae	337	22450	45	140	962	150	50
Actinastrum hantzschii		50				10	
Ankistrodesmus acicularis		75				10	
A. angustus		50					
A. arcuatus		25					
Characium spp.				10	12	15	5
Coelastrum microporum		25					
Crucigenia uadrata		25					
Dictyosphaerium pulchellum						5	
Gloeoactinium limneticum		50				5	
Kirchneriella lunaris		175	15	10	12	45	
K. obesa			5				
Scenedesmus acutus		125					
S. acuminatus		25					
S. ecornis					12		
S. spp.					19		
Selenstrum minutum		25					
Tetrastrum glabrum		25					
other Chlorococcales		475	5	30	38	30	
total Chlorococcales		1150	25	50	82	110	5
Lyngbya limnetica	12			5	13		
Spirulina laxissima		25	5				
S. subtilissima		50					
Chroomonas acuta		2400		5	12		
Cryptomonas spp.		2500	5	10	38	180	10
Chlamydomonas spp.	13	275	5	5		20	50
other algae		247400					
total algal number thousand ind./liter	362	271250	85	215	1112	510	115

Table IV

A quantitative analysis of the plankton algae on September 9, 1976

Sampling spot	1	2	3	4	5	6	7
Achnantes minutissima			5		15	10	25
Amphora ovalis var. *pediculus*							25
Cocconeis pediculus					5	5	
C. placentula					30	35	
Cyclotella spp.	25	1050	85	1000		10	100
Melosira granulata var. *angustissima*	12						
Nitzschia acicularis		150	20	200			100
Stephanodiscus hantzschii		10250		3100			100
Synedra acus				50			25
other Bacillariophyceae	150		150		10		25
total Bacillariophyceae	187	11450	260	4350	70	60	750
Actinastrum hantzschii		50					
Ankistrodesmus acicularis		100		50			25
A. angustus	13	300	5	250			
A. arcuatus		50	5	50			
Characium spp.		50				10	
Coelastrum microporum		50					
Dictyosphaerium pulchellum		100		100			25
Didymocystis tuberculata		100	10	150			
Gloeoactinium limneticum							25
Kirchneriella lunaris		50		50		5	125
Oocystis borgei		250	5	50			
Scenedesmus acuminatus		250		350			
S. acutus				50			
S. ecornis				50			
S. intermedius		450					50
S. opoliensis		50					
S. quadricauda	12	150	5	150			25
S. spinosus		350		150			25
S. sp.		250		150			
Schroederia setigera		50		50			
Tetraëdron minimum		50					
T. muticum		150		50			75
Treubaria triappendiculata		50		550			
other Chlorococcales	38	350	15	800	5	10	175
total Chlorococcales	63	3250	45	3050	5	25	600

Table IV (cont.)

Sampling spot	1	2	3	4	5	6	7
Lyngbya limnetica					250		480
Merismopedia glauca					150		25
Oscillatoria chlorina	12						
Chroomonas acuta		50	15		485	255	50
Cryptomonas spp.		5000	35	500		10	275
Euglenophyta spp.	12	1950	5				425
Chlamydomonas spp.		300		1350		25	25
other algae	13		90	8700	5		150
total algal number thousand ind./liter	287	18400	450	19350	565	375	2780

Role, development of the filamentous algae, tangle plants

We differenciate two outward forms of eutrophication developing as a result of abundant nutritive matter supply: the planktonic and the benthic eutrophication (F e l f ö l d y 1974).

Benthic eutrophication, i.e. the multiplication of the fixed plants (as tangles, filamentous algae) is more favorable from the point of view of water quality especially in such sewage secondary treating ponds. The nutrients getting into the ponds infiltrate fixed into the submerged plant bodies (being extracted from the water) and the leaving water becomes considerably cleaner. Thus part of the organic matter and the inorganic nutrients remain in the pond (B r i n g m a n n 1961, G e s s n e r – K a n k a l 1952, K a n a b o v 1962, M a c k e n t h u n 1962, B e c k 1965, N o r m a n n 1967). By continous thinning of tangle and algae, however, this mass of polluting matter (fixed into the plants) can be extracted from the pond and the vegetation held at an optimal level (K r a n i c h 1968).

The planners designed this or a similar role to the reedy twin-pond we refer to details later and actually this favorable situation developed in all the three twin-ponds. Two months later following the filling up of the ponds filamentous algae (most probably *Cladophora fracta* K ü t z.) appeared first on the spears of bulrush, reed, slowly starting to grow, later on the bottom of the pond in small spots. These small spots that thrived within some weeks to an area of several squaremeters and begant spindle into the upper layers of the water, got broken. This happened so that the oxygen bubbles developed in the stands got caught in the algal plaitings and could not reach the surface. The bubles increased, multiplied and started to lift slowly the upper part of the stand. Through the fast increase of the cells and the stands this waddinglike filamentous green algae entangled the entire water-mass as a certain and got to the surface forming spumous green spots (Figures 6 and 7).

We observed the most extensive multiplication in the reedy twin-pond where most of the open water surface was covered by the *Cladophora* stands. Their multiplication is less extensive in the algal and fish ponds.

The appearance of the filamentous algae beside its great advantage (an essential part of the mineral nutrients remains fixed in the ponds) sooner or later gives much worry. After their appearance and mass-like multiplication the water differing from the previous period cleared considerably towards the end of the algal ponds, became free of the suspended matter. The ponds became transparent down to the bottom, their water crystal clean, thus the algal grass living at the bottom also got sufficient light quantity. However, the danger emerged what is going to happen if this enormous alga-mass once starts to get destructed whether the lower or inner stand-parts under the effect of the overshadowing, or in its entire mass under an effect of any water-fungi infection. This represents a secondary pollution of the water of the ponds that may be stronger and more serious than the intel of an inadequately treated sewage. All living organisms can be intoxicated and destructed through extensive filamentous algal rot. The ponds after such a catastrophy could be restored only after several weeks and even so a resettlement of the filamentous algae cannot be excluded.

The aim must be the regulation, the leveling of the population of the filamentous algae during the operation of the ponds (K r a n i c h 1968, T ó t h et al. 1969). Through continous (or repeatedly accomplished gradual) exploiting and lifting of *Cladophora* one should leave in the ponds an amount that is sufficient to perform the secondary treatment but is not going to have annoying after-effects.

The attempts carried out so far (by hand, lifting from boat) did not bring results. One should look definitely for a mechanical solution since there is an immense algal mass in question (T ó t h et al. 1969).

Beside the appearance in large extent of the filamentous algae we looked parallelly for the possibility to determine their quantity, their growth. Because of the methodological difficulties we could carry out only one series of measurement, thus the published data offer essential only within a $\pm$ 20% error limit of the quantitative conditions.

We established the course of our survey and sampling on October 11, 1975 that the different ponds have differing filamentous tanle cover (we enumerated here the *Cladophora* and *Potamogeton* stands together which consist of 70% *Cladophora fracta* K ü t z. and 30% *Potamogeton pectinatus* L.).

In ponds No 3 and 6 the cover is related to the open-water surface without the bulrush, reed.

The quantity of the filamentous tangle in the six ponds corresponded to 200000 kilograms of air dry matter. Till mid-November the stand increased by a further 10%. We were worryied about the Winter, what is going to happen with this enormous stand beneath ice and snow. Fortuna-

Pond	Bottom	Total water-mass (from bottom to surface)
No 2	70%	15%
No 3	100%	75%
No 4	70%	10%
No 5	70%	15%
No 6	100%	75%
No 7	40%	10%

tely during the Winter except for some *Cladophora* that was frozen in the ice and got there destructed the filamentous algae weathered out the winter.

In March and April, 1976, as a first worrying sign, the fact attracted our attention that, contrary to the previous year the stands that sunk during the Winter to the bottom did not emerge to the surface, only sporadically in small spots. Then we demanded again the that Tiszai Vegyi Kombinát urgently begin with the thinning of the algal mass, partly through exploitation, but this was not done of a lack of adequate equipment.

In May and June the plankton algae multiplying in masses in the algal pond No 2 and in the fish ponds indicated that the *Cladophora* stand just vegetates, does not multiply, is not able to extract the nutrients from the water.

This stagnant labile situation was followed in July by a gradual overcharge of the inner sewage treatment plant, a considerable worsening of its purifying efficiency which resulted in the fact that till the end of July a water of 220 mg/l chemical oxygen demand arrived to the ponds, the bacterial number increased to 200000–500000 per milliliter and water fungi spores and filaments appeared in amounts of 10–100 millions/liter (which all indicate a polysaprobic water quality). Consequently the chemical oxygen demand increased also in the ponds, bacteria (100000-200000 ind./milliliter) and fungi appeared in quantities indicating a polysaprobic water quality. The *Cladophora* grass-spots became black, got destructed, the water became grayish, opalescent, the dissolved oxygen decreased critically (K i s s – S z a b ó 1978–79). Such phenomena accompanied, the fast destruction of the filamentous algae weighing nearly 200 metric tons. Till December, 1976 no recent *Cladophora* community or submerged vegetation appeared in the ponds and the till then crystal clear water even in the reedy and fish ponds remained disturbed, opalescent.

In spite of the phenomena described there is hope that in the ponds a submerged vegetation of optimal composition will develop with a good purifying effect, that eventually will not consist of filamentous algae but of tangle plants. We state this since we observed in 1976, even if only sporadically, the development of tangle vegetation, too. In the fish pond No

4 by the end of March the *Potamogeton crispus* L. appeared forming circular spots of several square meters. But it disappeared by July. In the fish pond No 3 on the bank *Ceratophyllum sumbrtsum* L. appeared sporadically in August and September. In the ponds No 6 and 7 in August and September *Lemna trisulca* L. formed scarce stands of one spuare meter each. In addition, it is to be expected that the *Potamogeton pectinatus* L. appears again. These three tangle species represented in 1976 only coloring spots in the ponds but they did not play any role in the purification.

Role and development of the reed stand

According to the plans the planners wanted to establish in the pond-system a dense reed stand by active planting. The higher aquatic plants play an important role in the secondary treating effect of the pond-system (Nümann 1970, Seidel 1966, Seidel et al 1976). The reed, bulrush, club-rush which spread along the weirs near the bank are essential for revetment.

In the reedy pond planted bulrush and reed stalks serve as substrate for the filamentous algae and other aquatic organisms. The biotecton of the reed stalks has an essential purifying effect. Partly it filters and lets settle the organic matter formed, and the pollution, partly nevertheless it also plays an important role in the binding of the dissolved organic matter and nutrients. The biotecton of purifying effect that develops in this way, can be thinned to the desired extent simply by cutting the reed mid-yearly. If the *Cladophora* species had not multiplied in the ponds, the essential part of the purification would have been carried out by the biotecton, respectively this would have catch, filter the plankton algae multiplied and swum forth in the algal ponds.

The N, P binding capacity of the reed and bulrush itself in sot too large since the carbon comes from the athmosphere, N and P from the deeper layer of the pond-bottom assured and it covers only a small part of its matter demand from the water.

The higher plants in the pond-system developed in the following way. In 1975 during the filling up the grasses and *Ranunculus*-species tolerating the water-covering survived and lived till mid-May and peeped out from the water. In April a rich *Polygonum amphibium* L. stand appeared in the ponds which has been ousted parallelly by the mass-like multiplication of the filamentous algae and by the reaching of the final water-level and vanished. In the reedy ponds *Typha latifolia* L. and *T. angustifolia* L. developed primarily in stands bunched in spots which covered the reedy pond No 3 in 40%, No 6 in 25% till the end of Autumn.

Lemna minor L. formed mainly in pond No 3, along the bank and on the clearings among the reed-spots by the end of September and in October spots of some 10–20 meters in diameter appeared.

Beside the club-rush the reed *Phragmites communis* Trin. and *Schoenoplectus lacustris* L. appeared in spots which formed in first line along the bank mixed vegetations. Beside them *Butomus umbellatus* L. occurred sporadically, too.

After the freezing in of the ponds the bulrush, reed and club-rush was cut from the ice, taken out of the ponds, respectively it was burnt on the ice. The cut plantal mass represented roughly some 1000–2000 kilograms.

In 1976 the development of the reeds in the pond-system was somewhat more favorable than in the previous year. 40% of the total stand was *Typha latifolia* L., 40% *T. angustifolia* L., the rest, 20%, consisted of mixed reed, bulrush, club-rush.

In the algal, respectively fish twin-ponds mainly the bank margin was grown in by reed although not to such an extent that the entire bank-margin was surounded by a closed stand. In these ponds only less than 5% of the entire surface of the pond was covered by reed.

In the reedy ponds there is mainly a bulrush stand, the cover of pond No 3 is approximately 40%, that of No 6 30%.

In November, 1976 the reed-bulrush stand of the ponds has been reaped by underwater cutting. After the destruction of the *Cladophora* stand in the pond-system this biotecton-community living on the stalks of reed and bulrush took over partly the function of purification. After the reaping of the reed this effect considerably decreased. That is why such a rich plankton algal population could have developed in the reedy ponds by the end of the Winter.

Unfortunately the cut reed has not been transported from the ponds and remained on the weirs. One part was blown back by the wind into the ponds, one tried to burn the other part on the weirs after the Winter, but this succeded only partly, their further fate is unknown. After the burning the flue-ash, the embers came back to the ponds. This is also undesirable.

Zooplankton investigations

In addition to our chemical and botanical investigations we also observed the composition of the zooplankton community, the dynamics of the populations as well as the quantitative conditions. Our investigations were directed first of all to the *Rotatoria* and *Cladocera* but we also determined the number of the *Copepoda* and their proportion in the zooplankton community.

To get the samples we filtered 10 liters of water on No 25 plankton-net. After fixation with formaline the samples were processed in the laboratory. The species found are enumerated in a separate list (see the zooplankton species-list, Table 5).

During the period of investigation large quantities of zooplankton arrived from the inner treatment system to the ponds. Generally 3000–5000 ind./10 liters, but in some cases (in August, 1975, 45 000 ind./10 liters, in May, 1976, 32 000 ind./10 liters) we found very high values. But this enormous amount of zooplankton consisted only of some *Rotatoria* species

Table V

Frequency of the zooplankton species occuring in the secondary treating pond-system
+ rare, + + moderately frequent, + + + frequent.

Species / sampling spot	1	2	3	4	5	6	7
Rotaria rotatoria (Pallas)			+				
Brachionus angularis Gosse			+	+	+		
Brachionus urceolaris Linné		+	+	+ +	+	+	+
Brachionus calyciflorus Pallas		+	+	+	+	+	+
Brachionus calyciflorus f. doras Gosse		+					+
Lepedella patella (Müller)	+					+	
Lecane closterocerca (Schmarda)	+			+	+		
Lecane flexilis Gosse	+	+		+	+		+
Lecane hamata (Stokes)	+ + +	+ +	+	+	+ +	+	+ +
Lecane bula Gosse	+			+	+		+
Lecane lunaris (Ehrb.)	+		+	+			+
Lecane elachis Harring et Myers)	+						
Euchlanis parva Rousselet	+	+	+		+	+	+
Euchlanis dilatata Ehrb.			+			+	
Keratella quadrata (Müller)	+ +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
Keratella cochlearis (Gosse)		+		+		+	
Trichocerca caspica v. *longicauda* Tshugunoff				+			
Trichocerca bicristata (Gosse)	+ +	+		+			+
Asplanchna priodonta Gosse		+	+	+	+	+	+
Cephalodella gibba (Ehrb.)	+			+			
Polyarthra dolichoptera Idelson		+	+ +	+ + +	+	+ +	+ +
Polyarthra longiremis Carlin	+	+			+		+
Filinia longiseta (Ehrb.)		+					
Hexartha mira (Hudson)		+	+	+		+	+
Testudinella patina (Herrmann)	+	+	+	+	+	+	+
Daphnia magna Straus	+	+ +	+ +	+ +	+ +	+ +	+ +
Daphnia pulex Leydig em. Scourfield	+	+	+	+		+	+
Daphnia longispina O. F. Müller	+ +	+ +	+ +	+ +	+ +	+ +	+ +
Simocephalus exspinosus (Koch)		+	+	+		+	+
Simocephalus vetulus (O. F. Müller)	+	+	+	+	+	+	+
Moina rectirostris (Leydig)		+	+		+	+	+

Species \ sampling spot	1	2	3	4	5	6	7
Ceriodaphnia laticuada P. E. Müller	+	+	+	+	+	+	++
Ceriodaphnia quadrangula (O. F. Müller)		+					
Scapholeberis microcephala (Sars)	+	+	+	+	+	+	+
Graptoleberis testudinaria (Fischer)	+	+	+	+	+		+
Oxyurella tenuicaudis (Sars)	+	+	+	+		+	
Pleuroxus trigonellus (O. F. Müller)		+	+	+			
Chidorus sphaericus (O. F. Müller)		++	+++	++	++	+++	+++
Chidorus latus Sars		+					
Bosmina longirostris (O. F. Müller)		+	+	+	+	+	+
Alona guttata Sars			+			+	+
Cyclops sp.	+	+++	+++	+++	+++	+++	+++
Calanoida sp.		++	++	++	+++	++	++
juv. Copepodit	+	+++	+++	+++	+++	+++	+++

and from *Protozoa. Lecane hamata* was present in greatest number, but also other *Lecane* species (as *L. bula, L. lunaris* etc.) appeared. Beside the above named species *Keratella quadrata* was also frequent (but in small individual number).

The composition of this community of great quantity but poor in species entirely changed in the algal ponds. The altered ecological conditions (exposure, dilution, temperature etc.) caused the destruction of most species arrived in. This increased the organic matter load of the first twin-pond. In this twin-pond newly formed zooplankton communities were richer in species but their individual number was considerably lower (82–87% less) (Figures 4 and 5).

In 1975, following the filling up of the algal ponds a relatively species-rich zooplankton community developed (3000 ind./10 liters) the most characteristic members of which were *Keratella quadrata, Daphnia magna* and some *Copepoda* species. The high individual number can be related to the Chlorococcal algae that occurred at the same time in large amounts.

In the reedy ponds the macrovegetation was scarcely developed, the algal number was moderately high, thus the species-communities got into just somewhat different ecological conditions than those developed in the preceding twin-pond. This is shown also by the appearing species. Under the effect of the gradually growing reed and bulrush spots the

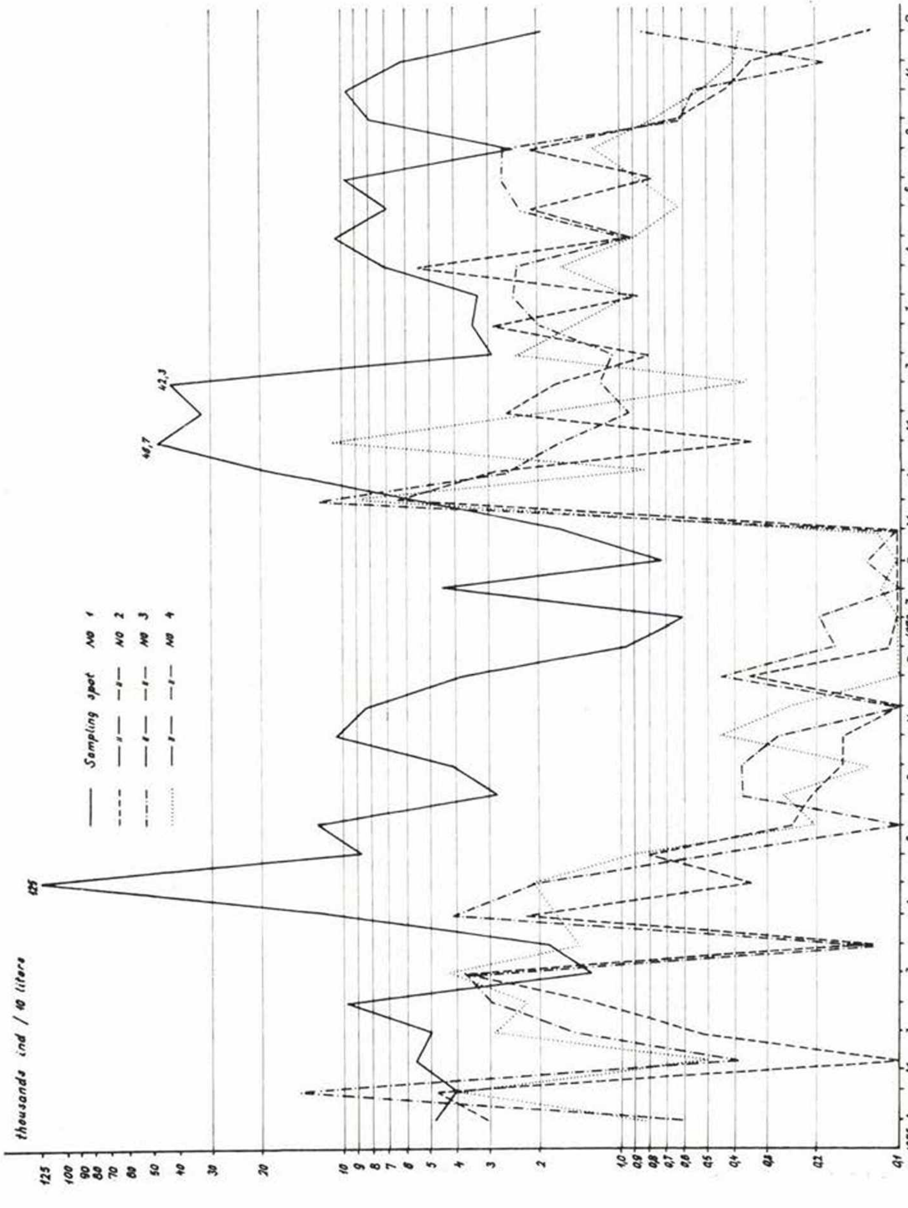

Fig. 5. Variation of the zooplankton quantity in 1975 and 1976

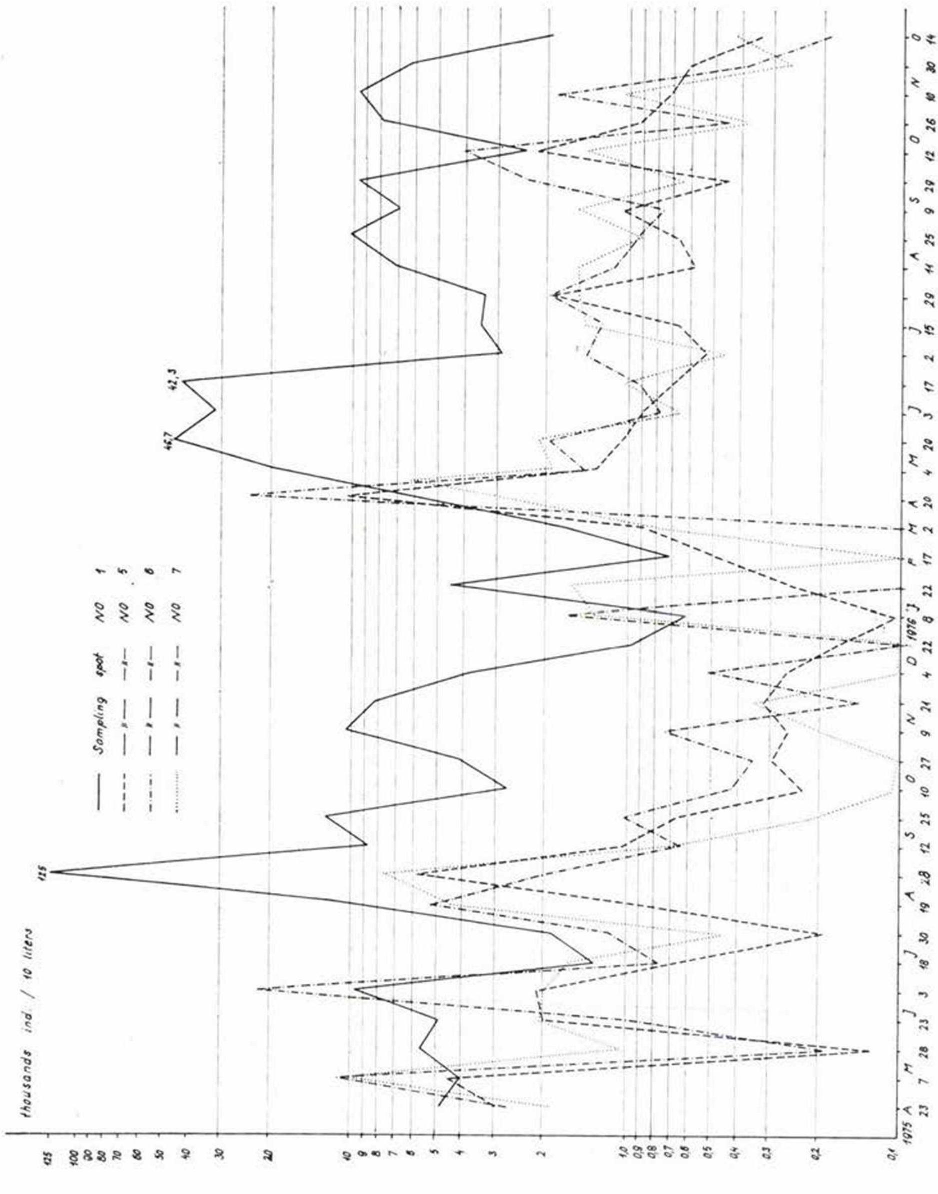

Fig. 6. Variation of the zooplankton quantity in 1975 and 1976

community developed in the preceding twin-pond was completed by some species preferring the vegetation *(Simocephalus vetulus, Moina rectirostris).*

In the fish ponds a zooplankton-mass appeared then in species-composition and individual number entirely similar to the algal ponds.

The algal number and the quantity of the zooplankton decreased in the pond-system by the further multiplication of the filamentous algae and macrovegetation. In vain was the pond-system supplied by water that was rich in zooplankton, the microfauna reached only in a low individual number the pond-system because of the lack of nutrients, the increasing purification.

In the algal ponds *Brachionus calyciflorus, Polyarthra dolichoptera, Chidorus sphaericus, Graptoleberis testudinaria* etc. supplemented the species already mentioned. In the reedy twin-pond more and more vegetation rich in epiphyton species *(Simocephalus exspinosus, Euchlanis dilatata)* appeared.

In the fish ponds the water was less transparent and the bank-protecting vegetation and the filamentous algal grasses were also less developed then in the preceding twin-ponds. Thus nearly the same ecological factors effected the zooplankton members as in the preceding algal twin-ponds. This was expressed in the similarity of the species composition.

After the freezing in of the pond (November) the filamentous algae produced O_2 in adequate quantity, in the water mostly juvenile Copepoda were present. Females with eggs were not found in these months. The Rotatoria were represented by *Keratella quadrata* and *Polyarthra dolichoptera.*

From March, 1976, synchronosly with the overcharge of the inner sewage treatment system which led to the infavorable alteration of the chemical parameters – a new period succeeded in the life of the pond-system. A zooplankton large in number but poor in species reached the ponds. The dominant species was *Lecande hamata* (5000 ind./10 liters) now too.

In the algal ponds, similarly to the preceeding, the arriving fauna disappeared and its place was taken by a new community. *Keratella quadrata* was in greatest individual number (4000–10000 ind./10 liters), but *Daphnia magna* and *Polyarthra dolichoptera* populations also had a large individual number.

In the reedy ponds following the long Winter the macrovegetation developed very slowly, thus the water of the twin-pond was somewhat turbid in this period. The composition of the zooplankton community was similar to that of the algal ponds.

In the fish ponds zooplankton communities indentical to the preceding twin-ponds developed. However, in this twin-pond the number of the *Cyclops* species and juvenile Copopodites increased.

The filamentous algae were gradually destructed from May because of the previously mentioned reasons and their place was taken over by unicellular algae appearing in more and more quantity. Hence the species composition of the zooplankton became very varied which meant at the same time an increase in the individual number too. In the algal ponds, just as on the preceeding case the number of species increased. Among others *Scapholeberis microcephala* preferring the waters rich in nutrients also appeared. The communities developed in the other twin-ponds were very similar. Almost no differences were to be found between the twin-ponds units of differing function. The list of the species identified enlarged especieally in the fish ponds which is unfavorable not only for the purification but also the recipient (namely the River Tisza) since the mineral nutrients, the phytoplankton and zooplankton members that got over could act as inoculators speeding up this way the eutrophication of the River Tisza. This unfavorable phenomenon lasted till November, 1976 when the ponds freezed in again, the species and individual number decreased because of the could wather as well as the unfavorable oxygen conditions emerging accidentally.

Summary

In our investigations we searched an answer to the question how phytoplankton communities appearing in the ponds, filamentous algae stands, tangle plants, bulrush-reed stands and zooplankton communities influence water quality, what role they play in the final purification of the pretreated sewage getting in the pond-system, and how pollution of the River Tisza could be reduced by such a sewage secondary treating pond-system.

The 154 algal taxons found indicate that in this often extreme environment the species compositions is more poorish and not to much varied. Since the saprobiologic water quality characterizable by algae was almost without exception and continually favorable, in this pond-system one has to face more trophity problems. This is indicated by the high algal numbers and by the often high chlorophyll content.

In the period examined the quantity of the plankton algae varied between wide limits showing a good connection with other parameters of water quality. In our opinion the fluctuation of the phytoplankton to such a great extent is unfavorable for both water quality and secondary treatment. In the case of too low algal number the nutrition supply of the organisms consuming the phytoplankton (which play also a role in the secondary treatment) grows worse. In the case of too high algal number in turn a nocturnal oxygen deficiency may occur, the chemical oxygen demand may increase, the quality of the water lifted into the River Tisza becomes unfavorable since in the body of the algae the nutrients extracted from the water, the best part of the polluting matter swims off.

During the period examined the essential part of the purification in the sewage secondary treating pond-system was carried out by the *Cladophora—Potamogeton* stands. As a result of their metabolic activity the

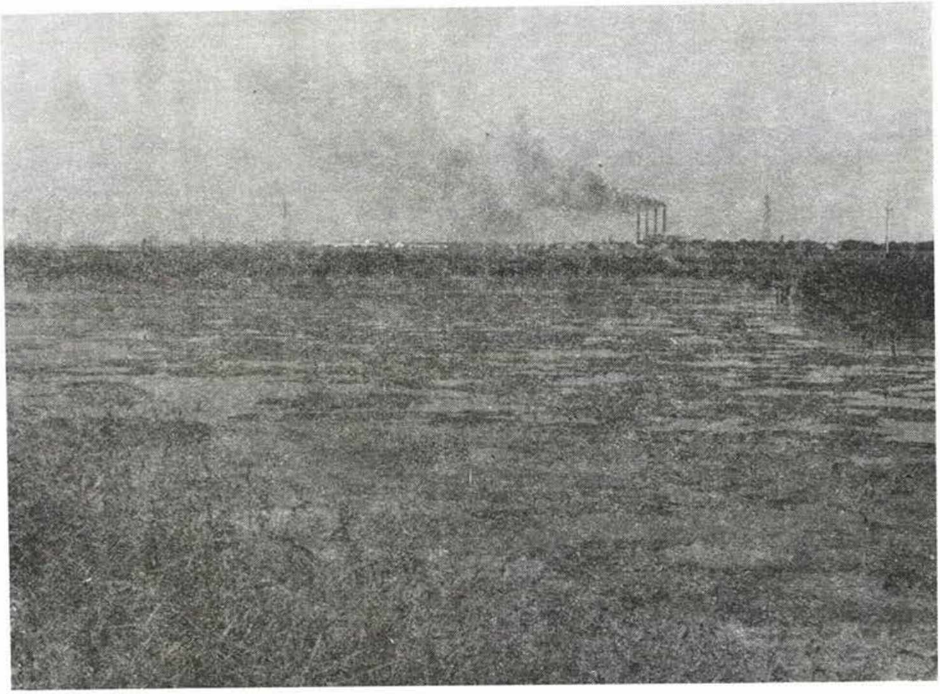

Fig. 7. Surface *Cladophora* stand of the algal pond No 5 in August, 1975

water transparency improved considerably and the suspended matter, the N and P content decreased (Kiss – Szabó 1978 – 79). That is one part of the "polluting matter" was bound in the body of the plants, thus the River Tisza was relieved from the mineral nutrients that would increase eutrophication.

The thinning, lifting out, keeping on an optimal level of the submerged aquatic plant-mass of many hundreds kilograms weight did not occur. That is why the binding of N and P decreased, and later on P was released. As a consequence of the degeneration of the stand and parallelly the arising water fungi infection in the Summer of 1976, the entire *Cladophora* and *Potamogeton pectinatus* mass got destructed causing heavy damages in the pond-system. At the same time the River Tisza was hit by an increased pollution.

Since the thinning of the dense compact stand of the filamentous algae as well as the tangle-likes, the keeping on optimal level is technically hardly effectuable, one should strive to develop the reed stand. The biotecton of the higher aquatic plants may act as an efficient active purificator.

On the basis of the experiences gained so far the plantation of the reed is difficult, it succeeds hardly. In addition the reed extracts less nutrient from the pond, and from the upper lavere of the pond-bottom. Consequ-

Fig. 8. Wadded mass of the subaquatic *Cladophora* stand

ently, further plantation of the better plantable bulrush and lacustrine club-rush should be solved in such a way that they grow in the ponds as an adjoining compact stand and not spots. The cutting of the bulrush and the club-rush and their thinning are solved problem thus it can be controlled vell: it is possible to establish a favorable vegetational community of purifying effect in the pond-system.

In addition to the chemical and algological investigations we carried out zooplankton examinations too. We found that the treated sewage arriving to the pond-system transports mostly Lecane species *(Lecane hamata, L. lunaris, L. bula* in large masses but of few species.

The species introduced into the algal ponds were mostly destructed because of the changed ecological circumstances (dilution, settling out, temperature etc.), their place was taken most often by populations of great individual numbers. The most characteristic species were *Daphnia magna, D. longispina, Chidorus sphaericus, Keratella quadrata, Brachionus calyciflorus, Polyarthra dolichoptera*. The communities got over from the algal ponds were supplemented in the reedy ponds by the species preferring the vegatation (as *Simocephalus exspinosus, Moina rectirostis*).

We found in the fish ponds often zooplankton in composition and indiindividual number very similar to the algal ponds.

In the course of our investigations we compared the effects of zooplankton the sewage subjected to a "normal" operation and an overcharged operation. During the second period (when overcharged) in comparison to the previous year 7–8% more zooplankton arrived to the pond-system. In the algal ponds 16–18% more zooplankton developed. From the fish ponds 16–18% more individuals left than in the previous periods.

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