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Original Research

Dynamics and Structure of Phytoplankton in Fishponds Fed with Treated Wastewater

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Abstract

The dynamics and structure of phytoplankton was studied in three nursery fishponds periodically fed with treated household sewage and wastewater from a fruit and vegetable processing plant. The ponds differed with respect to the availability of biogenic compounds (mostly nitrogen). It was found that total phytoplankton biomass ranged from 3.9 to 80.2 mg dm^{-3}. In two ponds nitrogen content averaged 1.97 and 2.40 mg dm^{-3}, respectively. Phytoplankton were dominated by diatoms of the genera *Fragilaria* and *Cyclotella* in spring, and by green algae of the genera *Coelastrum*, *Coenococcus*, *Pediastrum*, *Scenedesmus,* and cryptophytes in summer. In the pond with a significantly lower nitrogen content of water (1.37 mg dm^{-3}) the predominant phytoplankton group were small cryptophytes as mainly *Chroomonas acuta* and *Cryptomonas rostrata,* and diatoms of the genus *Acanthoceras* that were absent in the remaining two more fertile ponds. Green algae *Eudorina* and *Dictyosphaerium* were present in this pond only in spring and fall.

Keywords: ponds, phytoplankton, biomass, structure, wastewater-fed aquaculture

Introduction

The management of aquaculture systems involves control over food supply – aquatic plants are grown to provide the fish with food, fishponds are regularly fertilized and the fish are fed commercial fish food [1]. Fish farming results in nutrient deficiencies in ponds, including an exhaustion of nutrients required for the growth and development of plants (nitrogen, phosphorus, potassium). The deficiency of certain substances in fishponds may also result from the type of soil, because such ponds are usually established on wastelands poor in organic and mineral compounds. Nutrient deficiencies can be corrected through mineral fertilization [2-6] (fertilizer components are utilized by aquatic plants – the first link in the food chain) or organic fertilization, which is a food source for organisms consumed by non-predatory fish [1]. Organic materials of animal origin are commonly used as fertilizers [7, 8], but in many countries (e.g. in Asia) wastewater is also applied for this purpose [9-12]. In Europe, wastewater use in aquaculture has been investigated by, among others, Wolny [13], Danielewski [14], Olach et al. [15], Faina et al. [16], Tucholski [17], and Kuczyński et al. [18]. However, the above studies focused mainly on the ichthyologic aspect of the problem. The dynamics of phytoplankton development in fishponds enriched with mineral fertilizers have been analyzed by Januszko [3, 6]. Cupiak and Krzanowski [12] examined the impact of abiotic factors (water temperature, water exchange time, total nitrogen concentrations) on the chlorophyll content of water in sewage-fed fishponds. Wastewater is abundant in biogenic compounds [9, 19] that stimulate the growth of phytoplankton. Fish farming

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may affect the dynamics of seasonal changes in phytoplankton biomass. Juvenile silver carp and common carp can effectively filter and digest nanoplankton under experimental conditions, and microplankton in fertilized ponds [20].

The objective of this study was to determine the dynamics and structure of phytoplankton in nursery ponds periodically fed with wastewater treated by the activated sludge method in sequencing batch reactors (SBRs).

Materials and Methods

A field experiment investigating fish stocking material was carried out in three earth ponds characterized by a similar surface area (pond 1 – 1.04 ha, pond 2 – 0.94 ha, pond 3 – 1.00 ha) and maximum depth (1.5 m, 1.6 m, and 1.5 m, respectively, measured in the summer), located on the premises of a wastewater treatment plant in Olsztynek, northeastern Poland N=53º36'14.66" E=20º17'23.24" [21].

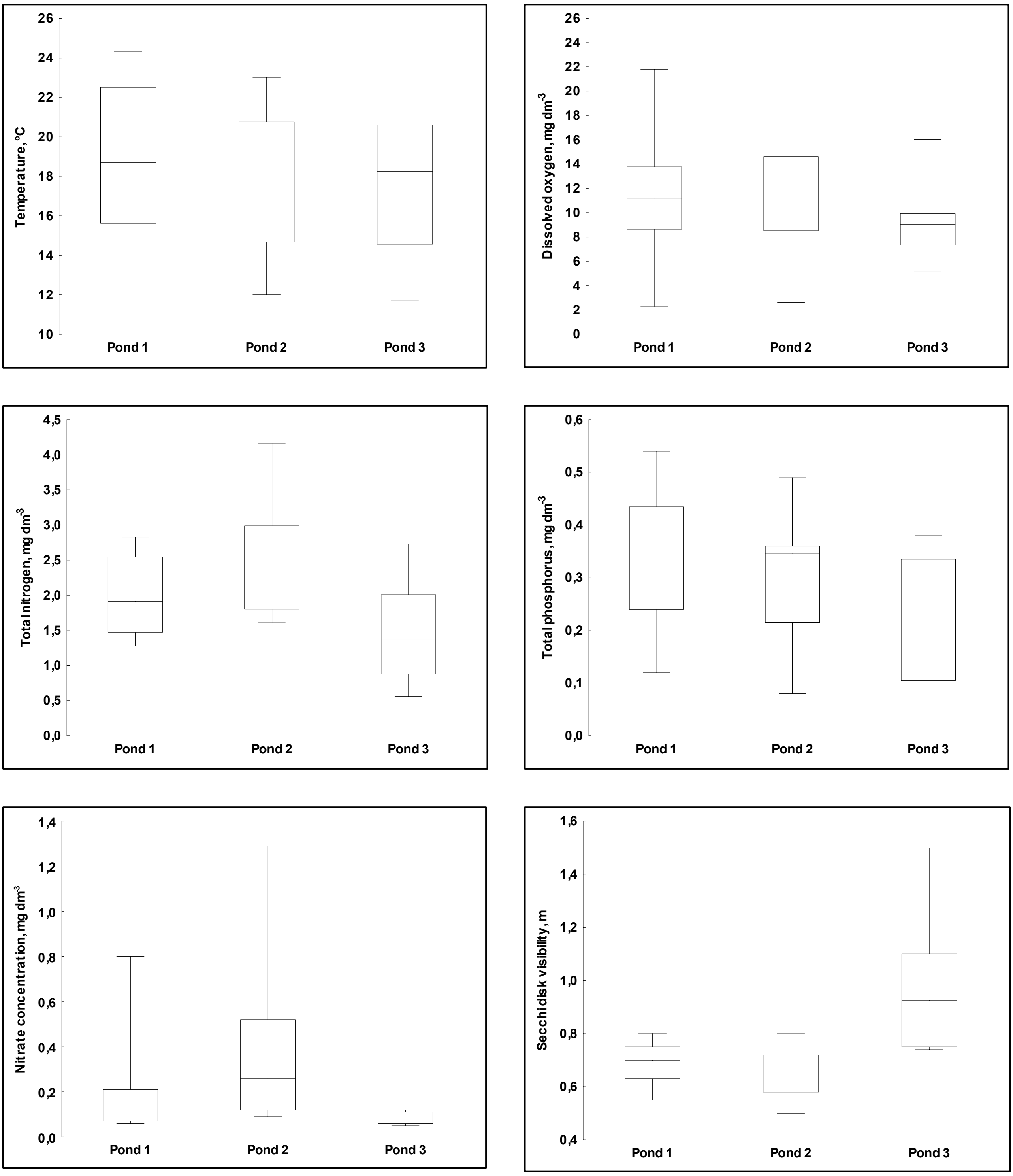

Fig. 1. Physico-chemical parameters (minimum, maximum, median, quartiles) during the growth season in three ponds in 2008.

The ponds were filled with water from underground springs at the bottom of pond 3, and were fertilized with treated effluents from the treatment plant. The effluents comprised household sewage and wastewater from a fruit and vegetable processing plant. Following mechanical treatment, wastewater was further purified in sequencing batch reactors (SBR). Wastewater was fed to the ponds four times, once before the production season and three times during the season. Pond 1 was stocked with tench and common carp fingerlings, pond 2 with common carp, tench, and pike-perch fingerlings, and pond 3 with common carp, tench, and common whitefish fingerlings at the ages of (0^+) and (1^+).

Studies of phytoplankton were conducted from April to October 2008, at one site in each pond. A pooled integrated sample was collected in April at a depth of 0.5 m and 1.3 m, and next single samples were taken separately from these water layers. Water temperature and transparency (Secchi disk) were measured, and the concentrations of dissolved oxygen, total nitrogen, nitrates, nitrites, amonium, total phosphorus, and phosphates were determined by standard methods. A quantitative analysis of phytoplankton was carried out using an inverted microscope, in accordance with the method proposed by Utermöhl [22] and the international and European standards for algal-based monitoring [23]. The specimens (counting units: single cells, cenobia, colonies, and filaments) were counted in sedimentation chambers (10 ml) at different magnifications: large taxa were counted over the entire chamber bottom at 100x magnification, medium-sized species were counted along 2-4 strips at 200x magnification, and the nanoplankton were counted in 100 fields of vision at 400x magnification. Biomass was estimated from cell volume. The significance of changes in the physicochemical parameters and total biomass of phytoplankton in the ponds was determined by the Kruskal-Wallis test and the Mann-Whitney U-test [24]. Hierarchical divisive classification (Macnaughton-Smith method) based on nitrogen and phosphorus concentration was done for three fish ponds (P1-P3) [25]. The Pearson correlation coefficient was used to determine the relationship between nutrient concentration and phytoplankton biomass.

Results

Environmental Conditions

Fig. 1 shows the ranges and median values of the measured physicochemical parameters. Total nitrogen and nitrates contents were significantly higher in ponds 1 and 2 than in pond 3 (KW-H(2;42)=10.066; p=0.007 and KW-H(2;21)=8.047; p=0.0178, respectively). Differences in the concentrations of remaining nutrients in water were less pronounced and statistically non-significant, but higher values were observed most often in ponds 1 and 2 than in pond 3 (Figs. 1, 2). The ratio $N:P<10$ was most frequently noted in the investigated ponds, $N:P>17$ was reported only in pond 2 in September. The principal inor-

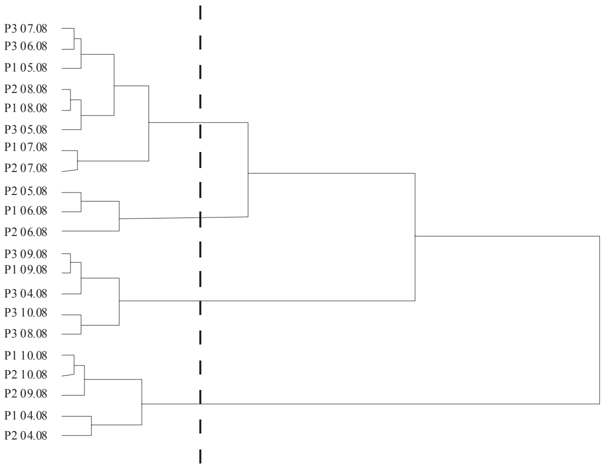

Fig. 2. Hierarchical divisive classification (Macnaughton-Smith method) of 21 chemical water samples from three fish ponds (P1-P3) characterized by nitrogen and phosphorus concentrations.

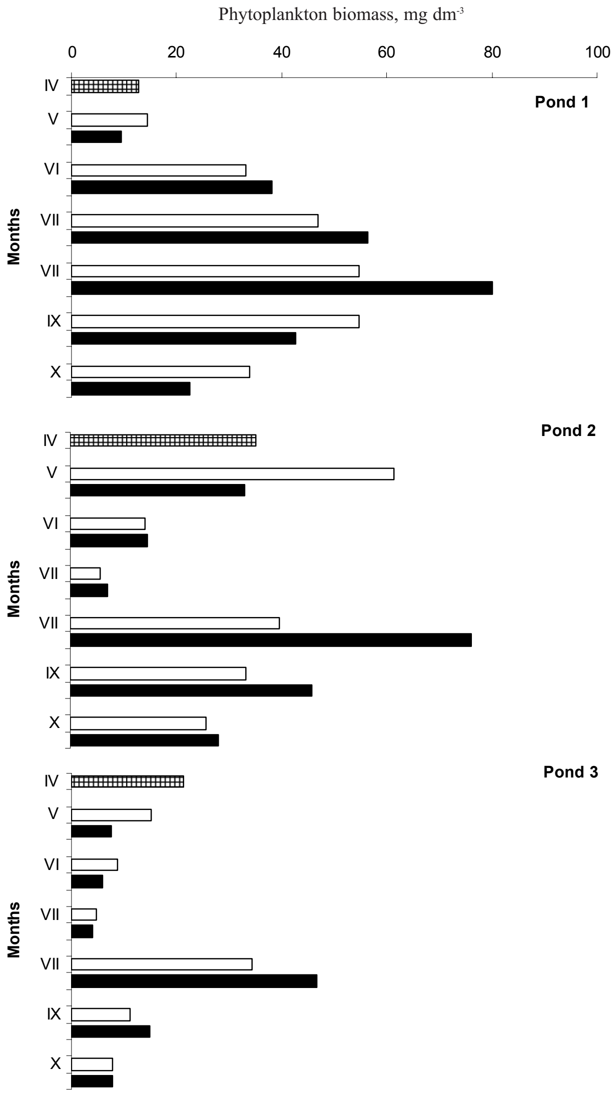

Fig. 3. Phytoplankton biomass in three wastewater ponds at different depths (checked – mixed samples from the depths of 0.5 and 1.3 m, white – 0.5 m, black – 1.3 m).

ganic forms of nitrogen and phosphorus accounted only for around 17 and 13% of TN and TP content, respectively. Organic nitrogen and phosphorus concentrations were in the majority.

Water transparency was lower in ponds with higher nitrogen levels and a higher oxygen content of water. In ponds 1 and 2 the maximum Secchi disk visibility reached 0.8 m, while in pond 3 the Secchi disk was visible at the pond bottom in October (statistically significant difference, KW-H(2;18)=8.389; p=0.015).

Phytoplankton Biomass

From April to October 2008 total phytoplankton biomass ranged from 3.9 to 80.2 mg dm^{-3} (Fig. 3). The most intensive growth of planktonic algae was observed in pond 1, with a biomass maximum in August. Two peaks were noted in pond 2, with lower total biomass in the spring (May) and higher in the summer (August). The two maxima were separated by a biomass minimum in July. In pond 3, the fluctuations in total phytoplankton biomass were significantly lower (KW-H(2.39)=11.038; p=0.004; Fig. 4). Similarly as in pond 2, phytoplankton biomass displayed two maxima, in April and August. Vertical differences in phytoplankton biomass were observed during summer. In most cases, greater biomass was noted at a depth of 1.3 m (Fig. 3). The above differences were least pronounced in pond 3. The maximal difference in phytoplankton biomass measured at a depth of 1.3 m and 0.5 m reached 35.3 mg dm^{-3} in pond 2 and 25.5 mg dm^{-3} in pond 1, but these differences were statistically non-significant over the entire growing season (U=158; n=36; p=0.913).

Among the bioavailable nutrients the statistically significant effect influencing mostly the phytoplankton development had only the nitrate content of water in pond 1 (r=-0.903). Furthermore, phytoplankton biomass was found to have weaker but also significant correlations with temperature and water transparency. The biomass development was directly related to temperature (r=0.491) and inversely related to Secchi disk visibility (r=-0.549).

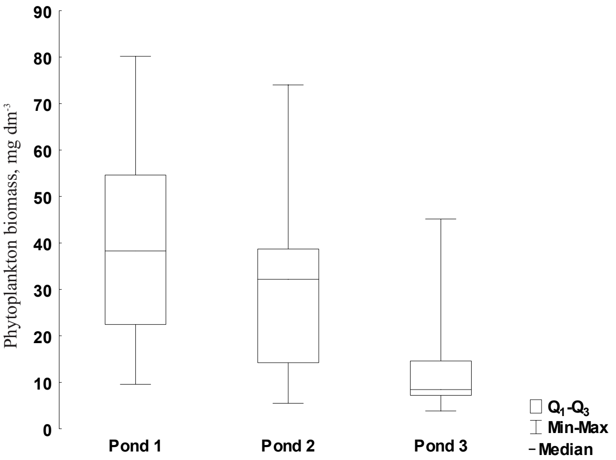

Fig. 4. Total biomass of phytoplankton in three ponds in 2008 (Kruskal-Wallis test: KW-H(2;39)=11.038; p=0.004).

Phytoplankton Composition

In pond 1, in April, the predominant phytoplankton group were diatoms *Fragilaria ulna* var. *acus* and *F. ulna* var. *angustissima* of the order *Pennales* (Table 1), which accounted for approximately 80% total biomass (Fig. 5). In May, cryptophytes (*C. rostrata*) developed abundantly at a depth of 0.5 m. Green algae, mostly of the genera *Chlamydomonas*, *Pediastrum*, *Scenedesmus*, and *Dictyosphaerium*, and diatoms also contributed a high share to total phytoplankton biomass. These three main groups of planktonic algae dominated also the deeper strata, even if their species composition changed (Fig. 5). *Chlorophyta* developed from June to August, accounting for 59 to 94% total biomass. Their biomass and percentage share were slightly higher at a depth of 1.3 m than at surface. The chlorococcal *Coelastrum astroideum*, *C. microporum*, *Coenococcus planctonicus*, *Pediastrum boryanum*, *P. duplex*, and *Scenedesmus acuminatus* were the predominant taxa. In July and August diatoms (mainly the nanoplanktonic *Cyclotella comensis* of the order *Centrales*) had a 27% share of total biomass. In September green algae of the genus *Coelastrum* co-dominated with cryptophytes of the genus *Cryptomonas* (around 40% each). In October, like in the summer months, an intensive growth of *Chlorophyta* was observed.

In pond 2, in April, phytoplankton structure was dominated by diatoms (*Pennales*), similarly as in pond 1. This is typical of the spring season. However, their biomass was approximately threefold greater (31.3 mg dm^{-3}) than in pond 1 (Fig. 5). In May cryptophytes and diatoms contributed most to the peak biomass, accompanied by chrysophytes *Dinobryon sociale* at a depth of 0.5 m (Table 2). In the summer the phytoplankton community was dominated by green algae (63-94% total biomass), as in pond 1. In June and July their biomass was three- and six-fold lower, respectively, than in pond 1. In August cyanobacteria, including *Merismopedia tenuissima*, *Aphanothece clathrata*, and *Aphanocapsa incerta,* had a biomass of around 12.0 mg dm^{-3}. In September, *Chlorophyta* and *Cryptophyta* developed most abundantly. In October, phytoplankton biomass was dominated by *Bacillariophyceae*, primarily the centric *C. comensis*, in contrast to pond 1.

Pond 3 was characterized by a different phytoplankton structure. In April, the predominant groups were diatoms, cryptophytes, and green algae (Fig. 5). At that time the co-dominants were diatoms of the genera *Fragilaria* and *Cyclotella*, crytophytes *C. rostrata* – common also in ponds 1 and 2, and green algae of the order *Volvocales* – *Eudorina elegans* (Table 3). A rapid growth of the nanoplanktonic *C. acuta* (up to 75% total biomass) was reported in May. Larger cryptophytes of the genus *Cryptomonas* dominated in June and July, accompanied by relatively abundant diatoms (7-39%) in deeper water layers. The summer peak biomass in August was formed mostly by the diatom *Acanthoceras zachariasii*, not noted in ponds 1 and 2. Diatoms, green algae (the chlorococcal *Dictyosphaerium pulchellum* var. *minutum*) and cryptophytes co-dominated again in September and October. Chrysophytes of the genus *Dinobryon* also contributed to total phytoplankton biomass in October.

Table 1. Dominant species (≥10% total biomass) of phytoplankton in pond I at depths of 0.5 and 1.3 m during the growth season in 2008.

Pond I				
2008	0.5 m	%	1.3 m	%
IV	*Ulnaria acus* (Kütz.) M. Aboal + *U. delicatissima* var. *angustissima* (Grun.) M. Aboal et P. C. Silva			69
V	*Cryptomonas rostrata* Troitz. emend I Kis.	42	*Ulnaria acus* (Kütz.) M. Aboal +*U. delicatissima* var. *angustissima* (Grun.) M. Aboal et P. C. Silva	28
	Ulnaria acus (Kütz.) M. Aboal +*U. delicatissima* var. *angustissima* (Grun.) M. Aboal et P. C. Silva	14	*Chlamydomonas* sp.	12
			Cryptomonas rostrata Troitz. emend I Kis.	12
VI	*Coelastrum astroideum* De Not. +*C. microporum* Näg. in A. Br.	52	*Coelastrum astroideum* De Not. +*C. microporum* Näg. in A. Br.	50
	Coenococcus planctonicus Korš.	32	*Coenococcus planctonicus* Korš.	32
VII	*Cyclotella comensis* Grun. in Van Heurck.	25	*Pediastrum boryanum* (Turp.) Menegh.	32
	Pediastrum boryanum (Turp.) Menegh.	22	*Cyclotella comensis* Grun. in Van Heurck.	13
			Coelastrum astroideum De Not. +*C. microporum* Näg. in A. Br.	11
			Pediastrum duplex Meyen	10
VIII	*Coelastrum astroideum* De Not. +*C. microporum* Näg. in A. Br.	22	*Coelastrum astroideum* De Not. +*C. microporum* Näg. in A. Br.	24
	Scenedesmus acuminatus (Lagerh.) Chod.	15	*Pediastrum boryanum* (Turp.) Menegh.	17
	Cyclotella comensis Grun. in Van Heurck.	12	*Scenedesmus acuminatus* (Lagerh.) Chod.	12
	Pediastrum boryanum (Turp.) Menegh. +*P. duplex* Meyen	11		
IX	*Coelastrum astroideum* De Not.	30	*Coelastrum astroideum* De Not.	37
	Cryptomonas rostrata Troitz. emend I Kis.	27	*Cryptomonas rostrata* Troitz. emend I Kis.	37
	Chroomonas acuta Ut.	12		
X	*Coelastrum astroideum* De Not. +*C. microporum* Näg. in A. Br.	41	*Coelastrum astroideum* De Not. +*C. microporum* Näg. in A. Br.	43
	Pediastrum boryanum (Turp.) Menegh. +*P. duplex* Meyen	10	*Coenococcus planctonicus* Korš.	12

Discussion

Fertilization stimulates primary production in fishponds and is thus contributing to an increase in fish production levels [1]. The mineral forms of nitrogen and phosphorus in treated wastewater support the growth of phytoplankton, which may form blooms if their biomass exceeds 3.0 mg dm^{-3} [26, 27]. Fertilizers applied in large, single doses are responsible for rapid, short-term bloom episodes, often leading to the mass die-offs of algae-causing oxygen depletions, particularly in deeper water layers [28]. The control exerted by zooplankton over phytoplankton population density becomes less effective, while the rate of regeneration of mineral nutrient resources (mostly P) increases, and so does the potential of fish as fertilizers [29, 30]. According to Persson [31], fish in fertile water bodies may release 0.53 mg P m^{-2} d^{-1} on average, which corresponds to approximately 110% and 42% of the external and internal phosphorus load, respectively. In addition, juvenile fish in ponds may consume planktonic organisms above 20 μm in size [20], and phytoplankton is the main component in its food [32].

In the analyzed ponds, phytoplankton blooms occurred throughout the entire production season, which is characteristic of the most fertile water bodies [33, 34]. According to the classification of Winberg and Ljahnovič (as cited in Januszko [3]), the studied phytoplankton showed a high degree of development (total biomass of 40 to 400 mg dm^{-3}) at the peak of the growing season in pond 1 stocked with tench and common carp fingerlings and in pond 2 stocked with common carp, tench, and pike-perch fingerlings. Average total phytoplankton biomass values in ponds 1 and

2 (38.5 and 31.5 mg dm^{-3}, respectively) were comparable with those noted in farm ponds (stocked mostly with carp) fertilized with mineral fertilizers, mainly salpeter, superphosphate, and urea [3-6]. Such values are typical of strongly eutrophicated polymictic [35] and even hypertrophic [27] water bodies. In pond 3, stocked with common carp, tench, and common whitefish fingerlings, the level of phytoplankton development was medium-productive (from 4 to 40 mg dm^{-3}), based on the classification of Winberg and Ljahnovič. Pond 3 was characterized by a great abundance of hydromacrophytes that covered around 25% of its surface area. This group comprised common reed, *Typha angustifolia,* and *Typha latifolia*, i.e. species that could considerably affect the water concentrations of biogenic elements [36].

The two patterns of phytoplankton biomass dynamics observed in this study are also encountered in many fish ponds [37], other fertilized ponds where fish receive extra

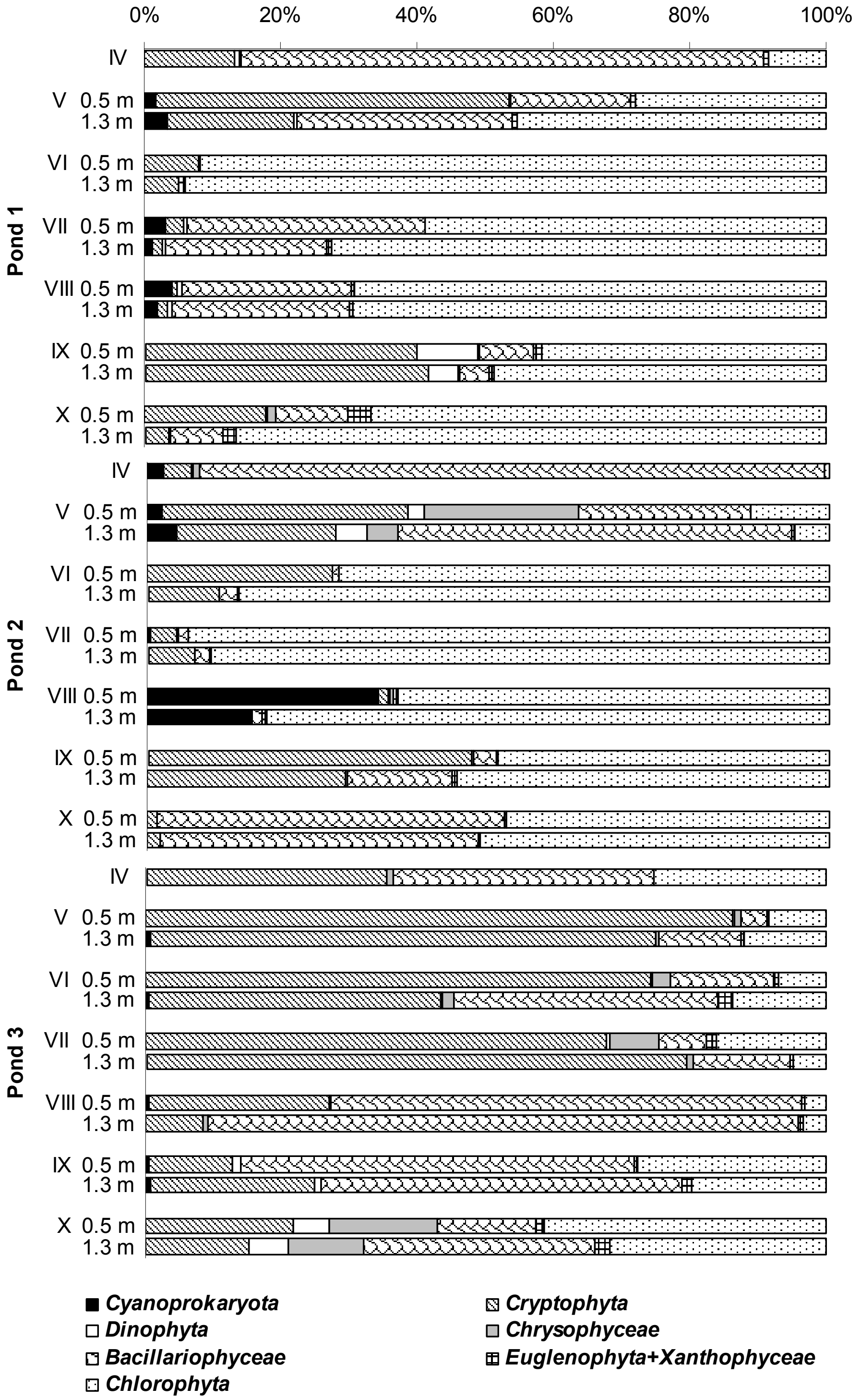

Fig. 5. Percentage contribution of particular groups of phytoplankton to the total biomass in three wastewater ponds at different depths.

Table 2. Dominant species (≥10% total biomass) of phytoplankton in pond II at depths of 0.5 and 1.3 m during the growth season in 2008.

Pond II				
2008	0.5 m	%	1.3 m	%
IV	*Ulnaria acus* (Kütz.) M. Aboal + *U. delicatissima* var. *angustissima* (Grun.) M. Aboal et P. C. Silva			90
V	*Cryptomonas rostrata* Troitz. emend I Kis.	36	*Ulnaria acus* (Kütz.) M. Aboal +*U. delicatissima* var. *angustissima* (Grun.) M. Aboal et P. C. Silva	36
	Dinobryon sociale Ehr.	23	*Cryptomonas rostrata* Troitz. emend I Kis.	23
	Ulnaria acus (Kütz.) M. Aboal + *U. delicatissima* var. *angustissima* (Grun.) M. Aboal et P. C. Silva	16	*Cyclotella comensis* Grun. in Van Heurck.	21
	Cyclotella comensis Grun. in Van Heurck.	10		
VI	*Coenococcus planctonicus* Korš.	67	*Coenococcus planctonicus* Korš.	67
	Cryptomonas rostrata Troitz. emend I Kis.	27	*Cryptomonas rostrata* Troitz. emend I Kis.	27
VII	*Coenococcus* sp.	61	*Coenococcus* sp.	45
	Coelastrum astroideum De Not. +*C. microporum* Näg. in A. Br.	10	*Coelastrum astroideum* De Not. +*C. microporum* Näg. in A. Br.	19
	Pediastrum boryanum (Turp.) Menegh.	10	*Pediastrum boryanum* (Turp.) Menegh. +*P. duplex* Meyen	15
VIII	*Coelastrum astroideum* De Not. +*C. microporum* Näg. in A. Br.	31	*Coelastrum astroideum* De Not. +*C. microporum* Näg. in A. Br.	44
	Merismopedia tenuissima Lemm.	18	*Coenococcus* sp.	13
	Aphanothece clathrata W. et G.S. West	15	*Aphanocapsa incerta* (Lemm.) Cronb. et Kom.	10
IX	*Cryptomonas rostrata* Troitz. emend I Kis.	45	*Coelastrum astroideum* De Not.	44
	Coelastrum astroideum De Not.	30	*Cryptomonas rostrata* Troitz. emend I Kis.	28
X	*Cyclotella comensis* Grun. in Van Heurck.	47	*Cyclotella comensis* Grun. in Van Heurck.	42
	Coelastrum astroideum De Not. +*C. microporum* Näg. in A. Br.	22	*Coelastrum astroideum* De Not. +*C. microporum* Näg. in A. Br.	27
	Coenococcus sp.	11	*Coenococcus* sp.	11

food [4], and in numerous shallow and deep water bodies [38, 39]. According to the model proposed by Oleksowicz [40], the seasonal changes in phytoplankton abundance noted in pond 1, with a maximum in August, are typical of water bodies rich in biogenic elements. The changes reported in pond 2, with two total biomass peaks (in the spring and summer), are characteristic of water bodies with a medium nutrient load. A similar growth pattern of phytoplankton was noted in pond 3, where the nitrogen content of water was significantly lower and the biomass maxima were half lower in comparison with the remaining two ponds. This indicates that the availability of biogenic compounds, in particular nitrogen, played a key role in phytoplankton development in the investigated ponds. A similiar situation has occured in fish farms (e.g. in Egypt) [41] and in many lakes [42]. Our results are consistent with the findings of Cupak and Krzanowski [12], who demonstrated that differences in the concentrations of chlorophyll *a* in wastewater-fertilized ponds were determined by the content of nitrogen compounds and temperature. This is contradicted by the fact that in ponds 1 and 2, where N:P<10 was recorded most frequently, blooms were formed primarily by green algae, accompanied by diatoms and cryptophytes. Blue-greens of the genera *Merismopedia*, *Aphanothece*, and *Aphanocapsa* had the status of a co-dominant only in August in pond 2 (N:P=7). A characteristic feature of water bodies with a low N:P ratio is usually the mass development of cyanobacteria [42]. Representatives of other taxonomic groups dominate at N:P>10 [43, 44]. However, the domination or co-domination of *Chlorophyta* are often observed in fertile ponds with a high fish stocking density [37, 45], in wastewater-fertilized ponds [11, 20], in ponds fertilized with mineral fertilizers [3, 6], in fertilized ponds where fish are fed extra food [45, 46], and in shallow water bodies in the temperate zone, e.g. in Polish and Dutch lakes [47, 48].

Table 3. Dominant species (≥10% total biomass) of phytoplankton in pond III at depths of 0.5 and 1.3 m during the growth season in 2008.

Pond III				
2008	0.5 m	%	1.3 m	%
IV	*Cryptomonas rostrata* Troitz. emend I Kis.			31
	Eudorina elegans Ehr.			24
	Cyclotella comensis Grun. in Van Heurck.			22
	Ulnaria acus (Kütz.) M. Aboal + *U. delicatissima* var. *angustissima* (Grun.) M. Aboal et P. C. Silva			12
V	*Chroomonas acuta* Ut.	75	*Chroomonas acuta* Ut.	59
	Cryptomonas rostrata Troitz. emend I Kis.	12	*Cryptomonas rostrata* Troitz. emend I Kis.	16
VI	*Cryptomonas rostrata* Troitz. emend I Kis.	74	*Cryptomonas rostrata* Troitz. emend I Kis.	43
			Fragilaria sp.	10
			Ulnaria acus (Kütz.) M. Aboal +*U. delicatissima* var. *angustissima* (Grun.) M. Aboal et P. C. Silva	10
VII	*Cryptomonas rostrata* Troitz. emend I Kis.	51	*Cryptomonas rostrata* Troitz. emend I Kis.	65
	Chroomonas acuta Ut.	13		
VIII	*Acanthoceras zachariasii* (Brun) Sim.	67	*Acanthoceras zachariasii* (Brun) Sim.	81
	Cryptomonas rostrata Troitz. emend I Kis.	26		
IX	*Cyclotella comensis* Grun. in Van Heurck	52	*Cryptomonas rostrata* Troitz. emend I Kis.	23
	Cryptomonas rostrata Troitz. emend I Kis.	12	*Cyclotella comensis* Grun. in Van Heurck	15
	Dictyosphaerium cf pulchellum var. *minutum* Delf.	10	*Fragilaria* sp.	12
X	*Dictyosphaerium cf pulchellum* var. *minutum* Delf.	28	*Dictyosphaerium cf pulchellum* var. *minutum* Delf.	14
	Cryptomonas rostrata Troitz. emend I Kis.	17	*Acanthoceras zachariasii* (Brun) Sim.	13
	Dinobryon sociale Ehr.		*Cryptomonas rostrata* Troitz. emend I Kis.	12
	+*D. crenulatum* W. et G.S. West	12	*Cyclotella comensis* Grun. in Van Heurck.	11

Ponds 1 and 2 were characterized by similarly high nutrient resources and average phytoplankton biomass, but different dynamics and slightly varied assemblages. The relative availability of inorganic and organic (for some species) N and P fractions could control both phytoplankton biomass and its composition [49]. But non-significant statistical correlation between nutrients and phytoplankton can point to top-down control [29]. The great biomass values caused good water oxygenation and low water transparency mainly in ponds 1 and 2. The average Secchi disk visibility reached 0.7 m, i.e. until half the depths of ponds like it were observed in Bulgarian fish ponds [34]. Significantly better visibility in pond 3 corresponded with lower phytoplankton biomass. A tendency to higher phytoplankton abundance at a depth of 1.3 m (below the maximum Secchi disk visibility) in summer was probably caused by declining bloom.

The vast majority of bloom-forming species were widespread, cosmopolitan, and common in ponds and lakes, including fast-reproducing algae known as r-strategists (opportunistic species). Representatives of dominant genera *Chlamydomonas*, *Coelastrum*, *Pediastrum*, *Scenedesmus*, *Eudorina*, *Fragilaria*, and *Cyclotella* belong to useful planktons for fish production and play an important role in nutrient removal and bioremediation [9, 11, 50]. Members of these genera, whose mass growth was noted in ponds 1 and 2, are considered E_{II} indicators, i.e. species typical of eutrophic and mesotrophic water bodies [51] as well as predominant phytoplankton species in intensive carp cultures [52]. *Coelastrum*, *Pediastrum*, and *Scenedesmus* represent J group of eutrophic chlorococcalens in shallow, enriched lakes and ponds settling into low light [53]. This assemblage was prominent in ponds 1 and 2, where maximum Secchi disk visibility reached 0.8 m.

An analysis of the total biomass, seasonal changes and structure of phytoplankton confirmed the distinctness of pond 3 stocked with common carp, tench, and common whitefish fingerlings. This fact was probably related to the water inflow from underground springs at the bottom of this pond. During the growing season, phytoplankton biomass was dominated by diatoms, similarly as in ponds stocked with the silver carp [4], and by cryptophytes. The pressure exerted by zooplankton and fry (top-down forces) in the first months of farming contributed to changes in the species composition of phytoplankton, supporting the growth of fast-reproducing single-celled (3-30 μm) r-strategists of the genera *Cryptomonas* and *Chroomonas*. The mass development in *A. zachariasii* in August in pond 3 resulted from environmental turbulence.

Conclusions

In three ponds fed with treated wastewater and stocked with different fish species, phytoplankton communities were characterized by different growth dynamics and displayed one or two biomass maxima. The noted biomass values exceeded the threshold level for algal blooms. The phytoplankton biomass in more fertile ponds 1 and 2 was typical of productive water bodies with a high degree of development of planktonic algae, mostly diatoms and *Chlorophyta*. The less fertile pond 3 was characterized by the medium-productive level of phytoplankton development with domination of cryptophytes and diatoms.

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