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Functional Groups of Phytoplankton and Their Relationship with Environmental Factors in the Restored Uzarzewskie Lake

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Received: 2 December 2019; Accepted: 20 January 2020; Published: 21 January 2020

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Abstract: Uzarzewskie Lake is a small, postglacial lake, located in western Poland. The lake is under restoration treatment since 2006. At first, iron treatment was done for 2 years. In the second stage, spring water was directed into the hypolimnion in order to improve water oxygenation near the bottom sediments. The purpose of our research was to determine changes in the contribution of functional groups to the total number of taxa and total biomass of phytoplankton due to changes in the physical and chemical characteristics of the restored lake. Phytoplankton composition was analyzed in three periods: (1) before restoration; (2) during the first method of restoration; and (3) when the second method was implemented in the lake. Epilimnetic phytoplankton was sampled every year monthly from March to November. The relationship between phytoplankton groups and environmental factors (water temperature, ammonium nitrogen, nitrate nitrogen, dissolved phosphorus, conductivity and pH) was examined, using the canonical analyses. The redundancy analysis indicated that the temperature, dissolved phosphates concentration, ammonium nitrogen and pH were the main determining factors of the phytoplankton community dynamics. During the study, 13 coda dominated the phytoplankton biomass. Cyanobacteria of the codon **H1** with such species as *Aphanizomenon gracile, Dolichospermum planctonicum, D. viguieri* dominated the phytoplankton community before restoration. **S1** group consisting of *Planktolyngbya limnetica, Limnothrix redekei* and *Planktothrix agardhii* mostly dominated during the period in which the first method was used. Improvement of water quality due to restoration efforts in the third period caused dominance of other groups, especially **J** (*Actinastrum hantzschii* and other Chlorococcales)**, C** (*Asterionella formosa* and other diatoms), **Y** (*Cryptomonas marssonii* and other cryptophytes)**, Lo** (*Peridiniopsis cunningtonii* and other dinophytes) and **X2** (*Rhodomonas lacustris*).

Keywords: functional groups of phytoplankton; innovative method of restoration; oxygenation near the bottom sediments; phytoplankton biomass; restoration treatment; small lake; sustainable restoration

1. Introduction

Due to the increasing eutrophication of waters, intensive algae blooms in lakes are noted worldwide, threatening freshwater biodiversity and supplying humans with water [1,2]. The restoration and preservation of aquatic ecosystems is a crucial issue in our society. To prevent the water blooms, attempts are being made to limit the anthropogenic deterioration of water quality. Functional groups were originally proposed to assess the ecological status of different types of lakes proposed by the European community [3]. If these protective measures do not bring the desired results within the required timespan, (in the European Union dictated by the requirements of the Directive 2000/60/EC of the European Parliament, WFD, 2000), restoration methods are being implemented to help improve water quality.

Despite lake restoration becoming more and more frequent, still little is known about the reaction of cyanobacteria blooms and the whole phytoplankton communities to restoration actions. Restoration activities do not only affect the long-term reduction in cyanobacteria abundance but contribute to phytoplankton adaptation to the new environmental conditions of a water body [4,5]. In this study, we focused on the changes in the phytoplankton community in a small lake restored first by phosphorus precipitation, and then by oxygenation of hypolimnetic waters by redirecting the inflows from two springs.

To analyze the impact of restoration on phytoplankton, the concept of functional groups [6] seems a suitable approach. Functional groups are used in several countries of the European Union to assess water quality and apply both to lakes and reservoirs, as well as rivers [7]. In each functional group, species with similar ecological characteristics are gathered [8], and thus their reactions to ecosystem changes caused by restoration activities should follow the same pattern. The use of this concept allows focusing on phytoplankton groups instead of individual species, which can be more useful from the application point of view. Thus, the purpose of our research was to determine changes in the phytoplankton functional groups due to changes in the physical and chemical characteristics of Uzarzewskie Lake during the restoration.

2. Materials and Methods

2.1. Uzarzewskie Lake and Its Restoration

Uzarzewskie Lake (52°26′53″ N, 17°08′00″ E) is a water body in the shape of a kettle, located on the River Cybina (an eastern tributary of the River Warta in western Poland, Wielkopolska Region). It is quite a small lake, covering 10.6 ha of area. The maximum depth of the lake is 7.3 m and the average depth is 3.4 m. It was assessed as a hypereutrophic lake [9]. This lake is dimictic with short mixing time. The bottom sediments of Uzarzewskie Lake provided a high internal load of nutrients [10].

The total catchment area of Uzarzewskie Lake is 160.8 km^2 and 79% of the direct catchment area is occupied by arable land [11]. The waters of Cybina River also supply the lake with nutrients, mainly from farmland and fish ponds. The excessive external load has resulted in very low water quality [12]. Very often cyanobacterial water blooms were noted, which excluded the lake from recreational use [13,14]. For this reason, in 2006, restoration treatments have been started. In the years 2006–2007, the method consisted of precise inactivation of phosphorus with iron sulfate (PIX-112) [10]. The coagulant was dosed 6 times in 2006 and 3 times in 2007 in quantities of 380 kg and 180 kg annually, respectively. These treatments did not bring the expected effect in the form of a clear reduction in the number of phytoplankton, especially cyanobacteria [15]. In 2008, the use of an innovative method of restoration was begun, which consisted of delivering water from two watercourses flowing from springs at the slope of the river valley directly to the hypolimnion, using two pipes (Figure 1). Water flowed to the hypolimnion by gravity and constantly, with a capacity of about 10 L per second. It was rich in nitrates and well oxygenated. The pipelines delivering this water were placed directly on the bottom of the lake and the water outflows were situated near the deepest place of the lake. Water spreading around this place caused improvement in the oxygenation of hypolimnetic water and increase in the redox potential over the bottom of Uzarzewskie Lake [16]. This procedure continues through the present.

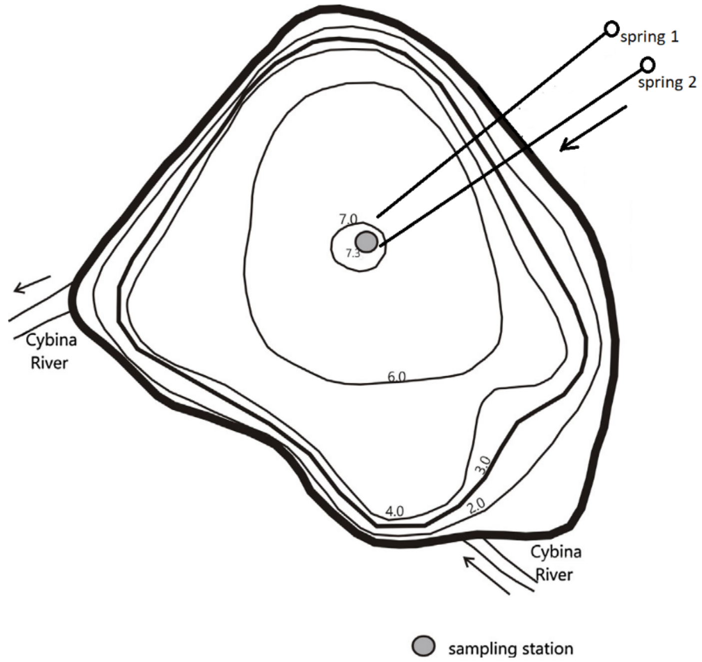

Figure 1. Uzarzewskie Lake and the location of the sampling station with the view of the system supplying hypolimnion with spring waters (according to Kowalczewska-Madura et al. [10], changed).

2.2. Sampling and Analysis

The study took place from 2005 to 2015, in three periods: (1) in the year 2005—before the restoration, (2) within 2006–2007—during the chemical treatment and (3) within 2008–2015—during the oxygenation of the hypolimnetic water layer. Phytoplankton was sampled usually once a month, except for some winter months, when the lack of a thick ice cover prevented sampling. Each time sample were collected at one station situated in the central part of the lake from the surface, 1 m and 2 m depths and fixed in situ with Lugol solution. The abundance of phytoplankton was calculated using the light microscope method [17]. Phytoplankton biomass was estimated using specific biovolumes obtained by geometrical approximations based on Hillebrandt et al. [18]. Phytoplankton functional group classification according to Reynolds et al. [6] and Padisák et al. [8] was used.

Together with phytoplankton sampling, the samples for chemical analyses were collected and Secchi depth, water temperature, electrolytic conductivity, pH, soluble oxygen and water saturation with oxygen were measured in situ using Secchi disc and YSI-meter. Results of the analysis of the physical and chemical variables of water quality were already published [11] and they were used here for statistical analyses as the restoration-dependent (PO_4-P, NO_2-N, NO_3-N and NH_4-N) and restoration-independent drivers of the phytoplankton community.

In order to determine changes in the composition of phytoplankton under the influence of restoration activities, functional groups with the highest share in the overall biomass of phytoplankton exceeding 25% were selected. The composition of functional groups among the three study periods mentioned above was compared.

The relation between the physico-chemical parameters of the water and functional groups of phytoplankton during three seasons (before restoration and when using the first and second methods) was analyzed by redundancy analysis (RDA). The relation between the most important functional groups of phytoplankton during three periods was analyzed by discriminant analysis (canonical variate analysis -CVA). The relative importance and statistical significance of each environmental factor in the ordination model were tested by a forward selection procedure and Monte Carlo permutation test. All ordination methods were applied with the use of the Canoco 4.5 package [19].

3. Results

3.1. The Number of Species in Functional Groups in the Three Periods of Study

The total number of phytoplankton species exceeded 300, then classified into 28 different functional groups. Not all coda were found in the three analyzed periods, and so in the pre-restoration period, representatives from 22 coda were found. During the restoration with the first and second method of restoration 25 and 27 coda were noted, respectively (Figure 2, Table 1). The most frequent coda were **J** (20%–22% in subsequent periods of research), **C** and **Y** (6%–8%, with the least during the period of using second method), **H1** (6%–7%), **X2** (6%–10%), **X1** (5%–7%), **F** (4%–6%), **S1** and **Lo** (4%–5%), and also **D** (4% each). Other functional groups were represented by fewer taxa. Representatives of several coda were found only in one research period, e.g., codon **K** was found only during the application of the first method. During the second method of restoration, representatives of coda **A**, **T** and **U** were found. They were not recorded in earlier periods of research.

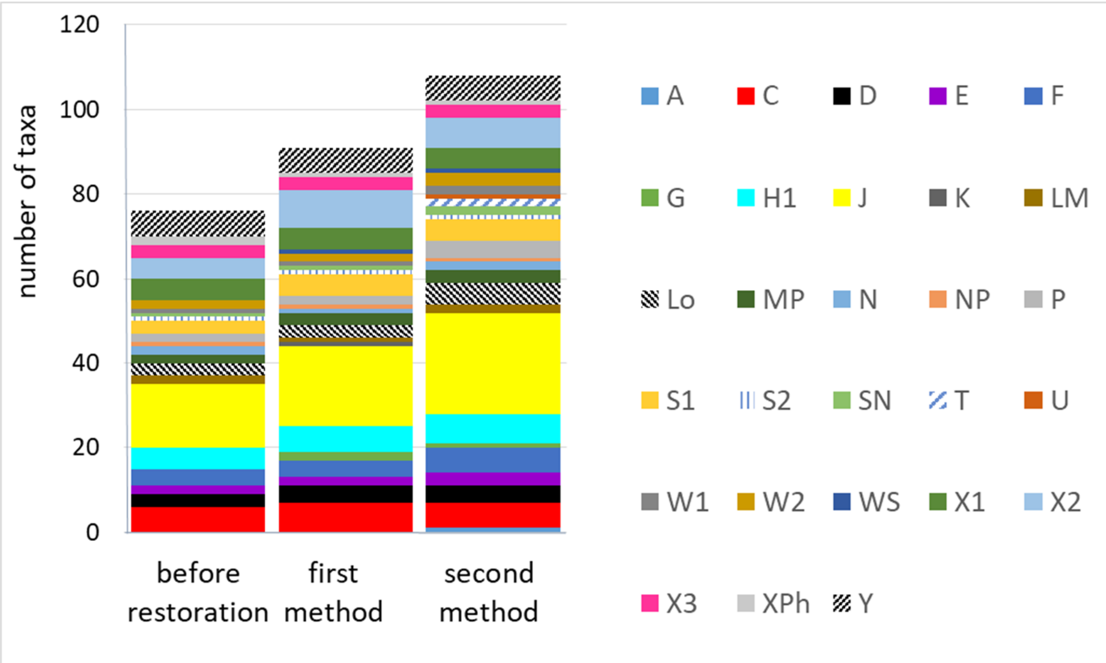

Figure 2. The contribution of the number of taxa from individual functional groups of phytoplankton to the total number of taxa in three study periods.

The number of functional groups, taking into account individual samples of the three research periods, was the highest during the period of restoration using the first method (14.7 on average). In the pre-restoration period, the average number of groups in subsequent months was 13.8 and in the period the second restoration method was 13.4. A similar trend was also observed for the number of phytoplankton taxa—the average number of taxa in individual samples was the highest during the period of using the first restoration method.

Table 1. Main representatives of the functional groups of phytoplankton noted in Uzarzewskie Lake.

Functional Group	The Most Abundant Representatives
A	*Acanthoceras zachariasii, Rhizosolenia longiseta*
C	*Asterionella formosa, Cyclotella meneghiniana, Stephanodiscus hantzschii*
D	*Nitzschia acicularis, Ulnaria acus*
E	*Dinobryon* sp., *Mallomonas* sp.
F	*Elakatothrix gelatinosa, Keratococcus* sp., *Oocystis* spp.
G	*Eudorina* sp., *Pandorina morum*
H1	*Aphanizomenon gracile, Dolichospermum planctonicum, D. viguieri*
J	*Actinastrum hantzschii, Coelastrum astroideum, Crucigenia tetrapedia, Pediastrum* sp., *Scenedesmus* sp., *Tetraëdron* sp., *Tetrastrum* sp.,
K	*Aphanocapsa* sp.
LM	*Microcystis aeruginosa, M. wessenbergii, Ceratium hirundinella*
Lo	*Peridiniopsis cunningtonii, Peridinium aciculiferum*
MP	*Achnanthes* sp., *Amphora ovalis, Nitzchia palea, Gomphonema* sp.
N	*Cosmarium bioculatum, Staurastrum* sp.
NP	*Ulnaria ulna*
P	*Closterium aciculare, Closterium acutum, Fragilaria crotonensis*
S1	*Planktolyngbya limnetica, Limnothrix redekei, Planktothrix agardhii*
S2	*Raphidiopsis raciborskii*
SN	*Dolichospermum compactum, Raphidiopsis* sp.
T	*Binuclearia lauterbornii, Mougeotia* sp.
U	*Uroglena* sp.
W1	*Phacus longicauda, Euglena* sp. *,Lepocinclis acus*
W2	*Trachelomonas hispida*
WS	*Synura uvella*
X1	*Ankistrodesmus gracilis, Monoraphidium irregulare, M. contortum, M. minutum, Schroederia setigera*
X2	*Rhodomonas lacustris, Bicoeca planktonica, Ochromonas* sp.
X3	*Chrysochromulina parva, Chrysococcus* sp.
XPh	*Phacotus lenticularis*
Y	*Cryptomonas marssonii, C. ovata, C. reflexa*

3.2. *Changes in the Biomass of Functional Groups in the Three Periods of Study*

The phytoplankton biomass throught this study varied between 0.68 and 136.5 µg/mL and was mainly dominated by species belonging to coda **H1** (*Aphanizomenon gracile* (Lemm.) Lemm., *A. flos-aquae* Ralfs ex Bornet and Flahault, *A. klebahnii* (Elenk.) Pechar et Kalina), *Dolichospermum* (= *Anabaena*) *viguieri* (Denis and Frémy) Wacklin, L.Hoffmann and Komárek, *Cuspidothrix issatschenkoi* (Usachev) P.Rajaniemi, Komárek, R.Willame, P. Hrouzek, K.Kastovská, L.Hoffmann and K. Sivonen, *Dolichospermum planctonicum* (Brunnthaler) Wacklin, L.Hoffmann and Komárek, *D. spiroides* (Klebhan) Wacklin, L.Hoffmann and Komárek), **S1** (shade-adapted cyanobacteria: *Pseudanabaena limnetica* (Lemm.) Komárek, *Planktolyngbya limnetica* (Lemm.) Komárková-Legnerová and Cronberg, *Limnothrix redekei* (Goor) Meffert, *Planktothrix agardhii* (Gomont) Anagnostidis and Komárek), **Y** (*Cryptomonas* spp.), **C** (*Asterionella formosa* Hassall), **D** (*Ulnaria acus* (Kützing) Aboal and *Nitzschia* spp.), **X2** (*Chrysochromulina parva* Lackey) and codon **J** (*Actinastrum hantzschii* Lagerheim, *Crucigenia tetrapedia* (Kirchner) W. et G. S. West, *Stauridium tetras* (Ehrenberg) E. Hegewald in Buchheim et al. (Syn. *Pediastrum tetras*), *Coelastrum astroideum* De Notaris, *C. microporum* Nägeli in A. Braun) (Figure 3).

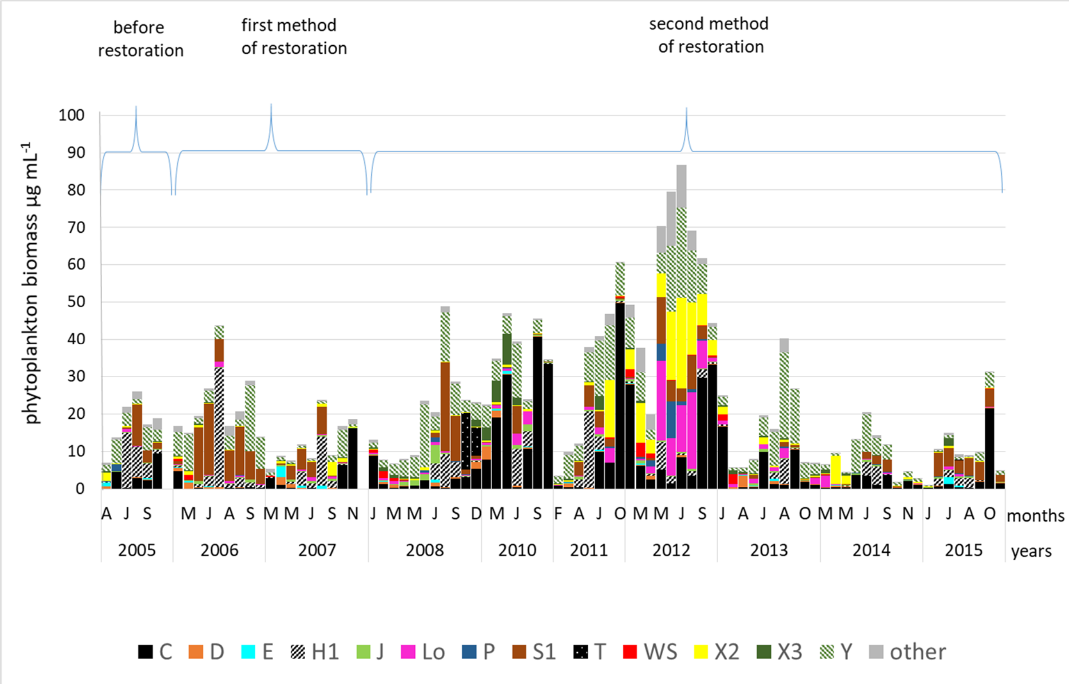

Figure 3. Distribution of phytoplankton functional groups in the three study periods (mean values from the surface layer up to 2 m).

In subsequent years of research, a different share of the biomass of particular functional groups in the total phytoplankton biomass was found. Cyanobacteria (coda **H1** and **S1**) dominated in the total biomass of phytoplankton in the first 3 years of our study (before restoration and during the first method of restoration). During water mixing period codon **Y** (*Cryptomonas erosa* Ehrenberg, *C. marssonii* Skuja, *C. ovata* Ehrenberg, *C. gracilis* Skuja, *C. reflexa* Skuja, *C. rostratiformis* Skuja) and codon **C** (*Asterionella formosa* and small centric diatoms, e.g., *Stephanodiscus hantzschii* Grunow) were the most abundant.

Coda **J** (green algae mentioned above) and **D** (*Fragilaria* spp., *Ulnaria ulna* (Nitzsch) Compère, *U. acus*) mostly dominated in spring or autumn. Such genera as *Cyclotella, Stephanodiscus, Ulnaria* and *Nitzschia* (from **D** group), especially dominated in 2010 while codon **X2** (*Rhodomonas lacustris* Pascher and Ruttner in Pascher, *Ochromonas* sp., *Rhodomonas lens* Pascher and Ruttner) especially dominated in the years 2011 and 2012 (Figure 3). Codon **P** (*Fragilaria crotonensis* Kitton and *Aulacoseira granulata* (Ehrenberg) Simonsen) dominated especially in spring 2005 and 2012.

3.3. The Relations of the Phytoplankton to Environmental Factors in Three Periods of Study

As shown by RDA analyses (Table 2, Figure 4), all the analyzed physical and chemical factors, except for NO_3-N, were significant for the distribution of phytoplankton coda. Water temperature was interrelated with the coda **S1, H1, Lo, J** and **P** (Figure 4), while pH had a significant impact on the distribution of taxa representing codon **T**.

Table 2. Results of the Monte Carlo permutation test (values of p and F are calculated using a test with 999 permutations). The overall percentage of explained variance was 22.98%. Bold = variables significantly adding to the model at $p \leq 0.05$ level. Explanations: EC—conductivity, NO_2—nitrite nitrogen, NO_3—nitrate nitrogen, NH_4—ammonium nitrogen, PO_4—orthophosphate phosphorus, Temp.—temperature.

Variable	Var.N	LambdaA	p	F
Temp.	6	0.11	0.002	29.98
EC	8	0.05	0.002	14.56
NO_2	12	0.02	0.002	5.39
PO_4	17	0.02	0.002	5.16
pH	7	0.01	0.032	2.75
NH_4	11	0.01	0.040	2.27
NO_3	13	0.01	0.056	2.09

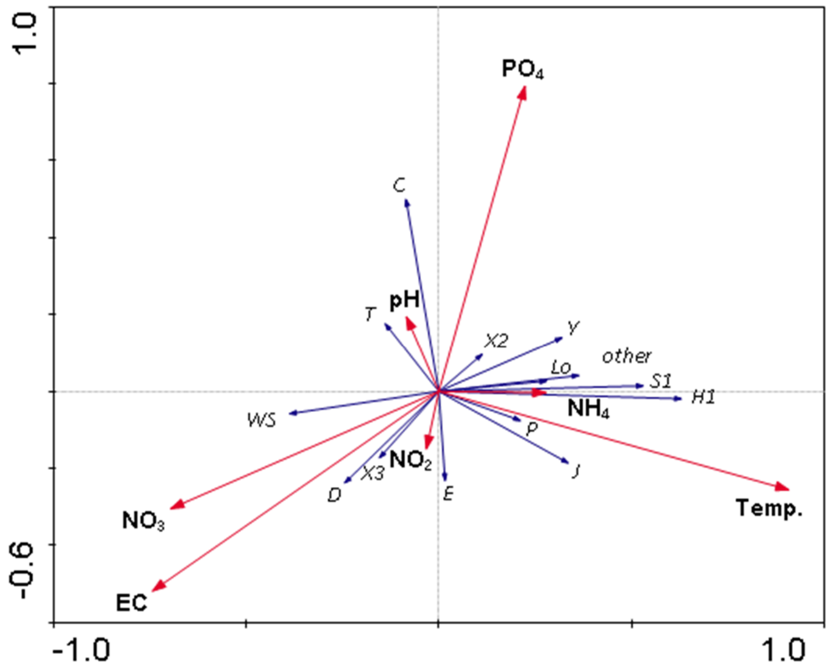

Figure 4. Results of redundancy analysis (RDA) illustrating the functional groups of phytoplankton distribution and environmental variables (physico-chemical parameters) in the Uzarzewskie Lake. Explanations: NO_2—nitrite nitrogen, NO_3—nitrate nitrogen, NH_4—ammonium nitrogen, PO_4—orthophosphate phosphorus, EC—conductivity, Temp.—temperature, phytoplankton dominating coda: **C**, **D**, **E**, **H1**, **J, Lo, S1, WS, X1, X3, Y**, other—the rest of phytoplankton coda.

The abundance of codon **C** was positively affected by PO_4-P concentration and pH, while NH_4-N positively affected coda **X2, Y** and **Lo**. Water conductivity along with NO_3-N positively affected the abundance of coda **WS, D** and **X3**, however, the correlation was not significant.

Analyzing the individual three periods of research (before, during the first and second restoration methods), significant decreases in the contribution of the **H1** group were found (Figure 5, Table 3). It was the highest before restoration and in subsequent years the share of this group decreased. Before restoration, a much lower share of **J** and **WS** groups was found. These groups increased their share in 2008 and 2013. In the period of using the first restoration method, especially codon **S1** was noted in a high percentage.

During the second method of restoration, the share of these groups was lower, while the share of taxa representing other groups increased, especially coda **J, Y** and **C**. Codon **C** was equally represented throughout the entire research period, a slight decrease was found during the use of chemical treatment (iron sulfate). Coda **S1** and **H1** decreased their share during the application of the second method (water from springs delivered to hypolimnion). Some groups were only noted in some years e.g., **T** (*Mougeotia* sp.) in 2008, or codon **Lo** (*Peridinium* sp.) in the year of 2012.

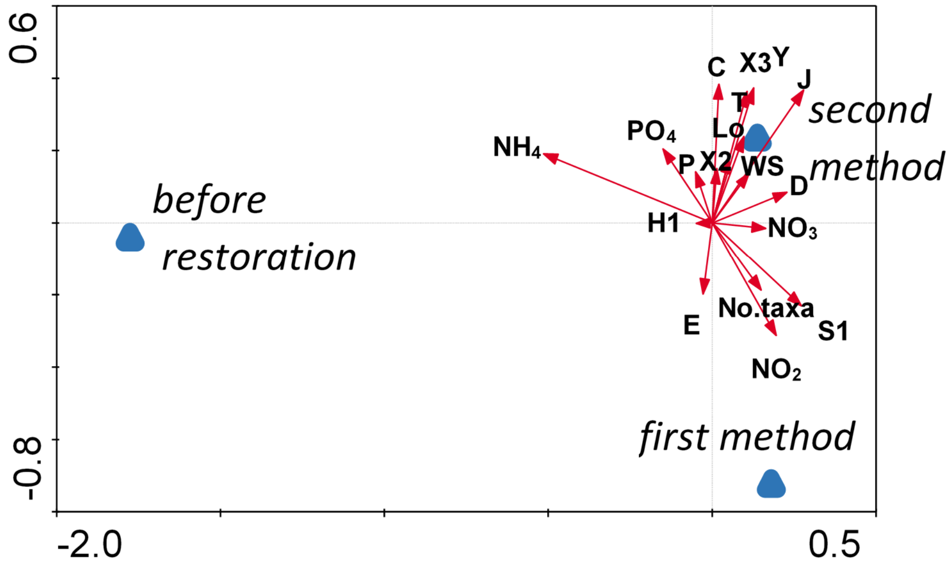

Figure 5. Canonical variate analysis (CVA), diagrams with axes 1 and 2 for the most important functional groups of phytoplankton and nutrients (ammonium nitrogen, nitrites and nitrates and dissolved phosphates) in three periods of investigations: before restoration and during the first and second method.

Table 3. Results of the Monte Carlo permutation test (values of p and F are calculated using a test with 999 permutations). The overall percentage of explained variance was 25.45%. Bold = variables significantly adding to the model at $p \leq 0.05$ level. Explanations: as in Figure 4, No. taxa—the number of taxa in the sample.

Variable	Var.N	LambdaA	*p*	*F*
NH_4	11	0.08	0.002	14.49
J	58	0.05	0.004	10.11
S1	66	0.05	0.004	8.69
C	52	0.02	0.020	4.75
NO_3	13	0.02	0.030	4.19
Y	78	0.02	0.030	4.50
No. taxa	83	0.02	0.030	4.10
NO_2	12	0.02	0.050	3.51
T	69	0.01	0.090	3.25
Lo	61	0.01	0.120	2.21
X3	76	0.01	0.206	1.57
E	54	0.01	0.108	2.10
WS	73	0.01	0.292	1.14
D	53	0.00	0.290	1.14
P	65	0.01	0.390	0.88
PO_4	17	0.00	0.560	0.50
H1	57	0.00	0.684	0.31
X2	75	0.00	0.902	0.08

4. Discussion

Restoration activities have a significant impact on the composition and abundance of phytoplankton species [20]. Cyanobacterial blooms have been found in Uzarzewskie Lake for years, which was largely due to unregulated water and sewage management in the catchment area [11]. The previous study showed that this lake was hypereutrophic [4].

In this study, the impact of restoration methods identified as sustainable on the development of phytoplankton was analyzed. In contrast to drastic methods (e.g., the use of high doses of chemical substances inactivating phosphorus), the methods analyzed in this paper only initiate and support naturally occurring processes of water quality improvement [16].

Different taxa numbers were found during the research periods, indicating environmental instability [21]. The highest taxonomic diversity was found during the period of application of the first method of restoration (Figure 5), which can be explained with the theory of intermediate disturbances [22,23]. The lowest biodiversity appears at the lowest level of disturbances because only the best competitors can persist under these conditions [24]. The lake is also diverse in terms of the number of functional phytoplankton groups. The species noted in the lake were classified into 28 functional groups. This is quite a significant number. In other water bodies, the number of coda was smaller, e.g., 12 functional groups in Lake Mogan [25], 16 in Liman Lake [26], 18 in a dam lake in Turkey [27] and 23 coda along the River Loire in France [7].

Phytoplankton biomass has undergone dynamic changes. The highest values of phytoplankton biomass were found during the restoration period with the second method, which aimed to oxygenate hypolimnetic waters and thus prevented the internal loading of nutrients. This stimulated the growth of large, long-living organisms, e.g., from coda **C** and **Lo**, not sensitive to periodic nutrient deficits [28]. Their growth was particularly intense in the years with high precipitation, e.g., in 2010 and 2012, which resulted in higher phytoplankton biomass. This was probably related to a greater supply of nutrients from the catchment. Periodic problems with the clogging of pipes supplying water from springs to hypolimnion may also have had some impact [11]. Also, the codon **X2** had high biomass in 2012, showing a clear correlation with PO_4-P concentration. Their numerous presence together with species from codon **Y** testifies to the high variability of the environmental conditions [28]. Coda **Y** (*Cryptomonas* spp.) and **X2** (mainly *Rhodomonas* spp.), correlated with PO_4-P concentration are rapidly developing pioneer algae groups. These highly flexible species are able to live in almost all lentic ecosystems when grazing pressure is low [8]. Their life strategy allows them to dominate the environment after the population of other algae collapse and they play a connecting role in the succession of summer phytoplankton. Due to their *r*-life strategy [29] and mixotrophic nutrition they are able to grow well or even outcompete cyanobacteria during colder seasons of the year, i.e., autumn, winter or spring [30].

The biomass of codon **C** (*Asterionella formosa* and centric diatoms) correlated not only with PO_4-P but also with pH. Centric diatoms belonging to this codon dominated mainly in the first and second periods owing to their low-light tolerance and fast growth [31,32].

Coda **H1** and **S1** representing cyanobacteria were closely correlated with the concentration of ammonium nitrogen in water (Figure 4). This is due to the fact that cyanobacteria representing these two coda prefer this form of nitrogen [33–40]. As the concentration of ammonium nitrogen was lower during the second method of restoration due to nitrification and denitrification processes in the hypolimnion [11], there was also a decrease in biomass of coda **H1** and **S1**.

The change of cyanobacteria belonging to codon **H1**, dominating before restoration, to **S1** during the period of the first restoration method and the numerous presence of green algae from codon **J** during the second method, is also associated with a decrease in dissolved phosphates concentrations as a result of restoration. According to Crossetti et al. [41] coda **S1** and **J** occurred in a shallow lake in Brazil under a lowered concentration of soluble phosphorus in the water. An additional reason for the intensive growth of phytoplankton, especially from the coda **H1** and **S1** (cyanobacteria), were very favorable temperature conditions in summer [42–44]. It is worth mentioning that the increasing trends of temperature in the last decades favor cyanobacterial blooms [45–48] and reconstruction of species composition towards an increase of the number of invasive taxa [49–51]. This was the cause of higher cyanobacteria biomass in 2015 than in other years of the second method application, as summer 2015 was extremely hot in Poland. Temperature is a factor that can very clearly affect the successful proliferation of most groups of phytoplankton [52], increasing their growth rates [53–55]. This is demonstrated by temperature correlations also with such coda as: **P** (*Fragilaria crotonensis* and *Aulacoseira granulata*) and **J** (*Actinastrum*, *Scenedesmus* and *Coelastrum*).

Coda **X3** (*Chrysococcus* and *Koliella*) and **D** (*Fragilaria* spp., *Ulnaria ulna*, *U. acus*), mostly found at a lower temperature, were correlated with EC and NO_2-N. Unlike cyanobacteria, these groups prefer other nitrogen forms such as nitrates and nitrites [20,56]. High biomass of codon **T** (*Mougeotia* sp.) in Uzarzewskie Lake was found especially in autumn of 2008 in the entire water column and was correlated with pH. This taxon may dominate in reservoirs from spring to early autumn [57,58]. There have also been cases when it caused intense blooms of water, associated with higher average annual temperatures, such as in Lake Geneva. *Mougeotia* sp. has lamellar chloroplasts that can move to present the largest surface area in relation to the light rays and this allows it to survive in low-light conditions [59].

Codon **Lo** (*Peridinium* sp.) was quite abundant in the year of 2012. This group prefers high concentration of dissolved oxygen in water, as the behavioral and physiological adaptation force dinoflagellates to remain in surface water, rich in oxygen [40]. The second restoration method helped to maintain aerobic conditions that can affect the development of this group of algae. It is worth noting that the average values of oxygen concentration in surface water from the entire research period were the highest in 2012 [11], in which organisms from codon **Lo** were the most abundant.

The biomass of phytoplankton and share of the functional groups in the period of the second method of restoration of Uzarzewskie Lake was very unstable. In the beginning, during the period 2008–2012, a higher biomass of phytoplankton could be observed. This trend was similar to the average values of both soluble reactive and total phosphorus in the water column [11] and was connected with quite high concentrations of phosphorus above the bottom sediments and its internal loading [60]. This increased internal loading was most likely associated with faster mineralization of organic matter as a result of oxygen supply to the bottom area. A similar increase in the first years of restoration was also found in Lake Durowskie [61]. The functional groups such as **C**, **T**, **Y** and **X2** were correlated with high phosphate concentration during those periods. That was also confirmed by the results of statistical analyses.

Summing up, the dominance of codon **H1** in the phytoplankton biomass in the Uzarzewskie Lake before restoration, and the change to codon **S1** during the first method of restoration and coda **C**, **J**, **Y** during the second method of restoration indicates the changes in environmental conditions, especially in trophic level. Phytoplankton groups have been replaced by others, which are indicators for the lower trophy. In turn, the share of cyanobacteria decreased. In such lakes, however, cyanobacterial blooms are decreasing gradually [62–64], and the stabilization of the ecosystem can last even many years.

5. Conclusions

The influence of particular physical and chemical properties of water on the qualitative and quantitative contribution of functional groups in the phytoplankton was demonstrated. The study performed from 2005 to 2015 in Lake Uzarzewskie allowed to analyze changes in the share of taxa representing individual functional groups in the total phytoplankton biomass. It was found that phytoplankton community was rebuilt. In the first study period i.e., before restoration, the **H1** group with such species as *Aphanizomenon gracile, Dolichospermum planctonicum, D. viguieri* predominated in phytoplankton biomass, although this trend was not statistically significant. During the use of the first restoration method (with iron-treatment), high biomass of the codon **S1** was found, mainly *Planktolyngbya limnetica, Limnothrix redekei* and *Planktothrix agardhii*. In the third period of research (oxygenation of hypolimnetic water layer), coda **J** (with *Actinastrum hantzschii* and other Chlorococcales), **C** (*Asterionella formosa* and other diatoms), **Y** (*Cryptomonas marssonii* and other cryptophytes) were dominant, indicating decreasing nutrient concentration and thus improving water quality.

Author Contributions: A.K.—analyzed the phytoplankton samples, performed statistical analysis, designed and wrote the manuscript, A.K. and A.B.—performed the phycological analyses, R.D.-P. and K.K.-M. prepared physico-chemical data, R.G.—reviewed the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by The Polish National Science Center as research project No. NN305 372838.

Conflicts of Interest: The authors declare no conflict of interest.

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