Arch. Pol. Fish. (2014) 22: 81-96
DOI 10.2478/aopf-2014-0008

RESEARCH ARTICLE

# Phytoplankton of artificial ecosystems – an attempt to assess water quality

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*Received – 24 October 2012/Accepted – 10 April 2013. Published online: 25 March 2014; ©Inland Fisheries Institute in Olsztyn, Poland*
Citation: Napiórkowska-Krzebietke A. 2014 – Phytoplankton of artificial ecosystems – an attempt to assess water quality – Arch. Pol. Fish. 22: 81-96.

**Abstract**. Phytoplankton changes in canals were described in light of communities in chosen lakes of the Konin lakes system, and links were identified between these changes and water quality assessments based on different biological indexes. Seasonal phytoplankton studies were performed in the Warta-Gopło (WG) and Konin Power Plant (EK) canals. 258 and 223 taxa from six divisions were identified that comprised a maximum biomass of 13.4 mg dm$^{-3}$ in the EK canal and 9.3 mg dm$^{-3}$ in the WG canal. The communities in the canals were co-dominated by diatoms, cryptomonads, and chlorophytes. Blooms of the cyanobacteria *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* were only noted in the WG canal. The phytoplankton in the EK canal and Lake Ślesińskie were closely similar. Consistent water quality assessments were obtained with the saprobic system (moderately polluted and good quality), while the results of the algal genus pollution index indicated there was a high degree of pollution. Classifications using the Shannon-Weaver and indexes (IT) indicated the water quality in the EK canal was good, while in the WG canal the water had low levels of pollution and was at a poor ecological potential. Classification modifications based on the Shannon-Weaver index permit assessing canal water quality analogously to the saprobity index. Using these indexes is proposed as a phytoplankton-based alternative to multi-metric assessments of ecological status or potential in small rivers, streams, and canals. The possibility of performing comprehensive, five-degree classifications was confirmed, thus, permitting the recommendation of this method for water quality assessments.

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**Keywords**: biomass, phytoplankton indexes, biological water quality, WFD, saprobity, the Konin lakes system

## Introduction

Phytoplankton dynamics and structure, which reflect the overall intensity of factors impacting communities, are basic indexes of the states of not only lentic but also lotic environments (Marshall and Burchardt 2004, Żelazowski et al. 2004). A significant challenge to the proper functioning of aquatic systems has become frequent water blooms comprising primarily cyanobacteria, dinoflagellates, cryptomonads, diatoms, and chlorophytes (Reynolds and Walsby 1975, Bucka 1987, 1989, Eloranta 1998, Hutorowicz 1998, Patowa 2003). This problem affects not only lakes but also rivers, mainly in lentic segments, and dam reservoirs, including drinking-water reservoirs, situated on their courses. In Poland these include the Sulejów, Włocławek, Siemianówka, Goczałkowice, Dobczyce, Brody Iłżeckie, and Chańcza dam reservoirs (Górniak and


Figure 1. Map of the Konin lakes system (acc. to Socha and Zdanowski (2001), changed), and location of sampling stations: 1 – EK canal, 2 – WG canal, 3 – Lake Licheńskie, 4 – Lake Ślesińskie

Grabowska 1996, Kabziński et al. 2000, Bucka et al. 2003, Prus et al. 2007). Water blooms of *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* were noted frequently in Jeziorsko Reservoir, which is linked with the Warta River, in the 1990s (Galicka and Lesiak 1996, Galicka and Kruk 1999). The occurrence of intense cyanobacterial blooms in other reservoirs or streams associated with this river could occur.

The aim of this study was to identify the planktonic algae in the canals supplying the entire Konin lakes system with waters from the Warta River and from the intake canal that directs waters from Lake Pątnowskie directly to the Konin Power Plant against the background of the phytoplankton structure from selected lakes in this system. An attempt was made to identify a dependence between variable phytoplankton structure and water quality assessments in these canals based on several biological indexes. An alternative method for assessing the ecological status or potential of smaller rivers and streams based on phytoplankton is proposed.

## Materials and methods

The Konin system comprises five lakes that are connected by intake and discharge canals that comprise the cooling circuit for the Pątnów and Konin power plants (Fig. 1). This system is supplied by waters from the Warta River through the artificial Warta-Gopło canal, which is also used as a sailing canal (Socha and Zdanowski 2001). The length of the canal from the Warta River to Lake Pątnowskie (WG canal) is 8.5 km at a depth of 3.5 m and a flow rate when the sluices are open is 0.10 m $s^{-1}$ (Kraszewski and Zdanowski 2007). The Konin Power Plant intake canal (EK canal: length – 1.5 km, depth – 3.8 m, flow rate – 0.32 m $s^{-1}$) supplies the power plant directly with water from Lake Pątnowskie, which is supplied by lakes Ślesińskie and Wąsosko-Mikorzyńskie. Both of these canals are cold with similar, average surface layer temperatures of 14.8 and 14.9°C, respectively, in the 1995-2010 period, while in the warm canals the average surface temperature exceeded 20.0°C (Pyka et al. 2013).

Phytoplankton studies were conducted from March to November in the EK canal in the 2004-2005 period and in the WG canal in 2005. Samples were collected from the water surface layer from central canal positions at sites 1 and 2 (Fig. 1). Quantitative phytoplankton analysis was performed with an inverted microscope according to the method by Utermöhl (1958) and to European and international monitoring norms (Kelly 2004). The organisms, or units, which were single cells, coenobia, colonies, or filaments, were counted under a micrometer ocular grid at various magnifications. Biomass was calculated with the cell volume measurement method (Pliński et al. 1984, Kawecka and Eloranta 1994). Observations of phytoplankton were performed with a light microscope.

Absolute permanent species (Tichler 1949, cited in Trojan 1975), which occurred at frequencies of 76-100%, were identified. The Shannon-Weaver (Shannon and Weaver 1949) and the evenness (Pielou 1969) indexes based on taxon biomass were used to determine species diversity. The Unweighted Pair Group method with Arithmetic Mean (UPGMA) cluster analysis based on similarity percentages was applied to determine phytoplankton community similarity (Multi-Variate Statistical Package, Kov. Comp. Serv. 1985-2009). The phytoplankton samples were divided as follows: spring (March, April, May); summer (June, August, September); autumn (October, November). The phytoplankton biomass data used in this study came from lakes Licheńskie and Ślesińskie (phytoplankton studies were conducted simultaneously at sites 3 and 4; Fig. 1), some of which are already published (Napiórkowska-Krzebietke 2009), in order to determine the degree of phytoplankton algae community similarity developing in the canals and lakes.

Water quality assessments were performed using different indexes based on the abundance, biomass, and values of indicator taxa:

1) algal genus pollution index (Palmer et al. 1977) – index factors are presented for each of 20 genera of the algae present in water and then totaled;
2) Shannon-Weaver diversity index (Shannon and Weaver 1949)

$$H' = -\sum^{n} i = 1 pi \times \ln pi$$

n – number of taxa, *pi* – proportion of *i*-th taxon in the community;

3) Saprobic index (Pantle and Buck method modified by Yap 1997)

$$S = \sum (r \times h) / \sum (h)$$

r – taxon saprobity rating (1 – oligosaprobic, 2 – β-mesosaprobic, 3 – α-mesosaprobic, 4 – polysaprobic), h – taxon frequency rating (1 – incidental with <100 cells $ml^{-1}$; 2 – frequent with 100-200 cells $ml^{-1}$; 3 – abundant with >200 cells $ml^{-1}$);

**Table 1**
Classification of water quality according to different biological indices and approaches

| Indices | | Class I | II | III | IV | V |
|---|---|---|---|---|---|---|
| Algal genus pollution index[1] | | | | | | |
| acc. to Palmer et al. (1977) | values | ≤14 | 15-19 | ≥20 | - | - |
| | quality | low organic pollution | moderate organic pollution | high organic pollution | - | - |
| Shannon-Weaver index | | | | | | |
| acc. to Wilhm (1975) | values | >3 | 1-3 | <1 | - | - |
| | quality | clean water | moderately polluted | heavily polluted | - | - |
| acc. to Yap (1997) | values | >2.68 | 2.01-2.68 | 1.34-2.01 | 0.67-1.34 | 0.00-0.67 |
| | quality | excellent | good | slightly polluted | moderately polluted | polluted |
| Saprobic index | | | | | | |
| acc. to Yap (1997) | values | 1.0-1.5 | 1.5-2.5 | 2.5-3.5 | 3.5-4.0 | - |
| | condition | very slight contamination | moderate contamination | heavy contamination | very heavy contamination | |
| acc. to Czech standards[2] | values | <1.5 | 1.5-2.19 | 2.2-2.99 | 3.0-3.49 | >3.5 |
| | status | high | good | moderate | poor | bad |
| acc. to Hungarian standards[3] | values | <1.8 | 2.3 | 2.8 | 3.3 | >3.3 |
| | quality | excellent | good | bearable | polluted | heavily polluted |
| Multimetric phytoplankton index | | | | | | |
| acc. to Picińska-Fałtynowicz and Błachuta (2011) | values | ≥0.80 | <0.80 - ≥0.60 | <0.60 - ≥0.40 | <0.40 - ≥0.20 | <0.20 |
| | status | high | good | moderate | poor | bad |

[1]the index factor for the following genera: *Oscillatoria* – 5, *Euglena* – 5, *Chlamydomonas* – 4, *Scenedesmus* – 4, *Chlorella* – 3, *Navicula* – 3, *Nitzschia* – 3, *Ankistrodesmus* – 2, *Phacus* – 2, *Stigeoclonium* – 2, *Synedra* – 2, *Anacystis* – 1, *Closterium* – 1, *Cyclotella* – 1, *Gomphonema* – 1, *Lepocinclis* – 1, *Melosira* – 1, *Micractinium* – 1, *Pandorina* – 1, *Phormidium* – 1. Larger value indicates more polluted water. [2]Rolauffs et al. (2004), [3]Imre (2004)

4) trophy index, IT (Picińska-Fałtynowicz and Błachuta 2011)

$$IT = \sum(D_i \times wT_i \times T_i) / \sum(D_i \times wT_i)$$

$D_i$ – seasonal mean of percentage share *i*-th taxon in total biomass of phytoplankton indicators, $wT_i$ – weight value of *i*-th taxon, $T_i$ – trophic indicative value of *i*-th taxon.

Canal water quality classifications were done according to different systems as presented in Table 1. The Shannon-Weaver index classification is determined using values calculated with taxon abundance ($H'_n$); however, the modification proposed in this paper entails applying an index value calculated with taxon biomass ($H'_b$) because of the requirements of the Water Framework Directive (2000/60/EC). In general, assessments are based on phytoplankton biomass, and the strict dependence between $H'_n$ and $H'_b$ was proved (Napiórkowska-Krzebietke 2009). Biological water assessments with the saprobity index according to Czech standard CSN 75 2221 (Rolauffs et al. 2004) are based on a five-degree scale, which is a universal system that does not refer to lotic water types or reference conditions and permits classifying biological water status as high, good, moderate, poor, bad. Analogously, an attempt was undertaken to classify ecological potential (both canals are designated as Artificial Water Bodies) as recommended by the Water Framework Directive (2000/60/EC) using one of the constituent modules of the IFPL multimetric phytoplankton index

(Picińska-Fałtynowicz and Błachuta 2011), i.e., the trophy index (IT) based on the biomass and indicative values of indicator taxa. The authorized IFPL method based on phytoplankton as a community indicator of water trophic status was developed for large Polish rivers, while for smaller rivers and streams the indicator community is phytobenthos (Picińska-Fałtynowicz 2011, Regulation 2011).

## Results

### Phytoplankton biomass

The total biomass in the Konin Power Plant intake canal (EK) in the 2004 vegetation season ranged from 1.3 to 10.3 mg dm$^{-3}$ (Fig. 2a), and the maximum was recorded in April. Similar planktonic algae biomass was noted in March. Fairly high phytoplankton biomass was still noted in May and June at 4.0 and 6.0 mg dm$^{-3}$, respectively, while by August it had decreased to just

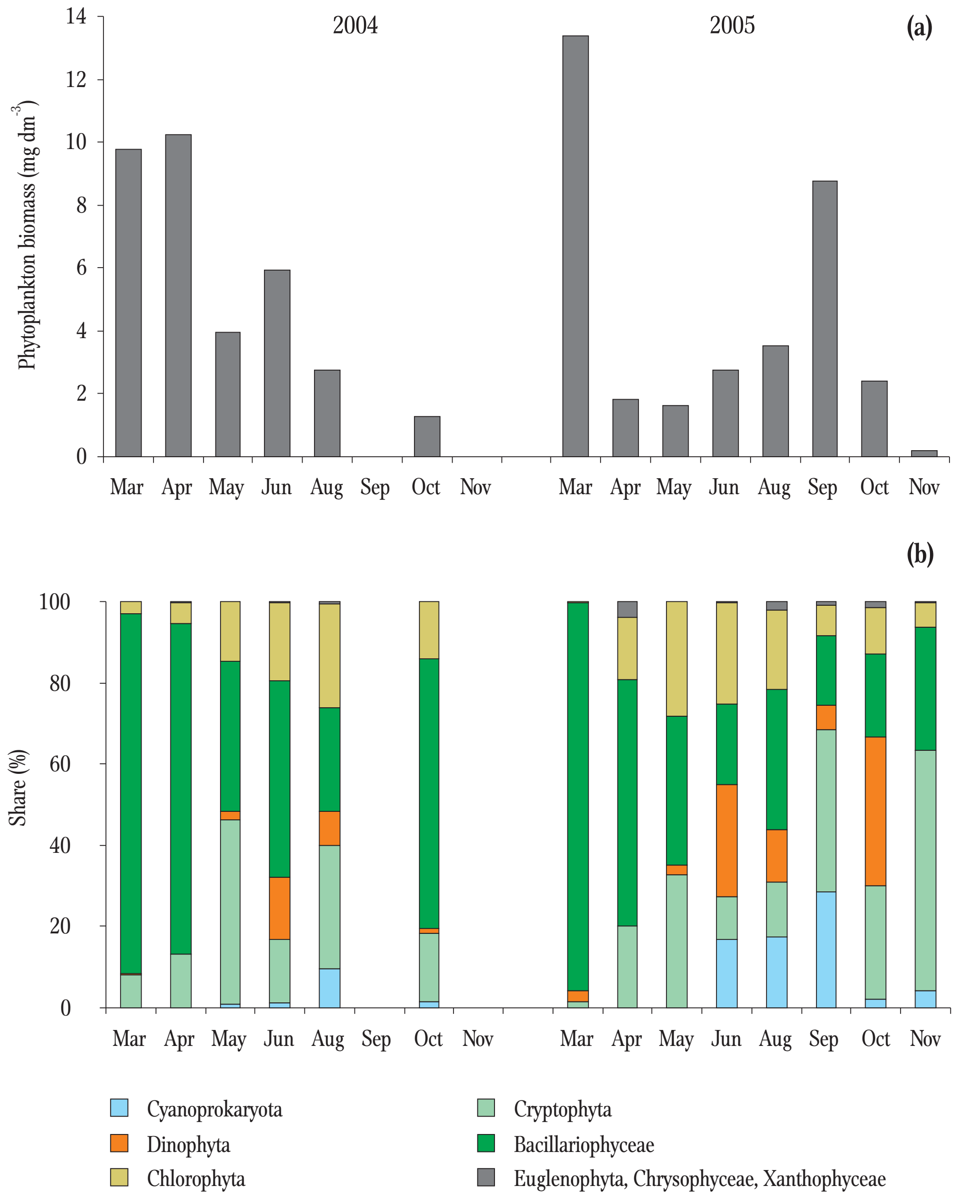


Figure 2. Total biomass (a) and structure (b) of phytoplankton in the intake canal of Konin Power Plant (EK canal) in 2004-2005.

**Table 2**
Dominant species (≥10% total biomass) of phytoplankton in intake canal of Konin Power Plant (Ek canal) during the growth seasons in 2004-2005

| | Phytoplankton species | |
|---|---|---|
| Month | 2004 | 2005 |
| March | *Cyclotella* sp.+*Discostella* cf *stelligera* (35%)<br>*Stephanodiscus hantzschii* (28%)<br>*Stephanodiscus neoastrea* (10%) | *Discostella* cf *stelligera* (89%) |
| April | *Stephanodiscus neoastrea* (69%) | *Stephanodiscus neoastrea* (38%)<br>*Chroomonas acuta* (12%) |
| May | *Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (36%)<br>*Cyclotella* sp.+*Discostella* cf *stelligera* (25%) | *Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (23%)<br>*Stephanodiscus neoastrea* (19%)<br>*Pediastrum boryanum*+*P. duplex* (15%) |
| June | *Cyclotella* sp.+*Discostella* cf *stelligera* (16%)<br>*Peridinium* sp. div. (15%)<br>*Stephanodiscus neoastrea* (15%)<br>*Aulacoseira* sp. (13%)<br>*Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (11%) | *Peridinium* sp. div. (18%)<br>*Ceratium furcoides*+*C. hirundinella* (10%)<br>*Cyclotella* sp.+*Stephanodiscus hantzschii* (10%) |
| August | *Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (22%)<br>*Stephanodiscus neoastrea* (10%) | *Discostella* cf *stelligera* (15%)<br>*Ceratium furcoides*+*C. hirundinella* (10%)<br>*Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (10%) |
| September | nd | *Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (37%)<br>*Anabaena sphaerica* f. *conoidea* (17%) |
| October | *Aulacoseira granulata* (32%)<br>*Cyclotella* sp.+*Discostella* cf *stelligera* (16%)<br>*Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (10%) | *Peridinium* sp. div. (36%)<br>*Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (22%)<br>*Discostella* cf *stelligera* (10%) |
| November | nd | *Chroomonas acuta* (27%)<br>*Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (23%)<br>*Discostella* cf *stelligera* (10%)<br>*Rhodomonas* sp. (10%) |

nd – no data

2.8 mg dm$^{-3}$. The minimum was noted in October. In contrast to the 2004 observations, two clear maximums in phytoplankton development were noted in 2005; the first occurred in as early as in March at 13.4 mg dm$^{-3}$, and the second, smaller maximum was noted in September at 8.8 mg dm$^{-3}$. Fairly high biomass was still noted in August at 3.5 mg dm$^{-3}$, but in the other months it did not exceed 2.8 mg dm$^{-3}$, and the minimum was confirmed in November at 0.2 mg dm$^{-3}$.

The phytoplankton biomass in the Warta-Gopło canal (WG) fluctuated to a lesser degree within a range of 0.3 do 9.3 mg dm$^{-3}$ from April to November 2005 (Fig. 3a). During this period, two distinct peaks of similar abundance exceeding 9.0 mg dm$^{-3}$ were observed in March and September. Fairly high algal plankton biomass of 6.0 mg dm$^{-3}$ was also noted in June. In the remaining spring and summer months of April, May, and August, biomass ranged from 1.7 to 3.9 mg dm$^{-3}$. Phytoplankton abundance in autumn was low within a range of 0.3-1.2 mg dm$^{-3}$.

## Phytoplankton structure

Diatoms dominated in the EK canal comprising approximately 85% of the total biomass in March and April 2004 (Fig. 2b), and were primarily *Cyclotella* sp., *Stephanodiscus hantzschii* Grun. (in Cl. & Grun.), and *S. neoastrea* Håk. et Hick. (Table 2). The occurrence of cryptomonads was distinct at from 8 to 13%; they included, among others, the genus *Cryptomonas*, which co-dominated with diatoms in May. Chlorophytes also comprised a fairly large share (15%), and were mainly from the genus *Pediastrum* (e.g., *P. boryanum* (Turp.) Menegh., *P. duplex* Meyen, *P. simplex* Meyen). In June, diatoms dominated the

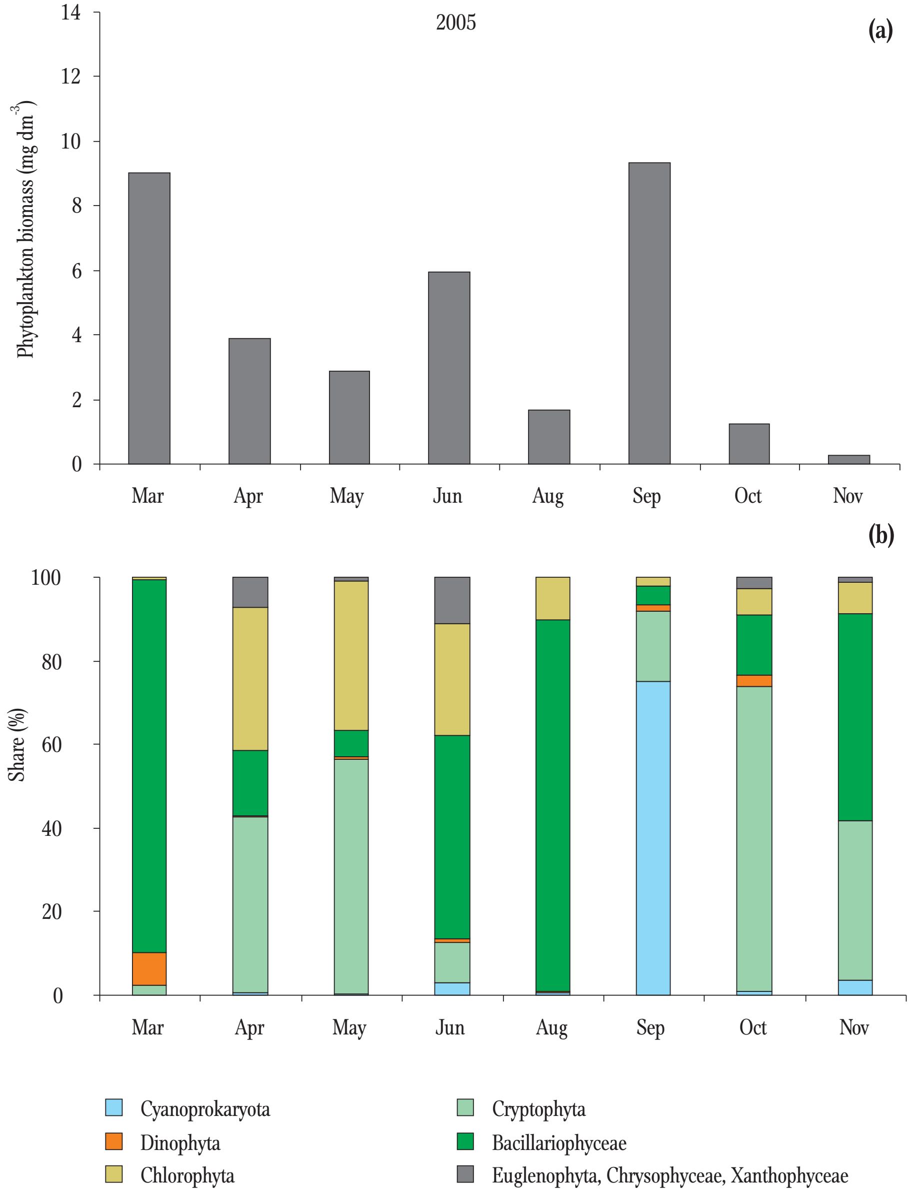


Figure 3. Total biomass (a) and structure (b) of phytoplankton in the Warta-Gopło canal in 2005.

phytoplankton again, while the often observed chlorophytes, cryptomonads, and dinoflagellates frequently from the genus *Peridinium* comprised more than 15% of the total biomass. The structure of the planktonic algae community in August comprised mainly Cryptophyta, Chlorophyta, and Bacillariophyceae (at approximately 27% each), while an approximate 10% share was contributed at this time by cyanobacteria and dinoflagellates. In October, when the total biomass was approximately five times lower than in June, the same species of the genera *Aulacoseira*, *Cyclotella*, and *Cryptomonas* dominated.

Analogous changes in the spring phytoplankton communities at the level of all taxonomic units and dominating species were also recorded in 2005. However, the planktonic algae communities in June and August were different (Fig. 2b). These regarded the relationship between the co-dominant algal groups in both years (Chlorophyta, Cryptophyta, Dinophyta, Bacillariophyceae). The biomass of the dinoflagellates *Peridinium* sp. div., *Ceratium furcoides* (Lev.) Langh., and *C. hirundinella* (O.F. Müll.) Bergh were decidedly higher (Table 2). The increase in the importance of cyanobacteria in the phytoplankton was also significant. In 2005, simultaneously with the increase in total algal biomass, the share of cyanobacteria increased from 17% in June to 28% in September. Among the cyanobacteria, the biomass of *Anabaena sphaerica* f. *conoidea* Elenkin was the highest at a maximum of 1.5 mg dm$^{-3}$ in September. *Aphanizomenon flos-aquae* (L.) Ralfs ex Born. et Flah., *Cuspidothrix issatschenkoi* (Usačev) Rajaniemi et al. (2005), and *Aphanocapsa incerta* (Lemm.) Cronb. et Kom. also developed fairly abundantly. A different phytoplankton structure was noted in October. In contrast to that in 2004, dinoflagellates of the genus *Peridinium* (36%) dominated the communities, while cryptomonads and diatoms comprised in excess of 20% of the total biomass. The shares of chlorophytes in both years were similar at approximately 13%. In November 2005, the phytoplankton was co-dominated by cryptomonads and diatoms. Throughout the study period, the algae that occurred permanently included euglenoids mainly of the genera *Euglena* and *Phacus*, but their shares of the total biomass did not exceed 2%, while xanthophytes and chrysophytes occurred rarely.

In March 2005, diatoms, mainly *Cyclotella* sp. and *Stephanodiscus hantzschii* (Table 3), dominated the phytoplankton in the WG canal when they comprised approximately 89% of the total biomass (Fig. 3b). The planktonic algae community in April was entirely different with nanoplanktonic organisms belonging to Cryptophyta co-dominated with Chlorophyta and comprised a biomass of 1.6 and 1.3 mg dm$^{-3}$, respectively. These were mainly *Chroomonas acuta* Unterm., *Cryptomonas rostrata* Troitz. emend. I. Kis., *C. ovata* Ehr., *C. marssonii* Skuja, and *Chlamydomonas* sp. div. Diatoms comprised just 16% of the total biomass. The phytoplankton structure was very similar in May, but in June the significance of diatoms increased again when they were represented mainly by the genus *Aulacoseira*. Chlorophytes also had a fairly large share of 27%, which included, among others, *Sphaerocystis* sp. and *Planctonema lauterbornii* Schmidle. The occurrence of chrysophytes of the genus *Dinobryon* was also distinct at 11%. In August, similarly to March, diatoms dominated the phytoplankton, but its structure in September was very different. Cyanobacteria comprised 7.0 mg

**Table 3**
Dominant species (≥10% total biomass) of phytoplankton in the Warta-Gopło canal during the growth season in 2005

| 2005 | Phytoplankton species |
|---|---|
| March | *Discostella* cf *stelligera* (81%) |
| April | *Chroomonas acuta* (28%) |
| | *Chlamydomonas incerta* (23%) |
| | *Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (14%) |
| May | *Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (47%) |
| | *Chlamydomonas incerta* (28%) |
| June | *Aulacoseira* sp. (31%) |
| | *Dinobryon divergens*+*D. sociale* (11%) |
| August | *Stephanodiscus neoastrea* (40%) |
| | *Discostella* cf *stelligera* (28%) |
| | *Aulacoseira granulata* (11%) |
| September | *Microcystis aeruginosa* (42%) |
| | *Aphanizomenon flos-aquae* (32%) |
| | *Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (14%) |
| October | *Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (61%) |
| November | *Stephanodiscus hantzschii*+*S. neoastrea* (22%) |
| | *Cryptomonas rostrata*+*C. erosa*+*C. marssonii* (18%) |
| | *Chroomonas acuta* (15%) |
| | *Discostella* cf *stelligera* (14%) |

**Table 4**
Number of species, varieties or forms of phytoplankton in Konin canals in 2004-2005

| Phytoplankton group | Species, variety, form | |
|---|---|---|
| | EK canal | WG canal |
| Cyanoprokaryota | 31 | 32 |
| Heterokontophyta: | 73 | 60 |
| Chrysophyceae | 3 | 5 |
| Xanthophyceae | 1 | 1 |
| Bacillariophyceae | 69 | 54 |
| Euglenophyta | 14 | 12 |
| Dinophyta | 9 | 8 |
| Cryptophyta | 6 | 6 |
| Chlorophyta | 122 | 103 |
| Total | 255 | 221 |

EK canal – the intake canal of Konin Power Plant, WG canal – the Warta-Gopło canal

$dm^{-3}$, or 75% of the total biomass, which led to the formation of a late-summer maximum. These included mainly *Microcystis aeruginosa* (Kütz.) Kütz. and *Aphanizomenon flos-aquae*. Cryptomonads also contributed a significant share to the total biomass at approximately 17%, and by October they dominated the planktonic algae community distinctly with a 73% share. In November, the phytoplankton was co-dominated by cryptomonads and diatoms.

## Phytoplankton diversity and similarity

In 2004 and 2005, 255 taxa at the rank of species, variety, and forma belonging to the six divisions of Chlorophyta, Cyanoprokaryota, Cryptophyta, Dinophyta, Euglenophyta, and Heterokontophyta were identified in the phytoplankton of the EK canal (Table 4). The most diverse were the chlorophytes (122), and many species were also noted among the diatoms (69) belonging to the division of Heterokontophyta and among cyanobacteria (31). Euglenoids, Chrysophyceae and Xanthophyceae, however, occurred fairly or the least abundantly. Substantially fewer taxa were identified in the phytoplankton of the Warta-Gopło canal (221), which belonged to the same divisions as those in the EK canal. Differences regarded mainly lesser diversity among chlorophytes (103) and diatoms (54), which could have been linked directly to the study period during which there was one vegetation season in the WG canal, while there were two in the EK canal. Fewer species with 100% frequency were also observed in the WG canal (Table 5).

The Shannon-Weaver diversity index, which was calculated based on taxon biomass, was within a range of 0.56 to 3.40 (Table 6) at a mean of 2.46 in the EK canal in both years of the study. This index in the WG canal fell within the slightly narrower range of 0.83-3.14 at a mean of 2.03. Analogously higher values of evenness were also noted in the EK canal at a mean of 0.54, while in the WG canal the mean was just 0.46. The lowest species diversity in each of the canals was observed in March (index value < 1.0), when the centric diatom *Discostella* cf *stelligera* comprised the highest share of the phytoplankton. The greatest diversity was noted in June and August (index value > 3.0) when several taxa from various systematic groups co-dominated: diatoms, cryptomonads, dinoflagellates (the EK canal) and diatoms and chrysophytes (WG canal).

Cluster analysis based on the percentage of similarities of taxonomic composition showed considerable distinctiveness among the phytoplankton communities developing in each of the two canals (Fig. 4). The first group included spring samples from the EK and WG canals in 2005 which exhibited the highest similarity at 64%, and the EK canal in 2004. Likewise, among the autumn samples the most similar phytoplankton developed in 2005 in each of the canals at 56%. However, samples collected in the EK canal in 2004 and in the WG canal in 2005 (EK-sum04, WG-sum05) comprised the center of the summer group at 48%.

Cluster analysis, again based on the percentage of similarities of taxonomic composition, indicated that the phytoplankton communities forming in the Licheńskie and Ślesińskie lakes system at this time and in the canals comprised three groups (Fig. 5). The first group comprised phytoplankton developing in Lake Licheńskie in both years of the study at 91% and in Lake Ślesińskie in 2005. The most similar to this group was the phytoplankton from the EK and WG canals in 2005, which comprised a separate group at 85%. The third at 87% included samples collected in 2004 from Lake Ślesińskie and the EK canal, through which water from this lake flowed indirectly.

## Biological water quality

The value of the algal genus pollution index, which is based on the presence of representative of 20 indicator genera, was within similar ranges of 20-36 in the two canals (Table 7). This permitted classifying these waters as class III quality, which is the worst class. The values of the Shannon-Weaver index, which was calculated based on the abundance of phytoplankton taxa, fluctuated in the EK canal from 0.73 to 3.04 at a mean of 2.30 in 2004 and 2.13 in 2005. A considerably lower mean of this index of 1.86 was

**Table 5**
List of species with the highest frequency (%) including absolutely constant taxa (76-100%) in the Konin canals in 2004-2005

| | EK canal | | WG cana |
|---|---|---|---|
| Species | 2004 | 2005 | 2005 |
| Bacillariophyceae | | | |
| *Amphora ovalis* | 100 | 100 | 88 |
| *Amphora pediculus* | 100 | 75 | 88 |
| *Asterionella formosa* | 100 | 50 | 50 |
| *Aulacoseira granulata* | 100 | 100 | 88 |
| *Aulacoseira* sp. | 100 | 100 | 100 |
| *Cocconeis placentula* | 83 | 88 | 100 |
| *Discostella* cf *stelligera* | 100 | 100 | 100 |
| *Epithemia adnata* | 83 | 100 | 38 |
| *Ulnaria acus* | 100 | 100 | 100 |
| *Ulnaria ulna* | 100 | 100 | 100 |
| *Navicula* sp. | 100 | 100 | 75 |
| *Nitzschia pusilla* | 33 | 63 | 100 |
| *Nitzschia palea* | 100 | 50 | 1000 |
| *Rhoicosphaenia abbreviata* | 100 | 100 | 100 |
| *Stephanodiscus neoastrea* | 100 | 100 | 100 |
| Dinophyta | | | |
| *Peridinium* sp. | 100 | 100 | 100 |
| Cryptophyta | | | |
| *Chroomonas acuta* | 100 | 100 | 100 |
| *Cryptomonas rostrata* | 100 | 100 | 100 |
| *Cryptomonas ovata* | 100 | 100 | 100 |
| *Cryptomonas marssonii* | 100 | 100 | 100 |
| *Rhodomonas* sp. | 100 | 100 | 100 |
| Chlorophyta | | | |
| *Chlamydomonas* sp. | 100 | 100 | 100 |
| *Coenococcus planctonicus* | 100 | 63 | 88 |
| *Kirchneriella* sp. | 100 | 100 | 88 |
| *Monoraphidium contortum* | 100 | 100 | 100 |
| *Pediastrum boryanum* | 100 | 100 | 100 |
| *Pediastrum duplex* | 100 | 100 | 100 |
| *Pediastrum simplex* | 100 | 88 | 63 |
| *Schroederia setigera* | 100 | 100 | 100 |
| *Scenedesmus acuminatus* | 100 | 75 | 75 |
| *Scenedesmus quadricauda* | 100 | 100 | 63 |
| *Scenedesmus* sp. | 100 | 100 | 100 |
| *Tetraedron caudatum* | 100 | 100 | 88 |
| *Tetraedron minimum* | 100 | 88 | 75 |
| *Tetrastrum glabrum* | 100 | 88 | 100 |
| Cyanoprokaryota | | | |
| *Chroococcus minutus* | 100 | 88 | 63 |

Codes of EK and WG are given in Tab. 4

confirmed in the WG canal. Classifications of water quality based on this index indicated class II in the EK canal and classes II and III in the WG canal. The values of the Shannon-Weaver index calculated with taxon biomass and modifications of the classification system based on this led the waters in both canals to be classified similarly as class II. The values of the saprobity index in the two canals fluctuated within similar limits of 1.85-2.04, and the mean values of this index were 1.90 and 1.94 in the EK canal in 2004 and 2005, respectively, and 1.94 in the WG canal. Three water quality assessment systems were

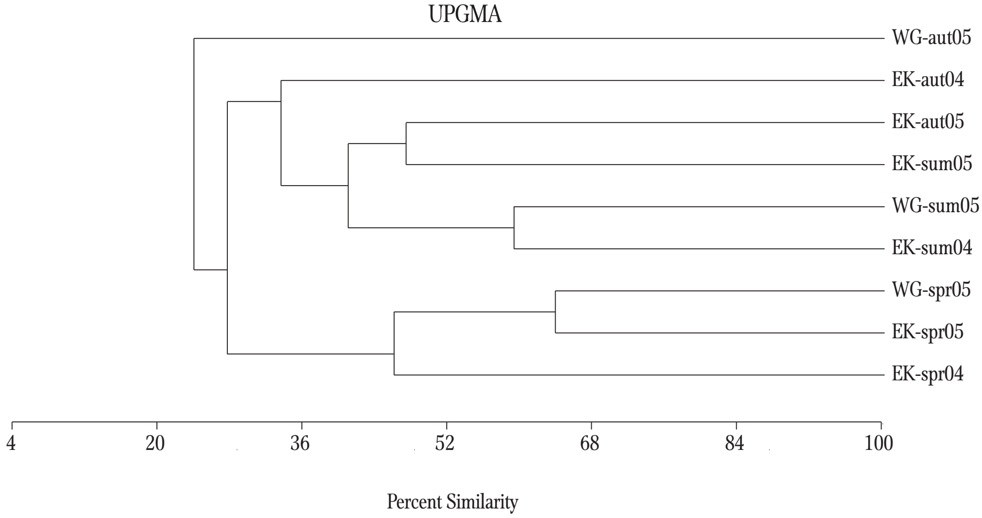


Figure 4. Hierarchical cluster analysis based on similarity of phytoplankton taxa in Konin canals in spring, summer and autumn 2004 and 2005, codes of EK and WG are given in Table 4.

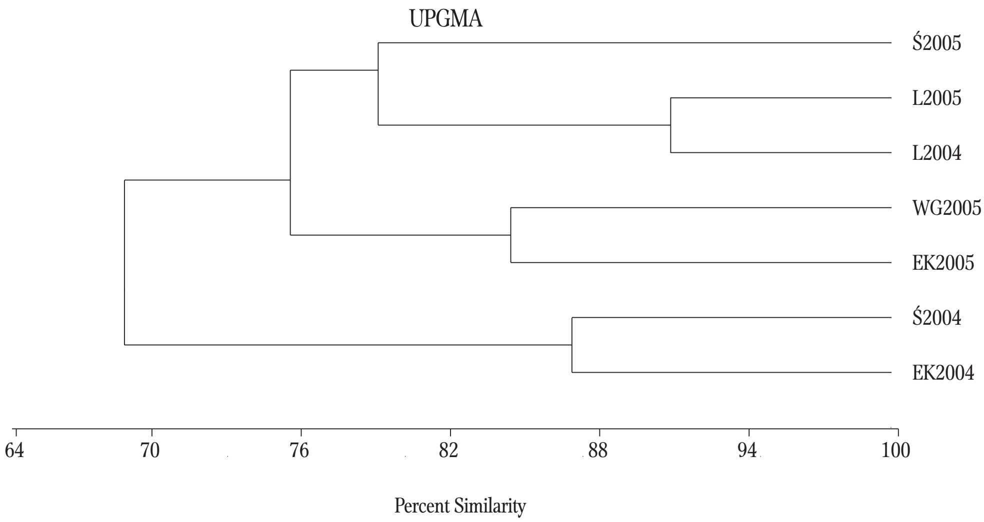


Figure 5. Hierarchical cluster analysis based on similarity of phytoplankton groups in Konin lakes and canals in 2004 and 2005, codes of EK and WG are given in Table 4, L – Lake Licheńskie, Ś – Lake Ślesińskie.

considered based on the saprobic system, and the waters in the two canals were determined to be of class II. The attempt to assess ecological potential based on one of the IFPL multimetric phytoplankton modules, i.e., the trophy index (IT), was ambiguous. Although the IT values in each of the canals differed only slightly at 3.24 and 3.46, based on their normalized values, which were 0.44 and 0.39, respectively, the waters were classified as class III in the EK canal and as class IV in the WG canal.

## Discussion

Two phytoplankton biomass peaks, one in spring (March or April) and one in late summer (September) were noted in the two artificial canals with varied flow rates. This type of phytoplankton dynamic is also observed in mountainous rivers and streams (Kawecka and Eloranta 1994). The higher phytoplankton abundance noted in the Konin Power Plant intake canal in early spring than in late summer in 2005 was somewhat dissimilar. Similar

**Table 6**
Number of taxa and diversity indices based on phytoplankton biomass of Konin canals in 2004-2005

| Canal | Date | Number of taxa | Shannon-Weaver diversity index* | Evenness* |
|---|---|---|---|---|
| Konin Power Plant intake canal | March 2004 | 72 | 1.87 | 0.44 |
| | April 2004 | 82 | 1.53 | 0.35 |
| | May 2004 | 77 | 2.13 | 0.49 |
| | June 2004 | 101 | 2.79 | 0.61 |
| | August 2004 | 111 | 3.01 | 0.64 |
| | October 2004 | 99 | 2.76 | 0.60 |
| | March 2005 | 49 | 0.56 | 0.14 |
| | April 2005 | 81 | 2.48 | 0.56 |
| | May 2005 | 96 | 2.91 | 0.64 |
| | June 2005 | 109 | 3.40 | 0.72 |
| | August 2005 | 105 | 3.40 | 0.73 |
| | September 2005 | 115 | 2.70 | 0.57 |
| | October 2005 | 111 | 2.53 | 0.54 |
| | November 2005 | 59 | 2.38 | 0.58 |
| Warta-Gopło canal | March 2005 | 57 | 0.83 | 0.21 |
| | April 2005 | 78 | 2.33 | 0.54 |
| | May 2005 | 95 | 1.75 | 0.39 |
| | June 2005 | 112 | 3.14 | 0.67 |
| | August 2005 | 63 | 1.87 | 0.45 |
| | September 2005 | 85 | 1.69 | 0.38 |
| | October 2005 | 88 | 2.04 | 0.46 |
| | November 2005 | 70 | 2.59 | 0.61 |

*based on taxa biomass

**Table 7**
Classification of water quality in the Konin canals in 2004-2005

| | EK canal | | | | WG canal | |
|---|---|---|---|---|---|---|
| | 2004 | | 2005 | | 2005 | |
| Indices | value | class | value | class | value | class |
| Shannon-Weaver diversity index* | 2.29 | $II^{1,2}$ | 2.13 | $II^{1,2}$ | 1.86 | $II^{1}/III^{2}$ |
| Own modification** | 2.35 | $II^{1,2}$ | 2.55 | $II^{1,2}$ | 2.03 | $II^{1,2}$ |
| Saprobic index* | 1.90 | $II^{2,3,4}$ | 1.94 | $II^{2,3,4}$ | 1.94 | $II^{2,3,4}$ |
| Trophy index*** | 3.24 | | 3.24 | | 3.46 | |
| | 0.44 | $III^{5}$ | 0.44 | $III^{5}$ | 0.39 | $IV^{5}$ |
| Algal genus pollution index | 32-36 | $III^{6}$ | 21-36 | $III^{6}$ | 20-33 | $III^{6}$ |

Codes of EK and WG are given in Tab. 4
*based on taxa number, mean seasonal value
**own modification – Shannon-Weaver diversity index based on taxa biomass, mean seasonal value
***Trophy index (IT) – the component of IFPL, expressed as the actual value and normalized value
[1]according to Wilhm (1975)
[2] according to Yap (1997)
[3]according to Czech standards (Rolauffs et al. 2004)
[4]according to Hungarian standards (Imre 2004)
[5]according to Picińska-Fałtynowicz, Błachuta (2011)
[6]according to Palmer et al. (1977)

phytoplankton dynamics were observed also in the Licheńskie and Ślesińskie lake systems (Napiórkowska-Krzebietke 2009), which, according to the model developed by the Plankton Ecology Group (PEG), is typical in eutrophic lakes in the temperate zone (Sommer et al. 1986, Kawecka and Eloranta 1994). However, both of the maximums in the Warta-Gopło canal were similar. In June a tendency toward the formation of a third peak was noted, but it was approximately 40% smaller than the maximums noted in spring and autumn, and was analogous to that noted previously by Galicka (1994) and Galicka and Lesiak (1996) in the Warta River.

Diversity was also noted in the structure of developing phytoplankton communities in the canals studied. Dominant or co-dominant diatoms throughout the vegetation season in the EK canal could be linked to the lotic character of this environment. Further evidence of this is the intense development of species of the genera *Cyclotella*, *Stephanodiscus*, and *Aulacoseira*, which occur abundantly in rivers such as the Warta and in reservoirs located on the Płociczno and Drawa rivers (Galicka and Lesiak 1996, Gołdyn and Szeląg-Wasielewska 2004, Szeląg-Wasielewska 2004). Diatoms are also the principle component of algal biomass in rivers on other continents, for example, near Chesapeake Bay in the USA (Marshall and Burchardt 2004). The totally different planktonic algae structure in the WG canal, which included, among others, the mass development of cyanobacteria in September 2005, could be linked to the lower water flow rate than that in the EK canal as well as to the formation of lentic water zones. This phenomenon was observed in 1999-2002 by Kraszewski and Zdanowski (2007). Additionally, long-term (1995-2010) studies of the waters in both of the canals indicate that resources of nitrogen and phosphorus are higher in the WG canal than in the EK canal when temperatures are similarly low (Pyka et al. 2013). Surface runoff from agricultural lands in the immediate vicinity of the WG canal could have contributed to higher nutrient resources in it (Socha and Zdanowski 2001). The waters of the Warta River in the area where the WG canal is located and which supply it directly, were characterized by high loads of nutrients, especially total phosphorous, and they were determined to be unclassified waters in 1996-2000 (Socha and Zdanowski 2001). However, the status of this river in 2001 according to the seston saprobity index permitted classifying them as class III (Żelazowski et al. 2004), while still remaining under heavy anthropogenic pressure (Szeląg-Wasielewska 2004).

One of the disturbing aspects of the mass development of the cyanobacteria *Microcystis aeruginosa* and *Aphanizomenon flos-aquae* in late summer in the Warta-Gopło canal is that its waters flow into the entire lakes system and the Konin canals. The biomass of these plankton species was approximately 7.0 mg $dm^{-3}$, and according to Nebaeus (1984), any biomass exceeding 3.0 mg $dm^{-3}$, is the threshold of water blooms. The occurrence of these species was also noted in lakes Licheńskie and Ślesińskie, but at substantially lower abundances (Napiórkowska-Krzebietke 2009). Water blooms of cyanobacteria, mainly of the genera *Microcystis* and *Aphanizomenon*, which formed maximums of approximately 30.0 mg $dm^{-3}$, have often been observed in the Jeziorsko drinking-water reservoir located on the Warta River (Galicka and Lesiak 1996, Galicka and Kruk 1999). The problem of cyanobacteria blooms has also affected other dam reservoirs including the Sulejów, Włocławek, Siemianówka, Goczałkowice, Dobczyce, and Brody Iłżeckie reservoirs (Górniak and Grabowska 1996, Kabziński et al. 2000, Bucka et al. 2003, Prus et al. 2007).

The dissimilarity of the algal communities of the EK and WG canals was determined by the larger share of dinoflagellates in the total biomass and the larger number of *Chlorophyta* and *Bacillariophyceae* taxa in the planktonic algae community in the former canal in comparison to the latter. Very frequent components of the phytoplankton in both canals included, among others, *Scenedesmus quadricauda* (Turp.) Bréb. sensu Chod., *S. acuminatus* (Lagerh.) Chod., and *Pediastrum boryanum*. These species were in the highest frequency of occurrence classes IV and V in the chlorophyte communities in the Warta River (Sitkowska and Dukowska 1999).

Cluster analysis confirmed that the spring and autumn planktonic algae communities were fairly similar in both canals in 2005, but that such similarity among summer communities was noted in different years of the study. The abundance and composition of the planktonic algae formed under varied conditions with different amounts of nutrients in the waters of the two canals (Pyka et al. 2013). The abundant freshwater clams inhabiting the bottom of the WG canal could also have had a substantial impact (Kraszewski and Zdanowski 2007), and, according to Hwang et al. (2004), these organisms can more effectively control the development of algae than zooplankton pressure can. Additionally, cluster analysis confirmed greater similarity between the phytoplankton communities in the EK canal and Lake Ślesińskie than that between the two canals.

Water quality assessments in the canals based on the different indexes were ambiguous. According to Wilhm (1975), the classification based on the Shannon-Weaver index indicated that in both canals the water was moderately polluted; this was analogous to the values of the index in lakes Licheńskie and Ślesińskie (Napiórkowska-Krzebietke 2009). However, the classification proposed by Yap (1997), which takes more classes into consideration, identified the waters of the EK canal to be of good quality, while those in the WG canal were slightly polluted. Whereas, the modification of this system permitted classifying the waters in the two canals as class II at good quality. The assessment of the ecological potential in accordance with the Water Framework Directive (2000/60/EC), which was performed with only the IT module of the multimetric phytoplankton index (Picińska-Fałtynowicz and Błachuta 2011) also produced differentiated results. The water in the EK canal was assessed to be at a moderate ecological potential, while that of the WG canal, with its higher content of nitrogen and phosphorous, was assessed to be at a poor ecological potential. Because of the closeness of the IT values (0.44 and 0.39) to the threshold value of 0.40 and the uncertainty of the assessment, the waters in the two canals could be similarly classified to class III if it were possible to asses these waters using both of the modules of the IFPL index. According to Hutorowicz et al. (2011), the most certain assessment is obtained when the values of the metrics based on the phytoplankton biomass are close to the mid range of a given class, and that the least certain assessments are obtained when the values do not differ much from the threshold values of the classes.

A high degree of consistency in water quality assessment in terms of organic pollution in the two canals was obtained with the saprobic system (class II) using three classification methods. According to Yap (1997), these waters can be classified as moderately polluted. The guidelines for Czech (Rolauffs et al. 2004) and Hungarian (Imre 2004) standards permitted classifying these waters accordingly as in a good biological state and of good quality. The algal genus pollution index (Palmer et al. 1997) was the most rigorous assessment, and the results of it were also the least similar to those of the other methods. According to this index, the waters of both canals were assigned to the class with high amounts of organic pollution.

Most of the indexes applied in this study are based on the abundance of all species (Shannon-Weaver index), the abundance and indicative values of indicator species (saprobity index), or only on the occurrence of representative of 20 indicator genera (algal genus pollution index). Only the IT index takes into consideration biomass and the indicative values of indicator taxa. Comparing the application of these indexes, water quality assessments based on the Shannon-Weaver and IT indexes best reflect certain phytoplankton diversity dynamics in the two canals.

The classification based on the Shannon-Weaver index proposed by Yap (1997), and which is modified to take into consideration values calculated from the biomass of all taxa, fully assesses the status of these artificial canals. Analogously, this index was found to be the best indicator of the water quality in the lakes and canals system of the Mae Moh Power Plant in Thailand (Junshum et al. 2008). However, the high degree of consistency in water quality assessments performed with the saprobic system also permits recommending this method for assessments. In summation, the high degree of similarity of the assessments performed with the Shannon-Weaver and saprobity indexes is evidence that supports proposing a multimetric system for assessing the ecological status or potential of smaller rivers and streams, including artificial canals, based on phytoplankton and taking into consideration these two indexes. The most appropriate classification system for the first index is that proposed by Yap (1997), while for the second index this would be the Czech standards (Rolauffs et al. 2004), both of which are based on a five-degree scale.

## Conclusions

The phytoplankton dynamics in the two canals are characteristic of basins with fairly high trophic status. The phytoplankton abundance and composition in the Warta-Gopło canal remain linked to the development of communities in both rivers and reservoirs located near their courses. Strict similarity can be seen, among other periods, during blooms of the cyanobacteria *Microcystis aeruginosa* and *Aphanizomenon flos-aquae*. The phytoplankton communities in the Konin system were strictly similar, especially between the EK canal and Lake Ślesińskie. Water quality assessment based on various indexes and classification systems was ambiguous. Consistent assessment was obtained based on the saprobic system, which indicated that the waters in both canals had moderate organic pollution, while they were simultaneously in good biological status. The most rigorous assessment method was the algal genus index pollution, which indicated that the canal waters had high levels of organic pollution. Based on the Shannon-Weaver and the IT indexes, the EK canal water was classified as of good quality but at a moderate ecological potential, while the WG canal water was slightly polluted and in a poor ecological potential, which reflected certain diversity in the phytoplankton structure. Implementing the modification to the classification system based on the Shannon-Weaver index permitted classifying similarly the waters of the two canals and analogously to that based on the saprobity index, i.e., to class II. Based on these, it was confirmed that it is possible to perform a consistent, five-degree classification. Using both the Shannon-Weaver and saprobity indexes based on phytoplankton for the multimetric assessment of the ecological status or potential of smaller rivers and streams, including artificial canals, is proposed as an alternative to the authorized assessment method based only on phytobenthos.

**Acknowledgments**. The material for this study was collected as a part of Inland Fisheries Institute statutory research project no. S-009. I would like to thank the reviewers for their valuable criticisms and helpful comments.

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