BACTERIAL CONTAMINATION IN THE WATERS OF TWO LAKE AND RIVER SYSTEMS IN NE POLAND IN RELATION TO THE PHYSICOCHEMICAL PROPERTIES OF WATER

A. Pietryczuk[1], A. Cudowski[1*]

[1]Department of Hydrobiology, Institute of Biology, University of Bialystok, Ciolkowskiego 1J, 15-245 Bialystok (Poland), *e-mail: cudad@uwb.edu.pl

Abstract

Determination of the sanitary-epidemiological status of waters used for tourism purposes is very important, hence the aim of this research was to determine the sanitary status of various types of surface water used for recreation. The research area included 18 stands on the Ostróda-Elbląg Canal and 25 on the Augustów Canal. Water samples were taken during the summer period in 2017-2018. Microbiological analyses were performed in accordance with PN-EN ISO standards and included determining the total abundance of such bacteria as *E. coli*, coliforms, fecal enterococci and *P. aeruginosa*. In addition, basic physicochemical analyses of water were performed according to standard methods. The presence of indicator bacteria in the water indicates their fecal contamination and possible epidemiological threat. The general average abundance of bacteria for the waters of the Augustów Canal was 1,628,000±784,000 CFU/mL, while for the Ostróda-Elbląg Canal 2,242,800±964,300 CFU/mL. The abundance of *E. coli* bacteria in the waters ranged from 0 CFU/100mL to 6400 CFU/100mL, coliforms from 0 CFU/100mL to 7,200 CFU/ 100mL, fecal enterococci from 0 to 5,800 CFU/100mL. The maximum values of these indicators were recorded in lakes. The *P. aeruginosa* bacteria were isolated only from waters from an artificial section of the river-lake systems, and their abundance fluctuated in the 120-860 CFU/100mL range. Statistical analyses have shown that the abundance of indicator bacteria depends on some physicochemical parameters of water, such as: EC, pH, temperature, total carbon concentration, total nitrogen concentration. Summing up, it can be concluded that the highest values of the abundance of indicator bacteria occurred in lakes. The river sections were characterized by higher values of an abundance of coliforms and *E. coli* bacteria and the total abundance of bacteria compared to canal waters, which indicates a fresh inflow of pollutants to the tested systems. In turn, the canal sections were the only habitat of *P. aeruginosa*.

Key words: Augustów Canal, Ostróda-Elbląg Canal, total abundance of bacteria, indicator bacteria, water quality

Introduction

Microorganisms may occur as natural (autochtonous) microflora of water or allochthonous microflora, coming from other sources. Allochthonous bacteria are not usually able to reproduce in an aquatic environment and occur in a resting state in water (Cabral 2010). Bacteria play an important role in biogeochemical processes in water, e.g. in carbon and nitrogen cycles, and in maintaining water quality thanks to their involvement in the biodegradation of pollutants produced by households, industry and agriculture. However, although autochthonous bacteria are indispensable for aquatic ecosystems and help maintain water quality (Wetzel 2001, Briée et al. 2007, Newton et al. 2011), allochthonous bacteria – entering rivers and lakes with industrial waste-water and surface runoff (Kundzewicz et al. 2010), human and animal excrement (Ihejirika et al. 2011), and heavy rainfall (Vignesh et al. 2013) – may pose serious sanitary and epidemiological problems. Transported over long distances in water, they may pose a serious threat to public health (Marcheggiani et al. 2015); hence, monitoring bacterial contamination is of immense importance, especially in those water bodies which are used by people for recreational purposes. In addition, the results of monitoring may be used to further our understanding of local water ecosystems, in particular the role of microorganisms.

The aim of this study was to determine the sanitary status of the Augustów and Ostróda-Elbląg Canals, as examples of alternately located lake and river ecosystems characterized by continuous transport, exchange and accumulation of matter, as well as transport and exchange of microorganisms (Hillbicht-Ilkowska and Wiśniewski 1996). Additionally, the aim of the study was also to compare the river, lake, and artificial sections of the canals in terms of the total abundance of bacteria (including indicator bacteria), as well as selected physicochemical parameters.

Materials and methods

Field studies

The research area included 18 sites located on the Ostróda-Elbląg Canal and 25 sites on the Augustów Canal, in north-eastern Poland. The canals were selected because they include artificial sections (including locks) and natural lake and river ecosystems. Water samples were collected during the summer seasons in relatively similar weather conditions (e.g not after extreme events such as storms or torrential rains that could temporarily and significantly affect the levels of the studied parameters) in 2017-2018. Samples for microbiological and chemical analyses were taken using a Limnos extractor at the depth of 0.5 m. The samples were transported to the laboratory in glass bottles (1L) in a refrigerator with a temperature of 4°C (PN-EN ISO 19458, PN-ISO 5667-5:2003). The following water parameters were measured on site with the HQD 9200 from Hach Lange: electrolytic conductivity, water temperature, and pH.

Laboratory tests

Total organic carbon (TOC) and total nitrogen (TN) were determined in non-filtered water subject to high-temperature catalytic oxidation in Shimadzu's TOC-5050A analyzer.

The total abundance of bacteria expressed in colony forming units per milliliter of water (CFU/mL) was determined by filter incubation on a nutrient agar (PN-EN ISO 6222). The determination of indicator bacteria was carried out by filter incubation on a suitable selective medium with the use of biochemical confirmation tests according to the following standards: PN-EN ISO 9308-1:2004+Ap1:2005+AC:2009 for *Escherichia coli* and coliforms, PN-EN ISO 7899-2: 2004 for fecal enterococci and PN-EN ISO 16266: 2004 for *Pseudomonas aeruginosa.*

Statistical analyses

The results were subjected to statistical analysis using Statistica v. 13.3 software. The Kruskal-Wallis test was used to estimate the difference between means. The significance of correlations was estimated by Pearson's coefficient. Differences were considered as statistically significant at $p<0.05$.

Results

The electrolytic conductivity (EC) of the Augustów Canal waters ranged from 266 (±13.3) µS/cm in Studzieniczne Lake to 498 (±23.9) µS/cm in the Piecówka River. In comparison, the waters of the Ostróda-Elbląg Canal were characterized by EC ranging from 210 (±8.4) µS/cm (Pauzeńskie Lake) to 699(±34.9) µS/cm (section between the towns of Elbląg and Nowakowo) (Table 1). The water pH in the Augustów Canal was in the range of 7.12 (±0.35) – 8.31 (±0.27), while in the Ostróda-Elbląg Canal it ranged from 7.23 (±3.82) to 8.07 (±0.40) (Table 1). Water temperature in the Augustów Canal ranged from 14.8 (±0.75) ºC (section in the town of Augustów) to 22.8 (±0.91) ºC (Lake Mikaszewo). The waters of the Ostróda-Elbląg Canal were characterized by higher temperatures: from 21.4 (±0.53) ºC in the Iława Canal to 26.7 (±0.53) ºC in the Liksajny Canal (Table 1). Total organic carbon (TOC) in the waters of the Augustów Canal ranged from 6.81 (±0.34) mgC/L in Białe Augustowskie Lake to 18.14 (±0.90) mgC/L in Białe Augustowskie Lake, whereas total nitrogen (TN) ranged from 654 (±32.04) µgN/L in the Piecówka River to 1311 (±65.55) µgN/L in the Kamienny Bród River. TOC concentration in the waters of the Ostróda-Elbląg Canal was higher and oscillated between 15.83 (±0.79) mgC/L (Sambród Lake) and 54.32 (±2.66) mgC/L (Dręstwo Lock). The waters of the Ostróda-Elbląg Canal were also characterized by a high TN range of 894 (±26.82) – 3976 (±178.92) µgN/L (Table 1).

Table. 1. Physicochemical characteristics of waters of the river-lake system of the Augustów Canal and the Ostróda-Elbląg Canal (mean value ± SD, n = 4)

parameter / position	EC [µS/cm]	pH	Temperature of water [°C]	The concentration of total organic carbon (TOC) [mgC/L]	The concentration of total nitrogen (TN) [µgN/L]
Augustów Canal					
Dębowo Lock	410 (±18.4)	7.88 (±0.39)	19.2 (±0.67)	8.88 (±0.26)	666 (±26.64)
Sosnowo Lock	422 (±11.1)	7.69 (±0.38)	17.4 (±0.87)	12.67 (±0.63)	678 (±18.98)
Białobrzegi Canal	381 (±19.5)	7.94 (±0.23)	19.2 (±0.96)	8.56 (±0.35)	1,087 (±54.35)
Augustów Canal	398 (±17.9)	7.89 (±0.15)	14.8 (±0.75)	12.98 (±0.64)	1,190 (±59.50)
Przewięź Lock	275 (±13.7)	8.13 (±0.16)	19.7 (±0.98)	7.65 (±0.38)	605 (±18.15)
Gorczyca Lock	281 (±14.6)	8.05 (±0.28)	20.1 (±0.96)	9.11 (±0.35)	711 (±22.75)
Paniewo Lock	285 (±13.2)	8.01 (±0.40)	22.4 (±1.12)	12.22 (±0.61)	811 (±32.44)
Mikaszówka Lock	282 (±10.1)	7.77 (±0.31)	19.8 (±0.99)	7.32 (±0.21)	775 (±38.75)
Sosnówek Lock	296 (±12.8)	7.12 (±0.35)	18.4 (±0.92)	7.87 (±0.39)	961 (±48.05)
Tartak Lock	384 (±18.2)	7.42 (±0.17)	17.9 (±0.89)	9.12 (±0.44)	899 (±44.95)
Kudrynki Lock	388 (±19.4)	7.71 (±0.38)	18.2 (±0.70)	8.44 (±0.42)	768 (±28.41)
Netta River	402 (±13.1)	7.66 (±0.36)	18.4 (±0.92)	9.82 (±0.39)	980 (±36.26)
Kamienny Bród River	400 (±20.1)	8.12 (±0.29)	14.8 (±0.74)	10.14 (±0.50)	1,311 (±65.55)
Rospuda River	466 (±23.3)	7.88 (±0.27)	16.9 (±0.47)	7.88 (±0.27)	1,115 (±55.75)
Serwianka River	270 (±9.5)	7.99 (±0.39)	21.3 (±1.06)	7.01 (±0.35)	1,085 (±54.25)
Czarna Hańcza River	400 (±16.6)	7.70 (±0.38)	17.9 (±0.80)	9.23 (±0.25)	887 (±39.91)
Piecówka River	498 (±23.9)	7.69 (±0.20)	15.4 (±0.77)	18.14 (±0.90)	654 (±32.04)
Necko Lake	414 (±18.7)	8.13 (±0.40)	20.8 (±0.81)	9.99 (±0.49)	1,245 (±62.25)

parameter / position	EC [µS/cm]	pH	Temperature of water [°C]	The concentration of total organic carbon (TOC) [mgC/L]	The concentration of total nitrogen (TN) [µgN/L]
Sajno Lake	389 (±15.4)	8.09 (±0.36)	22.3 (±1.11)	12.7 (±0.44)	987 (±49.35)
Rospuda Lake	430 (±11.5)	8.20 (±0.41)	22.2 (±0.62)	13.4 (±0.67)	1,344 (±67.20)
Białe Augustowskie Lake	269 (±12.0)	7.91 (±0.39)	16.5 (±0.49)	6.81 (±0.34)	954 (±47.70)
Studzieniczne Lake	266 (±13.3)	8.11 (±0.34)	20.2 (±1.01)	9.09 (±0.18)	1,111 (±33.33)
Orle Lake	332 (±14.6)	8.31 (±0.27)	19.6 (±0.39)	11.99 (±0.35)	1,145 (±28.62)
Paniewo Lake	280 (±14.1)	8.20 (±0.17)	20.1 (±0.80)	11.04 (±0.55)	1,288 (±57.96)
Mikaszewo Lake	241 (±8.5)	8.31 (±0.41)	22.8 (±0.91)	10.03 (±0.50)	1,376 (±45.40)
Ostróda-Elbląg Canal					
Elbląg-Nowakowo Canal	699 (±34.9)	7.52 (±0.15)	24.6 (±1.23)	19.42 (±0.97)	1,233 (±34.52)
Elbląg Canal	662 (±33.1)	7.40 (±0.37)	25.3 (±1.26)	19.03 (±0.95)	894 (±26.82)
Canal before Buczyniec	568 (±28.4)	7.32 (±0.23)	23.2 (±0.69)	24.45 (±1.22)	1665 (±59.94)
Awajki Canal	433 (±17.32)	7.31 (±3.99)	22.8 (±1.14)	22.98 (±0.68)	1,436 (±71.80)
Małdyty Canal	411 (±20.55)	7.23 (±3.82)	23.9 (±1.19)	22.87 (±1.14)	1459 (±72.95)
Liksajny Canal	391 (±19.55)	8.00 (±0.40)	26.7 (±0.53)	18.98 (±0.94)	1,221 (±54.94)
Miłomłyn Canal, ul. Kościelna	439 (±21.9)	7.60 (±0.25)	23.3 (±1.16)	19.23 (±0.61)	923 (±26.76)
Miłomłyn Canal, ul. Pasłęcka	377 (±9.4)	7.61 (±0.26)	21.8 (±0.80)	19.88 (±0.99)	889 (±43.56)
Iława Canal	398 (±11.9)	7.44 (±0.37)	21.4 (±0.53)	21.19 (±1.05)	967 (±48.35)
Zielona Lock	420 (±21.0)	7.32 (±0.36)	24.2 (±1.21)	23.45 (±0.65)	1,178 (±58.90)
Dręstwo Lock	244 (±7.8)	7.50 (±0.29)	23.1 (±1.03)	54.32 (±2.66)	1345 (±48.42)
Ruś Mała Lock	339 (±16.9)	7.88 (±0.33)	22.9 (±0.91)	18.91 (±0.66)	986 (±34.51)
Sambród Lake	402 (±19.2)	7.42 (±0.37)	27.8 (±1.11)	15.83 (±0.79)	3336 (±166.80)

parameter / position	EC [µS/cm]	pH	Temperature of water [°C]	The concentration of total organic carbon (TOC) [mgC/L]	The concentration of total nitrogen (TN) [µgN/L]
Ruda Woda Lake	404 (±20.2)	7.30 (±0.36)	26.6 (±0.93)	24.56 (±1.22)	1,681 (±84.05)
Ilińsk Lake	409 (±8.1)	7.59 (±0.25)	25.3 (±1.21)	22.9 (±0.45)	1,811 (±48.89)
Dręstwo Lake	392 (±16.0)	7.80 (±0.15)	25.9 (±1.29)	22.4 (±1.12)	1456 (±40.768
Pauzeńskie Lake	210 (±8.4)	7.55 (±0.30)	24.8 (±1.24)	28.6 (±0.85)	3,976 (±178.92)
Szeląg Wielki Lake	306 (±11.6)	8.07 (±0.40)	22.7 (±1.13)	21.8 (±1.09)	1,288 (±51.52)

The total bacterioplankton abundance in the waters of the Augustów Canal was the lowest in Białe Augustowskie Lake – 143,666 (±37,554) CFU/mL, and the highest in the Canal's section in the town of Augustów– 2,976,667 (±643,920) CFU/mL (Fig. 1).

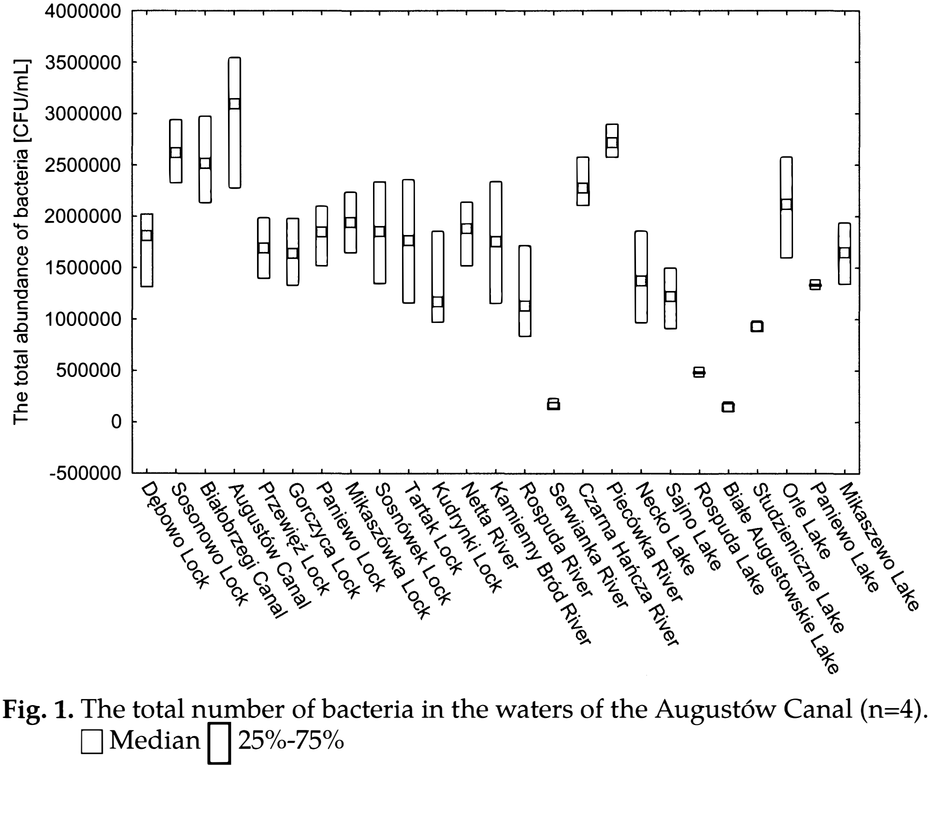

Fig. 1. The total number of bacteria in the waters of the Augustów Canal (n=4).
□ Median ▯ 25%-75%

The total abundance of bacteria in the waters of the Ostróda-Elbląg Canal ranged from 1,163,663 (±615 006) CFU/mL (the section in Miłomłyn at Pasłęcka Street) to 3,376,667(±290,229) CFU/mL (Dręstwo Lock) (Fig. 2). The abundance of coliforms and *E. coli* was the lowest in artificial sections of the canal – on average 1,012 (±666) CFU/100mL for coliforms and 523 (±276) CFU/100mL for *E. coli.* The highest abundance of coliforms and *E. coli* were recorded in lake ecosystems: 4,519 (±2,123) CFU/100mL and 3,631 (±2,121) CFU/100mL, respectively (Figure 3). The mean abundance of fecal enterococci was the lowest in artificial canal sections (465 (±2,12 CFU/100mL) and the highest in lake waters (4,350 (±1,317) CFU/100mL) (Figure 4). The presence of *P. aeruginosa* was recorded only in the artificial canal sections – on average 414 (±207) CFU/100mL (Fig. 4).

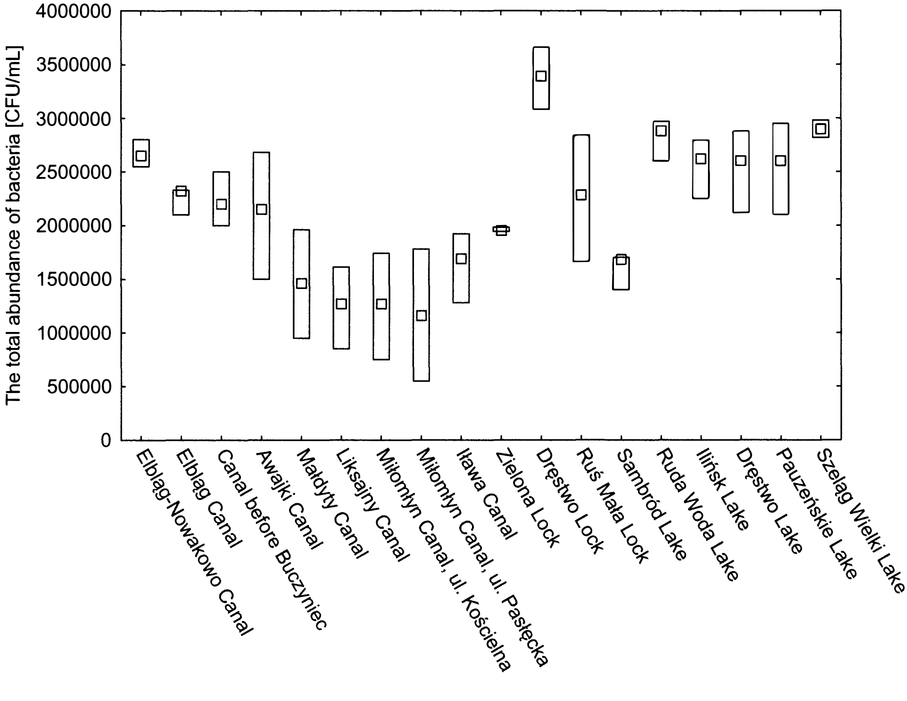

Fig. 2. Total number of bacteria in the waters of the Ostróda-Elbląg Canal (n=4). □ Median ▯ 25%-75%

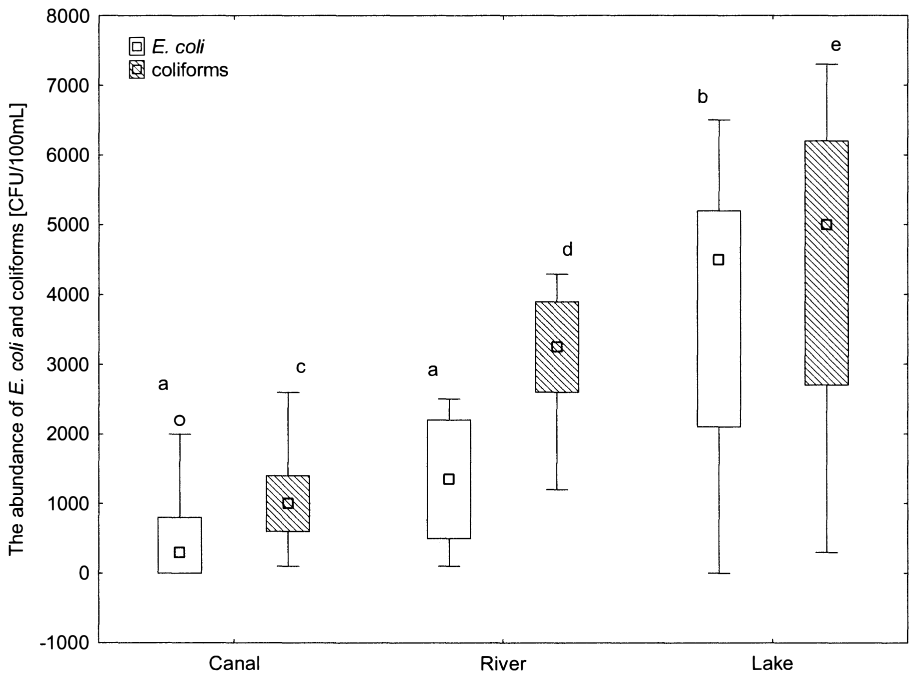

Fig. 3. The abundance of *E. coli* and coliforms in different types of waters of the river-lake system of the Augustów Canal and the Ostróda-Elbląg Canal.

□ Median ▯ 25%-75% I the range of non-rising values º- outliers

The same letters over a series of data mean that there are no statistically significant differences between them, while different letters mean statistically significant differences between the data (p<0,05).

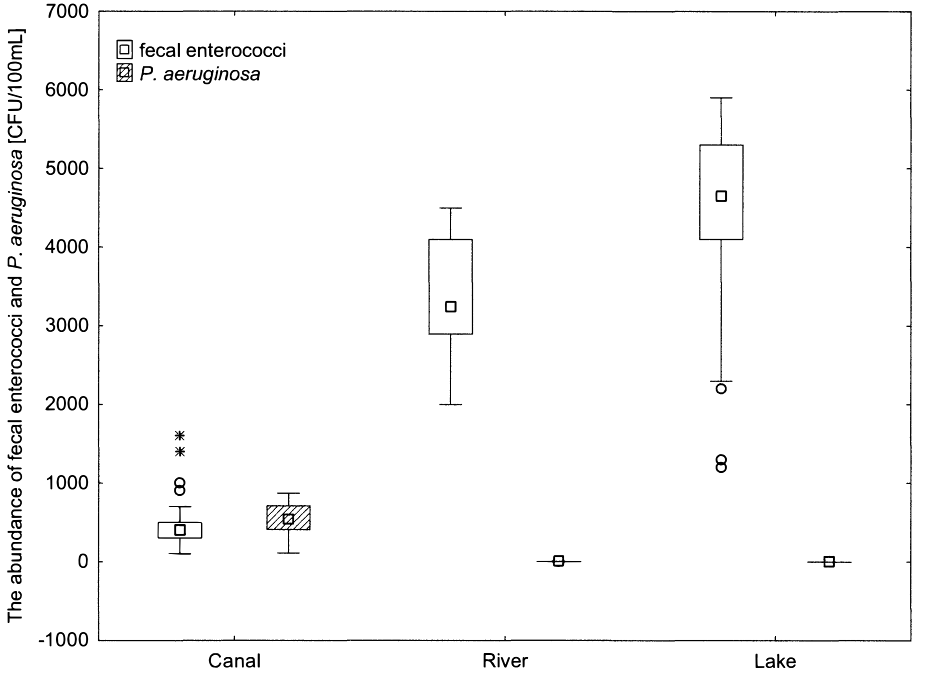

Fig. 4. The abundance of fecal enterococci and *P. aeruginosa* in different types of waters of the river-lake system of the Augustów Canal and the Ostróda-Elbląg Canal.

□ Median ▯ 25%-75% Ⅰ the range of non-rising values º outliers
* extreme values

The same letters over a series of data mean that there are no statistically significant differences between them, while different letters mean statistically significant differences between the data (p<0,05).

Discussion

In our study, the waters of the Ostróda-Elbląg Canal had a much higher total abundance of bacteria than the Augustów Canal. This difference may be attributed to the presence of poorly accessible moorlands and rushes near the Ostróda-Elbląg Canal, which serve as shelters and breeding grounds for multiple species. In addition, the Canal includes a waterway popular among tourists (Furgała-Selezniow et al. 2006); waters flowing through areas of intensive human use are particularly vulnerable to bacteriological contamination (Adewoye 2010). Finally, the Ostróda-Elbląg Canal flows mainly through urban and agricultural areas, which increases the risk of bacteriological contamination due to increased exposure to waste and run-off from the fields. All this contributes to increased microbiological contamination, additionally confirmed by elevated EC, total organic carbon, and total nitrogen.

The average abundance of coliforms and *Escherichia coli* was higher in the waters of the Ostróda-Elbląg Canal than in the waters of the Augustów Canal. The highest levels were recorded in lakes, probably due to the intensive use of these waters by people during the holiday season and discharge of sewage, as well as the run-off of fertilizers from fields (Hoyer et al. 2006, McLellan et al. 2007, Bradshaw et al. 2016). In general, the increased abundance of bacteria in lakes may be related by their constant supply by the rivers flowing into them. Finally, a significant factor is the presence of numerous bird species (Fogarty et al. 2003) – both the Augustów Canal and the Ostróda-Elbląg Canal are the habitats of many birds. The lowest abundance of coliforms and *E. coli* were recorded in artificial canal sections, especially those located at the beginning of the canal. Similar results were obtained by Barakat et al. (2013), who analyzed channels in the city of Beni-Mellal (Morocco). This indicates that the gradual deterioration of canal water status is most strongly influenced by human activity in the canal's catchment area, such as discharges from local sewage treatment plants and surface run-off from adjacent areas, especially urban agglomerations (Augustów, Elbląg, Ostróda).

A very important indicator of microbiological water pollution are fecal enterococci, which are a sign – in contrast to *E. coli* – of contamination distant in time (Anderson et al. 2005, Byappanahalli et al. 2012). The average abundance of enterococci was higher in the waters of the Ostróda-Elbląg Canal than in the waters of the Augustów Canal. Similarly to the coliforms and *E. coli*, the highest abundance of these bacteria were recorded in lakes, followed by rivers and artificial canal sections. Many species of fecal enterococci can be found in the sand on the beach and on aquatic plants (Boehm and Sassoubre 2014). Moreover, it has been shown that biogenic compounds are carried to lakes along with tributaries, which causes deterioration of water quality in flow lakes (Biedka and Wawrentowicz 2011). Along with rivers and watercourses flowing into lakes, bacteria can also get, hence the strong domination of fecal enterococci, into lake ecosystems. Enterococci are also abundant in animal feces (Layton et al. 2010), and since the rivers feeding the Augustów Canal flow through agricultural areas where animals graze, a higher abundance of these bacteria was recorded in river sections, compared to the artificial sections of the investigated canals. Another species of bacteria treated as an indicator of fecal water pollution is *P. aeruginosa*, present in soil, water, sewage, feces of warm-blooded animals, and on plants, from which they enter surface waters during rainfall (Niewolak and Opieka 2000). These bacteria can be found in increased amounts in rivers near urban areas (Mena and Gerba 2009). In our study, *P. aeruginosa* was found only in artificial canal sections, which confirms that the main source of these bacteria is water coming from urban areas.

Our study showed that the total bacterioplankton abundance and the occurrence of indicator bacteria depended on the physicochemical properties of waters. Water temperature is a particularly important parameter, as it modifies metabolic processes in the cells of microorganisms, thus regulating their abundance. The most sensitive to changes in water temperature are mesophilic bacteria because they are allochthonous organisms and water is not their natural habitat (Chomutowska 2009). In our study, an increase in water temperature correlated with a decrease in the abundance of *Escherichia coli* (r^2 = -0.69, $p<0.05$) and coliforms (r^2 = -0.71, $p<0.05$). In contrast, a positive correlation with water temperature was observed for *P. aeruginosa* (r^2 = 0.64, $p< 0.05$). These results are in line with observations that *Escherichia coli* survive in cooler water environment for longer than in the waters with higher temperatures that occur in late summer (Sampson et al. 2006).

The electrolytic conductivity value (EC) is an indicator of the amount of ions reaching water reservoirs (Suchowolec and Górniak 2006). High EC values indicate high chemical pollution of water. In our study, sites with high bacterial abundance were also characterized by high EC (r^2 = 0.72, $p<0.05$). EC also positively and statistically significantly correlated with the occurrence of *P. aeruginosa* (r^2 = 0.67, $p<0.05$). Another important factor determining the occurrence of indicator bacteria is water pH, with a slightly alkaline environment being optimal for aquatic bacteria (Chomutowska 2009, Augustynowicz et al. 2015). This was confirmed by a positive correlation between the abundance of coliforms (r^2 = 0.62, $p<0.05$) and the abundance of *E. coli* (r^2 = 0.78, $p<0.05$) and the pH of water in our study. However, no statistically significant correlation was observed between pH and total bacterioplankton abundance, probably due to the fact that many species of bacteria prefer water with lower pH (Starliper et al. 2015).

Total nitrogen (TN) and total organic carbon (TOC) are also important parameters determining the structure of bacterioplankton, which is an important component of the microbiological loop and actively participates in the decomposition of organic matter (Siuda and Chróst 2002). A large abundance of bacteria in water indicates an increased content of organic compounds in the water (Chomutowska 2009). Not surprisingly, our study showed that in waters with increased TOC concentrations there was a higher total abundance of bacteria (r^2 = 0.56, $p<0.05$) and P. *aeruginosa* (r^2 = 0.61, $p<0.05$). The Dręstwo Lock on the Ostróda-Elbląg Canal and the Piecówka River flowing into the Augustów Canal were characterized by the highest TOC concentrations. In the case of the Piecówka River, this may have been due to the run-off of water from agricultural lands along the river. It was also shown that TN concentrations in water positively correlated with the abundance of *E. coli* (r^2 = 0.64, $p<0.05$), coliforms, and fecal enterococci (r^2 = 0.69, $p<0.05$). The lakes of the Ostróda-Elbląg Canal were characterized by the highest concentrations of total nitrogen and total organic carbon in water. These compounds enter lake waters mainly as a result of sewage discharges and fertiliser run-off from farmlands (Hijosa-Valsero et al. 2016). As heterotrophic bacterioplankton can use them for its own metabolic needs (Zehr et al. 2002), it comes as no surprise that the abundance of bacteria was also highest in the lakes of the Ostróda-Elbląg Canal.

Conclusions

Our results showed that the Ostróda-Elbląg Canal was characterized by a much higher microbiological contamination in comparison to the river and lake system of the Augustów Canal, which is related to the higher fertility of its waters, as evidenced by the increased values of EC, total nitrogen, and total organic carbon. The highest values of total bacterial count and indicator bacterial count were recorded in lakes. River sections were characterized by a higher abundance of total bacterioplankton, coliforms, *E. coli* and fecal enterococci in comparison to the artificial sections of the canals, with the lowest microbiological contamination recorded in the initial sections of both canals. Moreover, *P. aeruginosa* was found only in the artificial sections, which indicates that its main sources were discharge from local sewage treatment plants and surface run-off from adjacent areas, especially from urban agglomerations.

References

1. Adewoye, S. O. (2010) Effects of detergent effluent discharges on the aspect of water quality of ASA River, Ilorin, Nigeria. Agriculture and Biology Journal of North America, 1(4):731–36.
2. Anderson, K.L., Whitlock, J.E., Harwood, V.J. (2005) Persistence and Differential Survival of Fecal Indicator Bacteria in Subtropical Waters and Sediments. Appl. Environ. Microb., 71(6): 3041-48.
3. Augustynowicz, J., Nierebiński, M., Zawada, M., Zielonka, D., Russel, S. (2015) The impact of basic physicochemical parameters on microbiological water quality on a selected section of the Vistula. Woda – Środowisko - Obszary Wiejskie, 15(1): 5–15 (in Polish).
4. Barakat, A., Baghdadi, M.E., Meddah, R., Rais, J., Nadem, S., Afdali, M. (2013) Evaluation of water quality in open channels flowing through Beni-Mellal City (Morocco). Journal of Water and Land Development, 19: 3–11.
5. Biedka, P., Wawrentowicz, D. (2011) The role of tributaries in shaping the quality of the lakes of the Suwałki-Augustów Lake District. Inżynieria Ekologiczna, 26: 7-17 (in Polish).
6. Boehm, A.B., Sassoubre, L.M. Enterococci as Indicators of environmental fecal contamination. [In:] Gilmore, M.S., Clewell, D.B., Ike, Y., et al., (eds.) Enterococci: From commensals to leading causes of drug resistant infection [Internet]. Boston: Massachusetts Eye and Ear Infirmary, 2014: pp. 1-21.
7. Briée, C., Moreira, D., López-García, P. (2007) Archaeal and bacterial community composition of sediment and plankton from a suboxic freshwater pond. Res. Microb., 158(3): 213-27.
8. Bradshaw, J.K., Snyder, B.J., Oladeinde, A., Spidle, D., Berrang, M. E., Meinersmann, R. J, Oakley, B., Sidle, R. C., Sullivan, K., Molina, M. (2016) Characterizing relationships among fecal indicator bacteria, microbial source tracking markers, and associated waterborne pathogen occurrence in stream water and sediments in a mixed land use watershed. Water Res., 101: 498-509.
9. Byappanahalli, M.N., Nevers, M.B., Korajkic A., Staley, Z.R., Harwood V.J. (2012) Enterococci in the Environment. Microbiol. Mol. Biol. Rev., 76(4): 685–706.

10. Cabral, J. P. S. (2010) Water microbiology. Bacterial pathogens and water. Int. J. Environ. Res. Public Health, 7: 3657-703.
11. Chomutowska, H. (2009) The influence of selected physicochemical factors on the Rospuda river's bacterioplankton. Ochrona środowiska i Zasobów Naturalnych, 40: 513-523 (in Polish).
12. Fogarty, L.R., Haack, S.K., Wolcott, M.J., Whitman, R.L. (2003) Abundance and characteristics of the recreational water quality indicator bacteria *Escherichia coli* and enterococci in gull faeces. J. Appl. Microb., 93(5): 865–878.
13. Furgała-Selezniow, G., Turkowski, K., Nowak, A., Skrzypczak, A., Mamcarz, A. (2006) The Ostroda-Elblag Canal in Poland: The Past and Future for Water Tourism. [In:] Hall, C.M., Härkönen T. (eds) Lake Tourism. An integrated approach to lacustrine tourism system, Chris Cooper (University of Queensland, Australia), 2006: pp. 131-148.
14. Hijosa-Valsero, M., Bécares, E., Fernández-Aláez, C., Fernández-Aláez, M., Mayo, R., Jiménez, J.J. (2016) Chemical pollution in inland shallow lakes in the Mediterranean region (NW Spain): PAHs, insecticides and herbicides in water and sediments. Scienc. Total Environ., 544: 797-810.
15. Hillbricht-Ilkowska, A., Wiśniewski, R. J. (1996) The functioning of river - lake systems in the post-lake landscape: the Krutynia River (Mazury Lake District). Zeszyty Naukowe Komitetu „Człowiek i Środowisko", 13: 1–461. (in Polish).
16. Hoyer, M.V., Donze, J.L., Schulz, E.J., Willis, D.J., Canfield, D.E. (2006) Total coliform and *Escherichia coli* Counts in 99 Florida Lakes with Relations to Some Common Limnological Factors. Lake and Reservoir Management ,22(2):141-50.
17. Ihejirika, C.E., Ogbulie, J.N., Nwabueze, R.N., Orji, J.C., Ihejirika, O.C., Adieze, I.E., Azubike, O.C., Ibe I.J. (2011) Seasonal influences on the distribution of bacterial pathogens and waterborne diseases transmission potentials of Imo river, Nigeria. J. Res. Biol., 1 (3): 163-72.
18. Kundzewicz, Z. W., Zalewski, M., Kędziora, A., Pierzgalski, E. (2010) Risks associated with water. Nauka, 4: 87-96 (in Polish).
19. Layton, B.A., Walters, S.P., Lam, L.H., Boehm, A.B. (2010) Enterococcus species distribution among human and animal hosts using multiplex PCR. J. Appl. Microbiol., 109(2): 539–74.
20. Marcheggiani, S., D'Ugo, E., Puccinelli, C., Giuseppetti, R., D'Angelo, A.M., Gualerzi, C.O., Spurio, R., Medlin, L.K., Guillebault, D., Weigel, W., Helmi, K., Mancini, L. (2015) Detection of emerging and re-emerging pathogens in surface waters close to an urban area. Int. J. Environ. Res. and Public Health, 12 (5): 5505-27.
21. McLellan, S.L., Hollis E.J., Depas M.M., Van Dyke, M., Harris, J., Scopel, C.O. (2007) Distribution and fate of *Escherichia coli* in Lake Michigan following contamination with urban stormwater and combined sewer overflows. Journal of Great Lakes Research, 33(3): 566-80.
22. Mena, K.D., Gerba, Ch.P. (2009) Risk assessment of *Pseudomonas aeruginosa* in water. Rev. Environ. Contamin. Toxicol., 201:71-115.
23. Newton, R.J., Stuart, E.J., Eiler, A., McMahon, K. D., Bertisson, S. (2011) A guide to the natural history of freshwater lake bacteria. Microbiol. Mol. Biol. Rev., 75: 14–49.
24. Niewolak, S., Opieka, A. (2000) Potentially pathogenic microorganisms in water and bottom sediments in the Czarna Hańcza River. Pol. J.Environ.Stud., 9 (3): 183-94.

25. Sampson, R.W., Swiatnicki, S.A., Osinga, V.L., Supita, J.L., McDermott, C.M., Kleinheinz, G.T. (2006) Effects of temperature and sand on E. coil survival in a northern lake water microcosm. Journal of Water and Health, 4(3): 389-93.
26. Siuda, W, Chrust, R. J. (2002) Decomposition and utilization of particulate organic matter by bacteria in lakes of different trophic status. Pol. J. Environ. Stud, 11: 53-65.
27. Starliper, C.E., Watten, B.J., Iwanowicz, D.D., Green, P.A., Bassett, N.L, Adams, C.R. (2015) Efficacy of pH elevation as a bactericidal strategy for treating ballast water of freight carriers. J. Advanc. Res., 6: 501–509.
28. Suchowolec, T., Górniak, A. (2006) Seasonality of water quality in small retention reservoirs in the Podlasie agricultural landscape. Woda – Środowisko – Obszary Wiejskie, 6(2): 347–58 (in Polish).
29. Vignesh, S., Muthukumar, K., Santhosh Gokul, M., James, R.A. (2013) Microbial pollution indicators in the Cauvery River, Southern India. [In:] On a sustainable future of the earth's natural resources. Springer Earth System Sciences, 20: 364-76.
30. Wetzel, R. G. Bacterioplankton. Limnology: Lake and River Ecosystems, 3rd ed. New York: Academic Press, 2001: pp. 489–525.
31. Zehr, J.Z., Ward, B.B. (2002) Nitrogen cycling in the ocean: New perspectives on processes and paradigms. Appl. Environ. Microb., 68(3): 1015-24.

Zdigitalizowano i udostępniono w ramach projektu pn.
Rozbudowa otwartych zasobów naukowych Repozytorium Uniwersytetu w Białymstoku – kontynuacja,
dofinansowanego z programu „Społeczna odpowiedzialność nauki" Ministra Edukacji i Nauki
na podstawie umowy BIBL/SP/0040/2023/01