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ABUNDANCE, PRODUCTION AND RESPIRATION OF BACTERIONEUSTON AND BACTERIOPLANKTON IN THE COASTAL LAKE DOŁGIE WIELKIE

Marta Zdanowicz, Zbigniew Jan Mudryk

Department of Experimental Biology,
Institute of Biology and Environmental Protection,
Pomeranian University in Słupsk,
Arciszewskiego 22b, 76-200 Słupsk, Poland
e-mail: marta.zdanowicz@apsl.edu.pl

Abstract

The paper presents the results of the study of abundance, production and respiration in surface layers and subsurface water in the coastal lake Dołgie Wielkie. Indicate that the total numbers of neustonic bacteria were higher than planktonic bacteria. The level of production and respiration rate were higher in the subsurface water than in surface layers. Bacterial abundance, production and respiration rate were changing with seasons.

Key words: coastal lake, surface layers, subsurface water, bacterial abundance, bacterial production, bacterial respiration

INTRODUCTION

The surface microlayer is the boundary layer between the atmosphere and the hydrosphere covering 70% of the earth's surface, where the transfer of material is controlled by complex physicochemical and biological processes (Wurl and Obbard 2004, Reinthaler et al. 2008). The surface microlayer is the thin (30 to 300 μm) layer representing unique physical, chemical and biological environment, completely different from the underlying parts of the water (Agogué et al. 2005). This unique ecosystem is an important boundary, as an area of exchange of matter and energy that both affects and is affected by global change (Saramento et al. 2015, Wurl et al. 2016). The surface microlayer is constantly exposed to such factors as wind, rain and undulation, which disintegrate its structure. For this reason, it undergoes dynamic changes both in time and space (Cunliffe et al. 2011, Perliński et al. 2017). How-

ever, according to Cunliffe et al. (2011), the surface layer has ability to reconstitute quickly on its own and to return to its original structure. Many mechanism, such as: adsorption, diffusion, flotation, convection, precipitation, air bubbles which cause accumulation of many types of various inorganic and organic particulate and dissolved compounds, can be observed in this air – water interface (Antonowicz et al. 2015). As well of a high concentration of inorganic and organic matter occurring in the surface microlayer many aquatic organisms find optimal conditions for growth in such a biotope. The surface microlayer represents an extreme environment for living organisms, but it is generally enriched in bacteria, microalgae, yeasts, molds and protists (Joux et al. 2006).

The bacteria, mainly heterotrophic organisms, play the key role in regulating accumulation, export, re-mineralization and transformation of the largest part of organic matter in the aquatic ecosystems (Bigg et al. 2004, Momzikoff et al. 2004). These processes include microbiological biotransformation of dissolved (DOM) and particulate (POM) organic matter of auto- and allochthonous origin. In water bodies, heterotrophic bacteria are able to decompose a wide spectrum of organic material from natural and anthropogenic origins, whose molecules differ in size (from monomers to polymers) (Agogué et al. 2005). For heterotrophic bacteria those compounds constitute a very important source of carbon, nitrogen and energy and are used for biosynthesis or respiration processes (Joux et al. 2006).

The heterotrophic bacteria play a central role in the organic matter and energy flux through water food webs. These organisms produce new bacterial biomass by incorporating a part of dissolved organic matter (DOM) (bacterial secondary production, BP) and they respire organic matter to inorganic compounds (bacterial respiration, BR) (del Giorgio and Cole 1998).The relative importance of bacterial pro-duction (BP) versus bacterial respiration (BR) is expressed by the bacterial growth efficiency (BGE). This parameter integrates various aspects of bacterial metabolism (Pradeep Ram et al. 2003).

The aim of the present paper was to determine spatial and seasonal dynamics of the changes in the abundance, production and respiration of bacteria in the surface layers and subsurface water in the coastal lake Dołgie Wielkie.

MATERIALS AND METHODS

Study area and sampling

The study has been carried out in the freshwater coastal lake Dołgie Wielkie which is a part of the World Biosphere Reserve (the Slovinski National Park) (Table 1). The lake has water area of 156.4 hectare with mean depth of 1.4 m. It's located within a typical forest catchment basin which makes a natural protection zone of this water body. Lake Dołgie Wielkie is a basin that shows an advanced natural eutrophication process. It is characterized by variable physical and chemical parameters which stand in close connection with its near – marine location. Lake Dołgie Wielkie was a bay of Gardno Lake, but some time ago (about 300 years ago) it separated and became an isolated non – estuarine lake.

Water samples were taken in 2006 quarterly (in spring, summer and autumn) at three sites placed in eastern (St. 1), northern (St. 2) and western (St. 3) part of the lake (Fig. 1). At each site, three layers of water were tested. Samples from the film layer (FL, thickness of 90 μm) were taken on a glass plate (Harvey and Burzell 1972), while samples of surface layer (SL) (thickness of 240 μm) were collected with Garrett net (Garrett 1965).

Table 1

Some chemical parameters of Lake Dołgie Wielkie according to Antonowicz et al. (2010)

Parameter in water	Unit of measure	Mean (SD)
N-T	mg dm^{-3}	0.77 (0.09)
N-org	mg dm^{-3}	0.69 (0.09)
$N\text{-}NH_4$	μg dm^{-3}	78.75 (11.85)
P-T	μg dm^{-3}	123.3 (36.53)
P-org	μg dm^{-3}	47.08 (30.53)
$P\text{-}PO_4$	μg dm^{-3}	76.21 (11.48)
Electrical conductivity	mS	0.089 (0.002)
Cl	mg dm^{-3}	15.86 (0.51)
O_2	mg dm^{-3}	9.22 (1.99)

Probes from subsurface water (SUB) were taken at the depth of about 10-15 cm. All water samples were placed in sterile glass bottles and stored in an ice – box at a temperature lower than 7°C. The time between the sampling and the analysis usually did not exceed 6-8 hours. From film layer and surface layer were isolated neustonic bacteria and from subsurface water – planktonic bacteria.

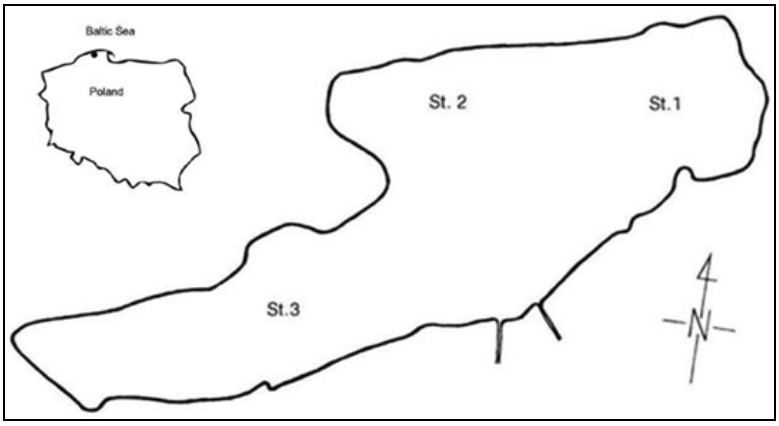

Fig. 1. Lake Dołgie Wielkie, northern Poland, with location of sampling sites
Geographic coordinates of lake Dołgie Wielkie 54°41'29.25" – 54°42'11.10"N, 17°10'13.10" – 17°12'34.18"E

Determination of bacterial parameters

Measurement of total bacterial number
The total bacterial number (TBN) was measured after staining with DAPI (4,6-diamidino-2-phenylindole) (Porter and Feig 1980). Aliquots of 10 cm^3 were preserved with formaldehyde at final concentration of 1%. Water samples (10 cm^3) were filtrated through black polycarbonate membrane filtres (Millipore) (0.2 μm pore size, 12 mm diameter). The filters were mounted on microscopic slides. Counting was performed at 600x magnification using OLYMPUS BX-41 epifluorescence microscope coupled with a Colour View III camera. Bacteria were counted manually in 20 different fields. Bacterial abundance per 1 cm^3 water was calculated according to a formula by Zimmermann and Meyer-Reil (1974).

Measurement of bacterial production
The production of bacteria (BP) in the water samples was determined by measuring the rate of incorporation of [methyl-[^{3}H] thymidine ([^{3}H]TdR) into the bacterial DNA (Simon and Azam 1989). In order to determine this parameter, 0.02 cm^3[^{3}H]TdR (NEN Life Science Products 60 Ci/nmol specific activity) was added to 10 cm^3 water samples in three replications with final concentration of 20 nM. Samples were incubated for 30 min. at 20°C. After this period, the incubation was stopped by adding 0.2 cm^3 of 37% formaldehyde to the samples. A prekilled samples was used as a blank. Samples were filtered with a Millipore sampling manifold on to 0.2 μm nitrate cellulose filters (Sartorius) (25 mm diameter). Filters were rinsed twice with 5 cm^3 10% ice-cold TCA and then dissolved in 1 cm^3 of ethyl acetate before counting and placed in scintillation vials (Packard) with 10 cm^3 LCS-cocktail (Packard). After the incubation the samples were radioassayed in a Packard TRI-CARB 2100TR liquid scintillation counter. The calculation of bacterial production was based on the thymidine incorporation (TdR) using a conversion factor $1.25 \cdot 10^9$ cells $\cdot$ nM^{-1} thymidine (Chróst et al. 1988).

Measurement of bacterial respiration
In order to determine the rate of bacterial respiration oxygen uptake was measured with Clark's electrode (Rank Brothers Ltd. Model 10) (Konopka and Zakharova 1999). Water samples were filtrated through filters of nitrocellulose (Millipore) (0.8 μm pore size, 47 mm diameter). After calibration of the Clark's electrode, 1.5 cm^3 of the water samples was put into the respiratory chamber. Changes in voltage on the electrode were recorded by an analogue recorder XY Line Record TZ 5000 and analysed by computer program BS81x-BS51x Data Recording System Ver 3.3.0.5. The number of measurements was set at 72, taken every 50 seconds. During the measurements, the Clark's electrode was connected to a flow stabilizer of temperature, which ensured thermal stability in the respiratory chamber. The oxygen uptake was converted into μl $O_2 \cdot h^{-1}$ per bacteria inhabiting water of the lake.
Oxygen consumption rates was converted to bacterial carbon units using a respiratory quotient RQ = 1.0 (del Giorgio and Cole 1998). The relative importance of bacterial production (BP) versus bacterial respiration (BR) was expressed by the bacterial

growth efficiency (BGE = BP/BP + BR). Production per bacterium was defined as the ratio of bacterial production (PB) to bacterial abundance (TBN) (P/B = BP/TBN) (del Giorgio and Cole 1998).

Statistical analysis

All statistical analysis (Spearman's rank correlation coefficient, linear regression, standard deviation – SD, coefficient of variation – CV) were calculated using Statistica 9.0 software. The normal distribution of the data was checked by using the Shapiro–Wilk test before statistical analysis. Relationships among parameters within the whole data set were examined using Spearman rank correlation. Linear regression analysis was used to analyse correlation between studied parameters. A value of $p < 0.05$ was defined as indicating a significant difference. The significance of differences between layers, sites and seasons in bacterial abundance, production and respiration rate was assessed using two-way ANOVA of variance and Kruskal–Wallis non-parametric equivalent of ANOVA, when mean values revealed a distribution other than normal.

RESULTS

The total bacterial number (TBN) in surface layers (FL, SL) and subsurface water (SUB) in the coastal lake Dołgie Wielkie are given in Table 2. The maximum values of TBN ($2.45 \cdot 10^9$ cell $\cdot$ dm^{-3}) were noted in FL, SL. The lowest total number of bacteria was determined in the subsurface water (SUB) ($1.86 \cdot 10^9$ cell $\cdot$ dm^{-3}). The seasonal changes of the total number of bacteria in surface layers (FL, SL) and subsurface water (SUB) are presented in Fig. 2. In all the studied water layers maximum values of TBN were determined in summer ($2.58 \cdot 10^9$ cell $\cdot$ dm^{-3}) and minimum were noted in spring ($2.02 \cdot 10^9$ cell $\cdot$ dm^{-3}).

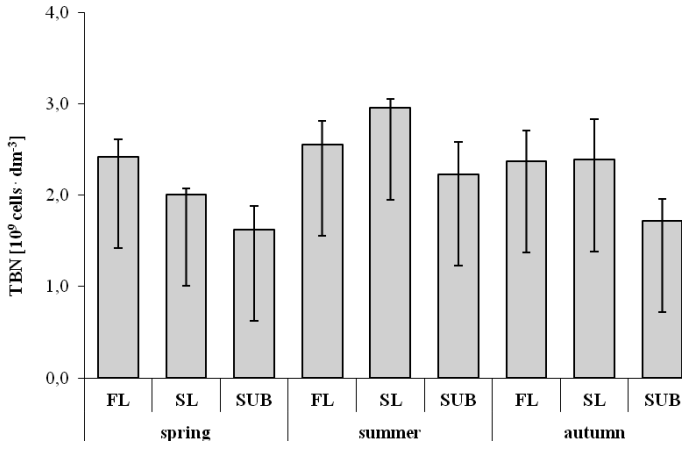

Fig. 2. Seasonal changes of the total bacterial number (TBN) in the film layer (FL), surface layer (SL) and subsurface water (SUB). Vertical bars represent standard deviation (SD)

Table 2

Total bacteria number (TBN), bacterial production (BP), bacterial respiration (BR), bacterial growth efficiency (BGE) and production per bacterium (BP/TBN) in different water layers in coastal lake Dołgie Wielkie

Layer	Statistic parameters	TBN [10^9 cells · dm^{-3}]	BP [µg C · dm^{-3} · h^{-1}]	BR [µg C · dm^{-3} · h^{-1}]	BGE [%]	BP/TBN [fg C · $cell^{-1}$ · h^{-1}]
FL	mean	2.45	12.52	31.60	25.96	5.41
	min	2.02	0.57	10.73	3.04	0.25
	max	2.72	29.98	54.41	50.04	14.84
	SD	0.25	9.98	13.23	14.84	4.88
	CV(%)	10.14	79.69	41.88	57.14	90.26
SL	mean	2.45	13.79	28.79	34.39	5.70
	min	1.94	2.94	5.50	5.41	1.41
	max	3.03	33.71	63.39	63.03	16.29
	SD	0.47	10.02	16.96	18.33	4.58
	CV(%)	19.26	72.64	58.90	53.31	80.37
SUB	mean	1.86	54.71	39.02	56.96	31.66
	min	1.33	10.54	10.11	24.20	5.90
	max	2.58	86.90	76.58	86.26	62.07
	SD	0.38	26.03	20.88	20.58	18.27
	CV(%)	20.21	47.58	53.53	36.13	57.70

Statistical tests (SD – standard deviation, CV – coefficient of variation)

In the coastal lake Dołgie Wielkie the bacterial production (BP) varied from 12.52 to 54.71 µg C ·dm^{-3} ·h^{-1} and the bacterial respiration (BR) varied from 28.79 to 39.02 µg C · dm^{-3} · h^{-1} (Table 2).The maximum values of BP (54.71 µg C · dm^{-3} · h^{-1}) and BR (39.02 µg C · dm^{-3} · h^{-1}) were noted in the subsurface water, the lowest bacterial production (BP) (12.52 µg C · dm^{-3} · h^{-1}) was determined in the film layer and the lowest bacterial respiration (BR) (28.79 µg C · dm^{-3} · h^{-1}) was noted in the surface layer. Average bacterial growth efficiency (BGE) changed in the range of 25.96 to 56.96% (Table 2). The highest rates of BGE in coastal lake Dołgie Wielkie were noted in the subsurface water, minimum values of this parameter were noted in the film layer.

The seasonal changes of the bacterial production (BP), bacterial respiration (BR) and bacterial growth efficiency (BGE) in surface layers (FL, SL) and subsurface water (SUB) are given in Fig. 3. From these data show that in all seasons maximum values of BP were determined in the subsurface water (SUB). In spring, the maximum values of BR were noted in surface layer (SL) (26.08 µg C · dm^{-3} · h^{-1}), in summer (44.82 µg C · dm^{-3} · h^{-1}) and in autumn (47.87µg C · dm^{-3} · h^{-1}) in subsurface water (SUB). The rate of BGE in the water of the coastal lake Dołgie Wielkie varied from 20.70 to 77.88% in spring, from 26.66 to 47.15% in summer and from 26.10 to 46.35% in autumn.

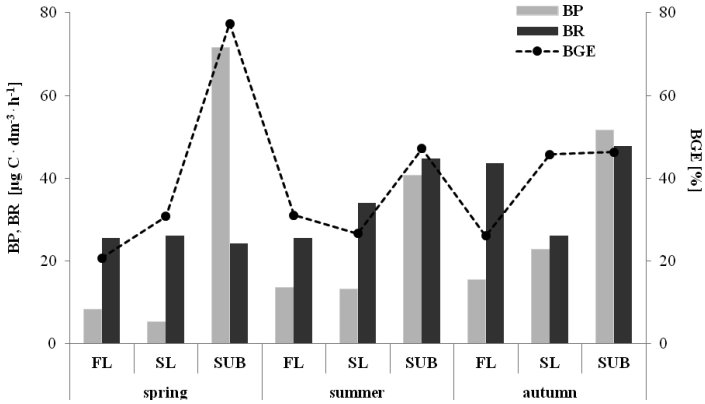

Fig. 3. Seasonal changes of the bacterial production (BP), bacterial respiration (BR) and bacterial growth efficiency (BGE) in the film layer (FL), surface layer (SL) and subsurface water (SUB)

The statistical analysis of the data from the water samples was performed to find the relations among bacterial abundance, production and respiration rate in coastal lake Dołgie Wielkie. The relations between the studied bacteriological parameters is given in the correlation table (Table 3). The bacterial production (BP) was positively and highly correlated with bacterial growth efficiency ($r = 0.83$; $p \leq 0.001$). Negative correlations with lower significance ($p \leq 0.01$) were observed between the total bacterial number (TBN) and bacterial production (BP) ($r = -0.51$), between the total bacterial number (TBN) and bacterial growth efficiency (BGE) ($r = -0.55$).

Table 3

Relationships between bacterial abundance (TBN), bacterial production (BP), bacterial respiration (BR) and bacterial growth efficiency (BGE)

Nonparametric Spearman's correlation coefficients in dataset			
	TBN	BP	BR
BP	-0.51**	-	-
BR	-0.10**	0.24***	-
BGE	-0.55**	0,83***	-0.20

n = 27 in all cases. Significance (p) is indicated by asterisks: * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

Correlations and linear regressions were carried out considering all observations in order to determine the relationship between the total bacterial number (TBN) and bacterial production (BP) (Fig. 4). Linear regression shows that in the coastal lake Dołgie Wielkie in all studied water layers, seasons and sites the TBN was negatively and significantly ($R^2 = 0.378$; $p \leq 0.001$) correlated with the BP. Further from linear regression was found relations between the bacterial growth efficiency (BGE) and

bacterial production (BP) (Fig. 5). The BGE was positively and significantly ($R^2 = 0.653$; $p \leq 0.001$) correlated with the BP.

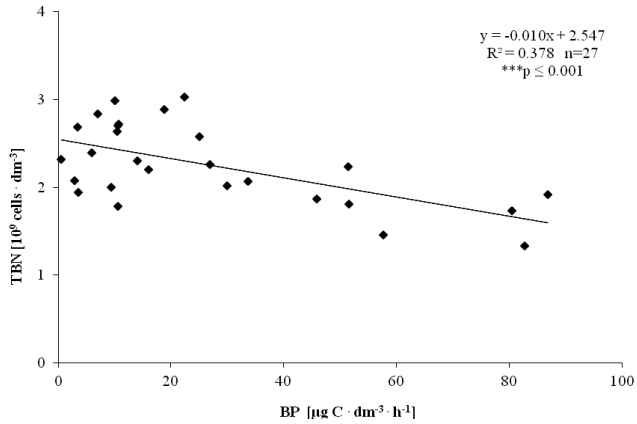

Fig. 4. Relationships between the total bacterial number (TBN) and bacterial production (BP). Solid line represents linear regression including all data (y – regression equation, R^2 – coefficient of determination, n – number of samples, p – significance level)

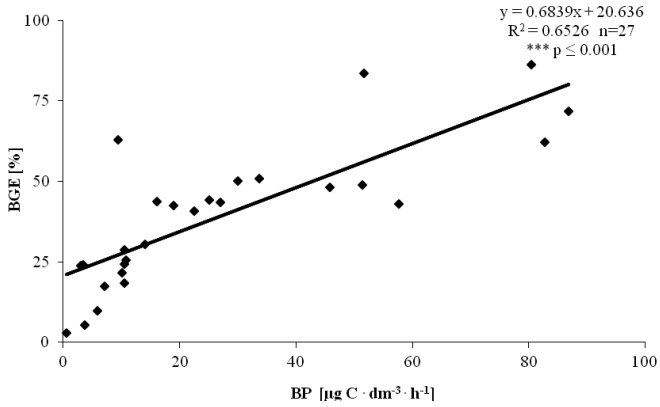

Fig. 5. Relationships between bacterial growth efficiency (BGE) and bacterial production (BP). Solid line represents linear regression including all data (y – regression equation, R^2 – coefficient of determination, n – number of samples, p – significance level)

By grouping the results by seasons, layers and sites the two-way ANOVA test and the Kruskal–Wallis non-parametric test was carried out for the bacterial abundance, bacterial production and bacterial respiration (Table 4). The analyses showed significant differences for the bacterial abundance (TBN) among layers and seasons using two-way ANOVA. The bacterial production (BP) rates were found to be significantly different between layers using the Kruskal–Wallis non-parametric test. The analyses showed no significant differences for the bacterial respiration (BR) rates among grouped data using two-way ANOVA.

Table 4

Analyses of two-way-ANOVA of variance and the Kruskal–Wallis test in the bacterial abundance (TBN), bacterial production (BP) and bacterial respiration (BR) due to layer, season and site

Source of variation	TBN		BP		BR	
	F	p	H	p	F	p
Layer	7.36	**	12.78	**	0.84	ns
Season	4.67	*	1.10	ns	1.61	ns
Site	0.04	ns	4.99	ns	0.19	ns
Layer × season	6.87	***	17.26	*	0.94	ns
Layer × site	1.97	ns	18.89	*	0.82	ns
Season × site	1.01	ns	6.90	ns	0.76	ns

TBN and BR – the two-way ANOVA test; BP – the Kruskal–Wallis non-parametric test
Explanations:
F – Fisher test, H – the Kruskal–Wallis test, p – significance level, ns – non significant
Significance (p) is indicated by asterisks: * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$

DISCUSSION

In all water ecosystems are present bacteria and their quantitative and qualitative distribution is characteristic of each reservoir. The availability of nutrients is generated mainly in the primary production process and is one of the most important factors, which have an affect on the abundance of bacteria. The abundance and distribution of microorganisms in water bodies is always a result of the interaction of abiotic and biotic factors and is constantly undergoing major or minor oscillations (Walczak and Donderski 2005, Joux et al. 2006).

Results of studies on the total bacteria number (TBN) of the neustonic and planktonic bacteria in coastal Lake Dołgie Wielkie showed that this parameter achieved higher values in the surface layers (FL, SL) than in the subsurface water (SUB). Similar results of the bacterial abundance were reported by other authors in freshwater basins (Kalwasińska and Donderski 2005, Walczak and Donderski 2005), in estuaries (Mudryk et al. 1999, Mudryk and Skórczewski 2007) and marine waters (Bigg et al. 2004, Aller et al. 2005, Joux et al. 2006). The primary stimulator of the high number of bacteria in the surface layers are secretions which coming mainly from phyto-and zooneuston (Wurl and Obbard 2004). These excretions contain mainly organic compounds such as proteins, carbohydrates and lipids and they are actively used by neustonic bacteria as a food materials and energy source (Antonowicz et al. 2015, Perliński et al. 2017). The higher total abundance of bacteria in surface layers is also due to the presence in these neustonic organisms of extracellular structures containing hydrophobic compounds (mucopolysaccharides, glycoproteins, phosphocholine and lecithin polymers) facilitating adhesion to surface waters (Walczak and Donderski 2005, Mudryk and Skórczewski 2007). Also, the motile bacteria can move and change the biotope from the deeper water parts to the surface layers by way of chemotaxis or flotation on the surface of gas bubbles (Wurl and Obbard 2004, Cunliffe et al. 2011). Another good stimulating factor for

the high abundance of bacteria in the surface water layers is good oxygenation. Direct contact of the surface layer with atmospheric air provides bacteria in this biotope an optimal level of oxygen that penetrates into the layer by simple diffusion (Antonowicz et al. 2015).

Based on the research, it was found that the abundance of bacteria in lake Dołgie Wielkie showed seasonal variability. The maximum total number of bacteria was generally observed in the summer. These regularities are consistent with estuarine and marine waters (Mudryk et al. 1999, Mudryk and Skórczewski 2007, Antonowicz et al. 2015) and freshwater basins (Kalwasińska and Donderski 2005). According to these authors, the main stimulator of the growth of bacteria in the summer is the intensive development of phytoplankton, which released assimilates constitute an optimal and easily assimilable nutrients for bacteria. At the same time, in shallow water basins, which include the coastal lake Dołgie Wielkie, macrophytes grow abundantly in the summer and they can expel more organic matter into the water than phytoplankton, among others low molecular weight compounds, which are immediately used by bacteria as a feed or energy substrate (Mudryk and Skórczewski 2007). Summer maxima of the total number of bacteria present in the examined coastal lake Dołgie Wielkie may also be the effect of relatively high temperatures at this time of year (Mudryk and Skórczewski 2007). According to Meyer-Reil and Köster (1992), temperature as one of the most important environmental factors influences significantly on the abundance of water microorganisms.

A level of bacterial production plays a key role in the functioning of aquatic ecosystems, because it allows to evaluate the amount of organic matter transferred between different trophic links. Research on the level of bacterial production in the surface layers and subsurface water in the coastal lake Dołgie Wielkie showed that the highest level of bacterial production was found in SUB. These results indicate that planktonic bacteria were characterized by higher metabolic activity as a short generation time and high rate of cellular protein synthesis. Previous studies (Maki and Hermansson 1994, Mudryk et al. 1999) have also shown that production of planktonic bacteria is higher than neustonic bacteria. According to Sommaruga et al. (1997) a strong inhibitory effect on bacterial production inhabiting in surface layers may have solar radiation, mainly UV.

There are significant seasonal differences in the level of bacterial production in lake Dołgie Wielkie. In water ecosystems the rate of bacterial growth and production are regulated primarily by temperature. For the reason the temperature largely explains the seasonal dynamics of changes in the level of bacterial production in lake Dołgie Wielkie, which reached its highest level in summer. These data correspond to the results obtained by Shiah et al. (1999), Mudryk and Skórczewski (2007) and Antonowicz et al. (2015) in aquatic basins. An important stimulator of bacterial productivity in the summer can also be released into the water by phytoplankton assimilation. The compounds secreted by phytoplankton are used by bacteria as food and energy substitutes (Gajewski and Chróst 1995).

According to del Giorgio and Cole (1998) the availability of oxygen significantly influences the metabolic processes of heterotrophic bacteria that are a key component of the microbiological loop. The level of respiration activity of bacteria is a very good measure of the intensity of organic matter mineralization in water ecosystems

(del Giorgio and Cole 1998). The rate of bacterial respiration depends mainly on the concentration and structure of the substrate, on the difference of physiological activity and on the enzymatic activity of these organisms (González et al. 2003, Skórczewski and Mudryk 2008).

The studies of bacterial respiration activity in different water layers in lake Dołgie Wielkie Lake showed that the respiration of planktonic bacteria was higher than the respiration of neustonic bacteria. According to González et al. (2003) bacterioplankton largely determines the amount of bacterial respiration in water ecosystems.

Small seasonal variations in bacterial respiration rate were observed in the waters of the lake Dołgie Wielkie. The highest level of this respiration process was observed in autumn. These results correspond with data published by Roland and Cole (1999), who showed the highest levels of respiration in early autumn, explaining higher levels of respiration at this time of year by the distribution of plant remains remaining after vegetation.

Oscillations of BGE coefficient depend on the concentration and composition of organic matter in the aquatic ecosystem (Obernosterer et al. 2005). It was found that this coefficient was higher in the subsurface water (SUB) than in the surface layers (FL, SL). This regularity results from a higher level of bacterioplankton production and respiration than neustonic bacteria. A similar value of BGE was obtained by Biddanda et al. (1994), Roland and Cole (1999), Smith and Kemp (2003). The level of BGE is subject to changes related to the type and availability of organic substrates (del Giorgio and Cole 1998). However, according to Smith and Kemp (2003), not only organic substrates regulate the level of BGE but the interactions between substrates and environmental factors too.

The above considerations give the ground to formulate the following conclusion:

- The total numbers of neustonic bacteria were higher than planktonic bacteria.
- The level of production and respiration rate were higher in the subsurface water than in surface layers.
- Bacterial abundance, production and respiration rate were changing with seasons.

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LICZEBNOŚĆ BAKTERII, PRODUKCJA BAKTERYJNA I POZIOM ODDYCHANIA W WARSTWIE FILMU, WARSTWIE BŁONY POWIERZCHNIOWEJ I W WODZIE PODPOWIERZCHNIOWEJ PRZEBRZEŻNEGO JEZIORA DOŁGIE WIELKIE

Streszczenie

W warstwach powierzchniowych i podpowierzchniowych jeziora Dołgie Wielkie badano liczebność, produkcję i poziom aktywności oddechowej bakterioneustonu i bakterioplanktonu. Uzyskane wyniki badań wykazały, że ogólna liczebność bakterii neustonowych była wyższa niż planktonowych. Poziom produkcji bakteryjnej i tempo procesów oddechowych były wyższe w wodzie podpowierzchniowej niż w warstwach powierzchniowych. W jeziorze Dołgie Wielkie stwierdzono dynamikę zmian sezonowych ogólnej liczebności bakterii i ich produktywności.