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THE SEASONAL DYNAMICS OF ORGANIC MATTER REMINERALIZATION BY BACTERIAL CONSORTIA IN THE HEATED KONIN LAKES

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ABSTRACT. In the course of a three-year study, analyses were carried out into primary production and bacterial production, as well as into total and bacterial destruction in the Konin lakes. Investigations demonstrated a significant correlation between the dynamics of microbiological processes and the seasonal variability of mineral and organic forms of nitrogen and phosphorus. The analysis of the chemical and microbiological composition of the lake waters indicates that in the fall-winter seasons, microbiological regeneration processes of the mineral forms of nutrients predominate in these waters. Under favorable thermal and oxygen conditions, heterotrophic bacteria and numerous chemolithotrophs completely decompose organic matter to the mineral level. This is reflected in the DOC decrease and, simultaneously, in the considerable increase in orthophosphates and nitrates. In the spring season, the high accumulation of nutrient compounds stimulates high primary production. The resulting substantial increase in DOC concentration determines the high productivity of bacteriocenosis, which activates a highly efficient microbiological trophic chain, thus contributing to the rapid decomposition of organic matter. Intensive processes of the microbiological decomposition and biotransformation of organic matter, which are dependent on thermal air currents and on water retention, with the simultaneously effective transfer of organic carbon to the higher trophic levels, are crucial factors that affect the homeostasis of the ecosystem of the Konin lakes.

Key words: BACTERIOPLANKTON, HEATED WATER, LAKE, POLLUTION

INTRODUCTION

In the heated Konin lakes, just as in “natural” reservoirs, a key function in the production of the basic pool of organic matter is performed by the primary production of phytoplankton (Socha 1994, 1997). The high temperature and very low water retention in the Konin lakes, resulting from technological processes, reduce the efficiency of grazing chains typical of lake ecosystems (Zdanowski 1994). For this reason, a considerable part of the organic matter accumulated in algae is transferred into

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alternative trophic pathways, mainly microbiological ones (Świątecki 1994, 1997). According to several authors, intravital assimilates released by algae may constitute up to 50% of the primary production (Søndergaard et al. 2000, Rosenstock and Simon 2001). Algae cell autolysis can also be a remarkable source of organic matter easily available to bacteria (Agusti et al. 1998). Microbiological processes of organic matter mineralization have been extensively discussed in the scientific literature; yet, based as it is on current knowledge, it is only able to provide a general outline of these phenomena. Current studies mainly focus on elucidating the metabolic capacity of bacteria for the utilization of particular forms of organic compounds. Bacteria that participate in processes of organic matter decomposition, constitute a highly diversified ecological group that includes both chemolithotrophic and heterotrophic bacteria (Donderski 1983, Świątecki 1997). Gradual decomposition of substrates by specialized groups of microorganisms enables complete regeneration of nutrient compounds. The rate of microbiological processes, determined by a variety of environmental factors, has been the subject of many papers (Simon and Tilzer 1987). Many authors have concentrated on the very rapid response of microbiocenoses to both stimulating and limiting factors. The concept of ecosystemic regulation, elaborated in the mid 1980s, takes into consideration a two-way mechanism of bacteria response to the activity of environmental factors, “bottom up” and “top down” of a trophic pyramid (Muylaert 2003). The availability of nutritional substrates, especially the limiting nutrients of phosphorus and nitrogen, is the major factor affecting the rate of microbiological transformations (Siuda and Güde 1994). Various groups of autotrophic and heterotrophic bacteria competing for nutrients possess specialized enzymes that enable them to acquire nitrogen and phosphorus from organic compounds (Chróst and Rai 1993). The intensity of bacteria proliferation is determined, to a great extent, by various survival strategies. A high level of cellular metabolism is typical of bacteria considered to be the so-called “r-strategists” (Weinbauer and Höfle 1998). The high enzymatic activity of these bacteria, determined mainly by the secretion of exo- and ectohydrolases, enables the very rapid digestion of the molecules of organic polymers (Sinsabaugh et al. 1997). The high metabolic flexibility of the bacteria, linked with the occurrence of a wide variety of constitutive and inductive enzymes, is a specific biochemical strategy that enables effective competition with other microorganisms for the acquisition of valuable nutritional substrates and nutrient elements (Cotner and Wetzel 1991). A number of publications have demonstrated the significant correlation between the rate of bacteria proliferation and the intensity of primary production (Lovell and Konopka 1985). The high metabolic activity of these forms of bacteria enables the rapid utilization and biotransformation of any available organic matter.

Extensive research on the Konin complex, carried out over many years, has indicated that, as a result of intensive exploitation of the lakes, specific biocenotic mechanisms have developed which have efficiently kept the balance of the ecosystem. These observations are the basis of a thesis, formulated in the last decade, which assumes that, despite intensified anthropogenic stress, the trophic state has been maintained at a moderate level (Zdanowski et al. 2002). The aim of the present study was to characterize microbiological processes and elucidate their significance in the generation of a specific ecological balance in the Konin lakes.

MATERIAL AND METHODS

Studies of the Konin lakes were carried out in 1993-1995. Samples to be analyzed were collected from four lakes: Licheńskie, Ślesińskie, Mikorzyńskie, and Gosławskie; and from three canals: the discharge canal of the Konin Power Plant, the discharge canal of the Pątnów Power Plant, and the Licheński canal. Samples were collected from lakes and canals, taking into consideration the seasons of the year and exploitation seasons. The basic microbiological analyses concerned the assessment of the total number of bacteria (BN) and their morphological structure, determined under a fluorescence microscope (DAPI staining; Norland 1993). Generation time and the rate of bacterial production were determined, based on changes in the number and biomass of bacteria in water samples incubated for 24 h. The rate of total destruction (TOC) was determined, based on changes in the amount of oxygen dissolved in water, after 24-h *in situ* incubation of a water sample. Bacterial destruction (BD) was calculated with the oxygen method, in water samples filtered through a membrane filter with a porosity of 1.2 µm. Primary production (PP) was determined based on changes in the oxygen content of water samples incubated *in situ,* with the method of dark and light bottles. Physicochemical parameters (the content of phosphates, organic phosphorus and nitrates) were determined following standard procedures (Hermanowicz et al. 1999).

RESULTS

Analyses of the Konin lakes demonstrated considerable seasonal diversity of individual microbiological, biological, and physicochemical parameters (Table 1).

TABLE 1

Microbiological, biological, and chemical parameters of the Konin lakes

Lake	Number of bacteria (10^6 ml^{-1})			Mean cell volume (mg l^{-1})			Time of multiplication (h)			Bacterial secondary production (mg C_{org} l^{-1} 24h^{-1})		
	avgerage	max	min	avgerage	max	min	avgerage	max	min	avgerage	max	min
Lake Ślesińskie	2.6	5.4	0.6	0.15	0.21	0.11	39.8	86.6	14.1	34.3	50.8	16.6
Lake Licheńskie	3.2	7.5	1.2	0.16	0.20	0.12	40.9	100.0	13.0	56.7	146.3	9.2
Lake Gosławskie	3.3	6.0	0.9	0.15	0.21	0.11	35.5	82.1	12.3	40.8	67.9	12.6
Konin Power Plant canal	3.1	8.2	0.4	0.14	0.21	0.11	17.7	23.7	10.2	51.0	128.4	0.31
Pątnów Power Plant canal	3.5	1.2	7.9	0.15	0.20	0.08	29.0	51.7	12.8	61.2	103.6	28.5
Licheński Canal	3.6	0.6	7.6	0.15	0.23	0.10	27.0	37.4	12.7	56.4	81.1	40.7
	Total oxygen consumption (mg O_2 l^{-1} 24h^{-1})			Bacterial oxygen consumption (mg O_2 l^{-1} 24h^{-1})			Bacterial respiration (mg O_2 cell^{-1} 24h^{-1})			Primary production (mg C_{org} l^{-1} 24h^{-1})		
Lake Ślesińskie	1.68	4.91	0.33	1.69	2.53	0.82	1.09	4.37	0.30	0.25	0.96	0.01
Lake Licheńskie	1.03	2.08	0.20	1.56	4.74	0.10	0.94	2.47	0.11	0.30	1.28	0.02
Lake Gosławskie	1.26	4.33	0.38	2.04	4.60	0.10	0.68	2.04	0.05	0.54	1.79	0.02
Lake Pątnowskie	1.46	4.86	0.59	1.72	5.65	0.10	0.67	2.80	0.05	0.41	1.36	0.02
Konin Power Plant canal	1.35	4.31	0.44	1.38	5.27	0.20	1.01	9.58	0.11	0.40	1.49	0.03
Pątnów Power Plant canal	0.99	2.58	0.14	1.0	2.02	0.10	0.28	0.89	0.02	0.41	1.77	0.03
Licheński Canal	1.24	4.45	0.20	1.41	3.15	0.30	0.86	3.88	0.12	0.30	1.24	0.01
	P-P_{org} (mg l^{-1})			P-PO_4 (mg l^{-1})			N-NH_4 (mg l^{-1})			N-NO_3 (mg l^{-1})		
Lake Ślesińskie	0.04	0.08	0.01	0.06	0.13	0.01	0.08	0.17	0.0	0.12	0.57	0.00
Lake Licheńskie	0.05	0.11	0.0	0.06	0.14	0.01	0.09	0.16	0.04	0.19	0.68	0.00
Lake Gosławskie	0.05	0.11	0.01	0.06	0.15	0.02	0.07	0.14	0.02	0.18	0.77	0.00
Lake Pątnowskie	0.04	0.10	0.0	0.06	0.15	0.01	0.08	0.22	0.03	0.17	0.64	0.00
Konin Power Plant canal	0.04	0.08	0.0	0.06	0.14	0.01	0.08	0.16	0.03	0.18	0.65	0.00
Pątnów Power Plant canal	0.05	0.11	0.0	0.07	0.17	0.02	0.09	0.21	0.03	0.25	0.78	0.00
Licheński Canal	0.05	0.1	0.01	0.07	0.15	0.01	0.11	0.26	0.03	0.20	0.68	0.02

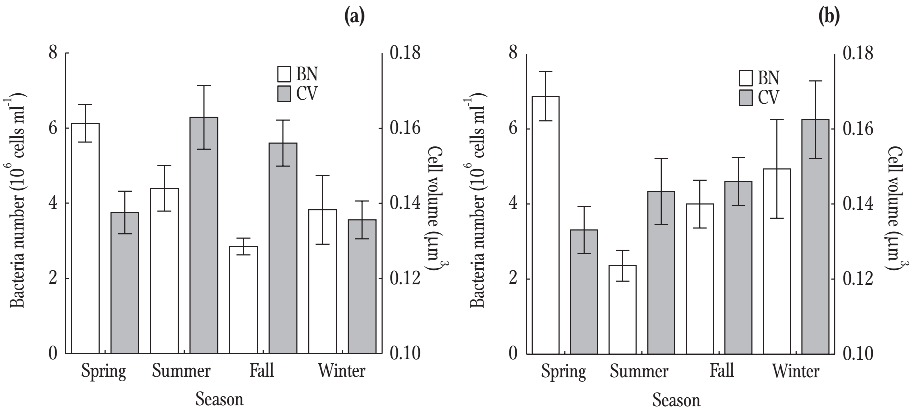

Fig. 1. Bacteria number (BN) and mean cell volume (CV) in lakes (a) and canals (b).

Seasonal dynamics of BN in the lakes and canals were characterized by the maximum values in the spring season, i.e., 6.2 and 6.9 10^6 ml^{-1}, respectively. In the summer (canals) and in the fall (lakes), the BN values observed were the lowest – 2.4 and 2.9 10^6 ml^{-1}, respectively (Fig. 1). In contrast, in winter, an increase in bacterial count was again reported in both the lakes and canals, i.e., 3.9 and 4.8 10^6 ml^{-1}, respectively. The size of bacterial cells fluctuated across a very wide range, from 0.08 to 0.23 µm^3. In the lakes, the highest volume of bacteria was recorded in the summer, in the period of high heating of the waters. The dynamics of bacteria size in the water of the canals were characterized by a successive increase from the spring until winter. The functional parameters of bacterioplankton in the lakes and canals differed considerably (Fig. 2). In the lakes, the rate of proliferation, and the size of the secondary production of bacteria, were within a wide range, i.e., respectively from 11.9 to 100.0 h (37.6 on average), and from 9.2 to 146.3 µg C_{org} l^{-1} 24h^{-1} (44.8 on average). The shortest time of generation and the highest production were noted in the summer and fall seasons (Fig. 2a). Considerably smaller fluctuations of these parameters were observed in water from the canals; simultaneously these samples demonstrated a higher rate of proliferation and level of secondary production of bacteria, i.e., 24.6 h and 56.2 µg C_{org} l^{-1} 24h^{-1} on average, respectively. A typical trait of the canal waters was the successive increase in the proliferation rate and secondary production of bacteria in the period from spring to winter. Total oxygen consumption (TOC) and bacterial respiratory activity (BR), in the waters of the lakes and canals examined, were

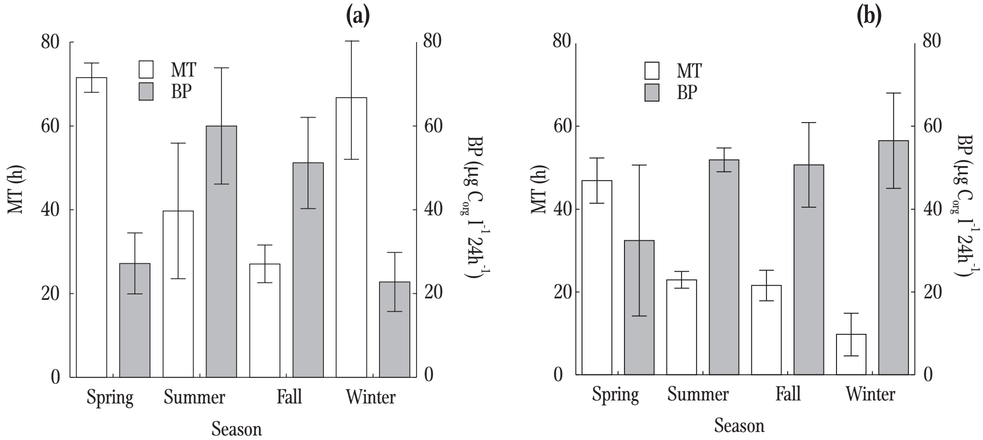

Fig. 2. Multiplication time (MT) and bacterial secondary production (BP) in lakes (a) and canals (b).

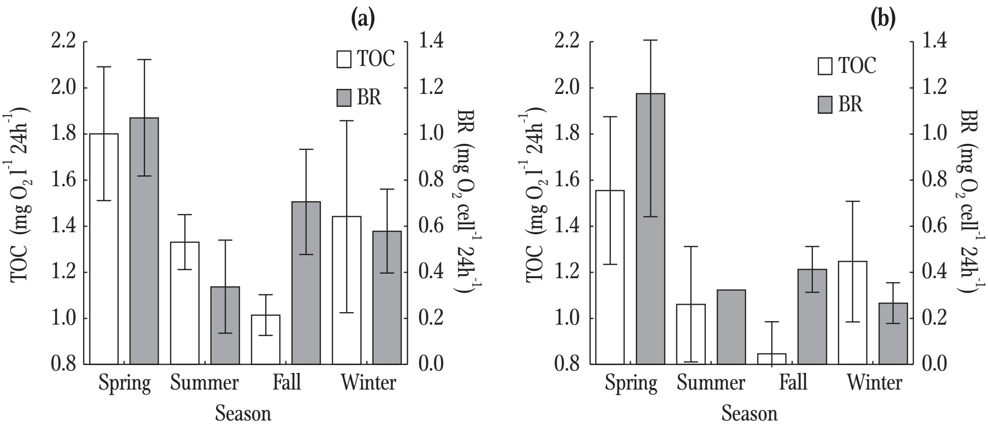

Fig. 3. Total oxygen consumption (TOC) and respiratory activity of bacteria (BR) in lakes (a) and canals (b).

characterized by a similar dynamics and measured, on average, for 1.35 mg O_2 l^{-1} $24h^{-1}$ and 1.75 mg O_2 $cell^{-1}$ $24h^{-1}$ in the lakes as well as 1.19 mg O_2 l^{-1} $24h^{-1}$ and 1.26 mg O_2 $cell^{-1}$ $24h^{-1}$ in the canals (Fig. 3). A significant correlation was demonstrated between the dynamics of the PP of phytoplankton and BD of organic matter. Both processes were characterized by a successive decrease of values in the period from spring to winter. In spring, in lakes and canals, PP was the highest at 0.94 and 0.84 µg

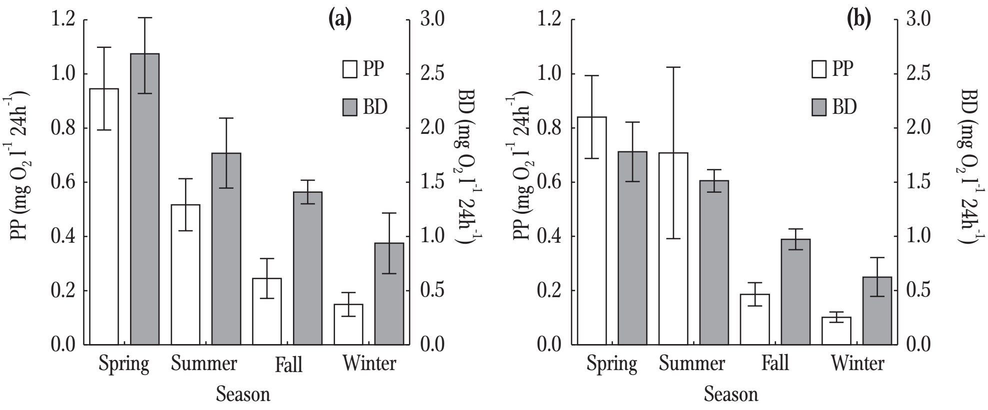

Fig. 4. Primary production (PP) and bacterial destruction of organic matter (BD) in lakes (a) and canals (b).

C_{org} l^{-1} 24h^{-1}, respectively (Fig. 4). In contrast, in winter, a decrease in PP was again reported in both the lakes and canals, i.e., 0.18 and 0.09 μg C_{org} l^{-1} 24h^{-1}, respectively. BD in the lakes and canals ranged widely, i.e., from 0.95 to 2.75 μg C_{org} l^{-1} 24h^{-1} and from 0.65 to 1.8 μg C_{org} l^{-1} 24h^{-1}, respectively (Fig. 4). An analysis of the physicochemical parameters of waters from the Konin lakes indicated the occurrence of characteristic seasonal regularities (Table 1). In general, the concentration of phosphates decreased proportionally as the temperature of water increased (Fig. 5a),

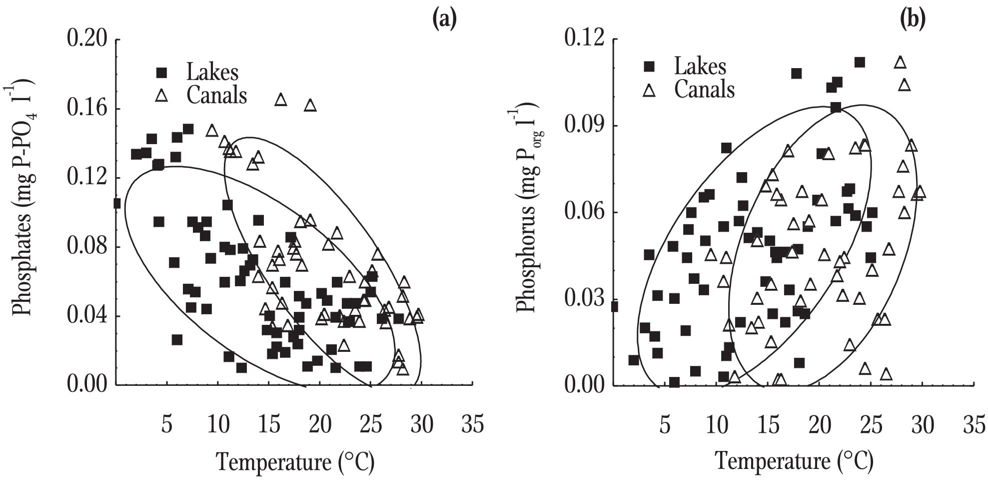

Fig. 5. Relationship between temperature and concentration of P-PO_4 (a) and Porg (b) in water of lakes and canals.

while the concentration of the organic form of phosphorus increased proportionally to temperature (Fig. 5b).

DISCUSSION

Equilibration of the processes of biomass production and organic matter destruction constitutes the principal mechanism stabilizing the structure and functioning of the ecosystem. In the Konin lakes, temperature and low retention are the main factors determining the course of the microbiological processes of destruction and mineralization of organic matter, and the rate of primary and secondary production (Zdanowski 1994, Świątecki 1997). In relatively warm waters, conditions favorable to the microbiological decomposition of organic matter have been observed to develop (Świątecki 1994). The results presented in this paper and data presented in other papers (Świątecki 1994, 1997, Świątecki et al. 2007, Marchlik et al. 2005), indicate the high efficacy of the microbiological processes in the water of the Konin lakes (Fig. 6).

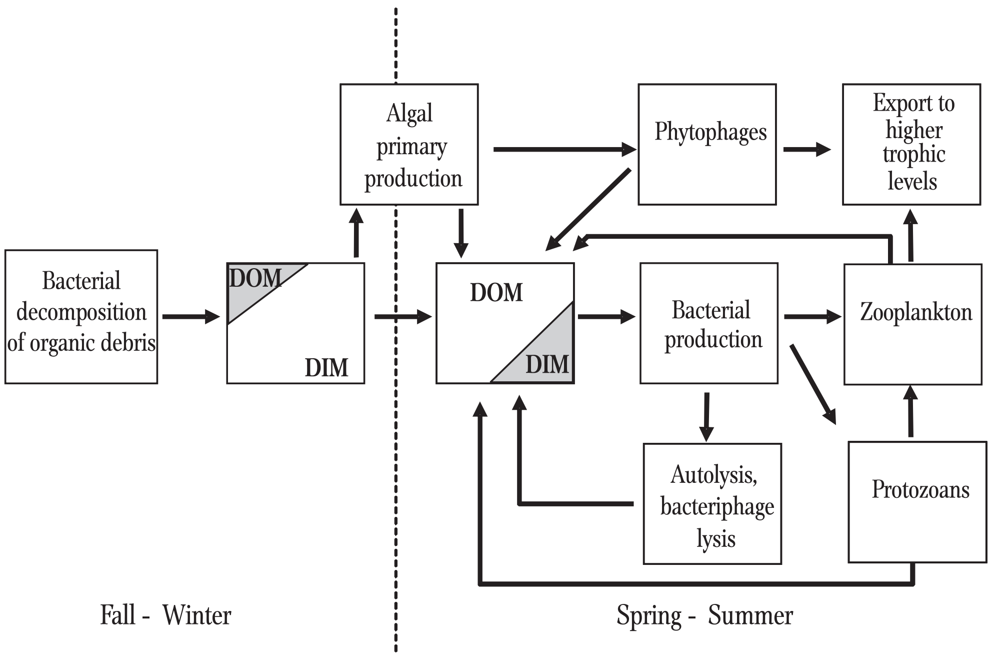

Fig. 6. A conceptual diagram of microbial process in the Konin lakes.

An analysis of the chemical and microbiological composition of the water indicates that, in the fall-winter periods, regeneration processes of mineral forms of nutrients play a key role in these waters. Under favorable thermal (a lack of ice cover) and oxygen conditions, bacteria accomplish the decomposition of organic matter to the mineral forms. A significant decrease in DOC (Świątecki et al. 2007), as well as an increase in orthophosphates and nitrates, reflect the efficacy of this process. A characteristic phenomenon of this period is the relatively low productivity of microbiological systems, as well as a relatively low rate of proliferation and the inhibited metabolism of bacterial cells. Such traits are typical of the bacteria in the group of so-called *K*-strategists (Weinbauer and Höfle 1998). A significant contribution to the pool of bacteria occurring in the water of the Konin lakes in the winter season is also ascribed to chemolithotrophic organisms, including mainly nitrifying bacteria (Świątecki 1994). The high accumulation of nutrient compounds and the increased retention of water in the spring result in short-term alga blooms (Socha 1994). The high primary production reported in this period affects changes in the structure and functions of bacteriocenosis. A characteristic phenomenon is also a gradual increase the concentration of DOC and a decrease the mineral forms of nutrients. The microbiological processes of decomposition of dissolved and particulate organic matter, constituted by remains of dead organisms, contribute to a progressive increase in ammonia nitrogen and organic phosphorus. In the summer season, the dominant group of bacteria, have extremely high metabolic activity (the so-called *r*-strategists). The high rate of their proliferation determines the high productivity of bacteriocenosis. A decrease in temperature and the content of easily-available organic matter in the fall season leads to the gradual inhibition of microbiological processes. In the winter-spring period, chemolithotrophs and heterotrophic *K*-strategists again carry out the regeneration of the mineral forms of nutrients. The occurrence of this specific cycle of consecutive microbiological processes of the destruction and mineralization of organic matter, and primary and secondary production, seems to be a key mechanism stabilizing the ecosystems of the Konin lakes. It should be emphasized that the intensity and, simultaneously, the efficiency of these processes are determined, to a great extent, by the specificity of these water bodies. The mineral and organic contaminations discharged into the Konin lakes are, to a considerable extent, "disposed of" by microorganisms. The microbiological processes of decomposition and biotransformation of these compounds, proceed with great intensity, as well as the effective transfer of organic carbon to higher trophic levels. A disputable issue is the role of physical factors, the artificially elevated temperature and the forced, very low water retention, in maintaining the specific ecological balance. In the course of the "exploitation" of the Konin lakes that has spanned dozens of years, processes stimulating the ecological balance have developed in the transformed ecosystem. One of them is the reduction of phytoplankton blooms only in early spring periods (Socha 1997). This phenomenon is determined by a recently reduced level of mineral contaminations, mainly of phosphorous compounds, as well as longer retention, occurring only in short time spans in the winter and early spring (Zdanowski in print). Intensive research into macrofiltrates, undertaken in recent years, has indicated that these organisms, especially mussels, can be an important factor stabilizing the structure and function of the Konin ecosystem (Protasov et al. 1997). Huge populations of *Sinanodonta woodiana* (Lea), and *Dreissena polymorpha* (Pall.), occurring in warm canals and lake tributaries, contribute to the bioconversion of particulate organic matter (POC) and its partial transformation into DOC (Sinicyna et al. 1997). This mechanism of water supplementation with the labile forms of DOC intensifies the microbiological processes. According to Świątecki (1997), the microbiological loop, proceeding efficiently in these waters, enables the rapid biotransformation and, consequently, the elimination of organic contamination of waters. This has been confirmed by the present study, in which very intensive microbiological destruction was demonstrated in the periods of high heating of the waters. The significance of these processes in balancing the ecosystems of the Konin lakes has also been proven in analyses of bottom deposits. According to Olejnik et al. (2000), the high enzymatic activity of bacteriobenthos, occurring in the polymictic, heated Konin lakes, is a mechanism that enables efficient self-purification of the lakes. In the sustaining of these processes, a significant role is played by the physicochemical parameters of over-deposit waters: high temperature, aerobicity, and intensive flow. It should be emphasized that favorable conditions occur in the heated Konin lakes over a substantial part of the year, which is a crucial factor determining the efficiency of the self-purification processes. A decisive factor is the multi-plane character of the biocenosis response to anthropogenic stress and, simultaneously, the occurrence of strong trophic links between individual groups of organisms. The "bottom up" and "top down" regulating processes, clearly noted in the Konin lakes, affect the specific structural, and especially functional, "adaptation" of the entire biocenosis of the ecosystem to thermal and hydrodynamic conditions created artificially by humans.

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STRESZCZENIE

SEZONOWA DYNAMIKA REMINERALIZACJI MATERII ORGANICZNEJ PRZEZ BAKTERIE W PODGRZEWANYCH JEZIORACH KONIŃSKICH

W trakcie trzyletnich badań zbiorników konińskich wykazano istotną zależność pomiędzy sezonową dynamiką procesów mikrobiologicznych a stężeniem mineralnych i organicznych form azotu i fosforu. Analiza składu chemicznego oraz parametrów mikrobiologicznych badanych wód wskazuje, że w okresach jesienno-zimowych dominują w tych wodach mikrobiologiczne procesy regeneracji mineralnych form biogenów. W korzystnych warunkach termicznych i tlenowych bakterie prowadzą dekompozycję materii organicznej do poziomu mineralnego, co objawia się spadkiem DOC, a jednocześnie znacznym wzrostem ortofosforanów i azotanów. Duże nagromadzenie związków biogennych stymuluje w okresie wiosennym wysoką produkcję pierwotną. Będący konsekwencją tych zjawisk, znaczny wzrost ilości DOC w okresie letnim determinuje wysoką produktywność bakteriocenozy, co uruchamia bardzo wydajny mikrobiologiczny łańcuch troficzny, przyczyniając się do szybkiego rozkładu materii organicznej. Uwarunkowane termiką i retencyjnością wód, intensywne procesy mikrobiologicznej dekompozycji i biotransformacji materii organicznej, a jednocześnie efektywne przenoszenie węgla organicznego na wyższe poziomy troficzne są ważnymi czynnikami wpływającymi na homeostazę ekosystemu jezior konińskich.