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THE INFLUENCE OF THE SHARE OF ARABLE LAND IN THE CATCHMENT AREAS OF TWO LAKES OF THE ŁĘCZNA-WŁODAWA LAKELAND ON THE BIOCHEMICAL PROCESSES IN SHORELINE SOILS

Summary

Between 2001 and 2016 the influence of diversified share of arable land in the catchment areas of Lake Długie (5.5% of arable land) and Lake Głębokie (73.5% of arable land) on the biochemical processes in shoreline soils was researched in five-year measurement cycles. The research chiefly encompassed the biochemical processes of conversion of nitrogen and phosphorus compounds (phosphatase, urease and protease activity). Simultaneously, the content of mineral nitrogen and assimilable forms of phosphorus in the shoreline soils of both lakes was investigated. During the observations the enzymatic activity in the Lake Długie shoreline soil was significantly greater than in the soil surrounding the shore of Lake Głębokie. However, the catchments areas of both lakes were characterised by similar changes in the enzymatic activity of shoreline soils. Between 2001 and 2006 the enzymatic activity in the soils under study was similar and exhibited a slight increasing tendency. In the consecutive measurement cycles (2011 and 2016) the activity of the enzymes decreased significantly. It was strictly correlated with the increasing content of nitrogen and phosphorus compounds in the soils surrounding both lakes. The biochemical and chemical indicators under analysis clearly point to rapid eutrophication in the shoreline habitats around Lakes Długie and Głębokie.

Key words: coastal soils, lakes, biochemical processes, eutrophication

WPŁYW UDZIAŁU GRUNTÓW ORNYCH W ZLEWNIACH DWÓCH JEZIOR POJEZIERZA ŁĘCZYŃSKO-WŁODAWSKIEGO NA PROCESY BIOCHEMICZNE W GLEBACH PRZYBRZEŻNYCH

Streszczenie

W latach 2001-2016, w 5-letnim cyklu pomiarowym, badano wpływ zróżnicowanego udziału gruntów ornych w zlewniach Jeziora Długie (5.5% gruntów ornych) i Jeziora Głębokie (73.5% gruntów ornych) na procesy biochemiczne w glebach strefy przybrzeżnej. Badaniami objęto procesy biochemiczne związane głównie z przemianami związków azotu i fosforu (aktywność fosfataz, ureazy i proteaz). Równolegle oznaczano zawartość azotu mineralnego i przyswajalnych form fosforu w glebach przybrzeżnych obydwu jezior. W okresie prowadzonych obserwacji aktywność badanych enzymów w glebie przybrzeżnej jeziora Długie była istotnie większa niż w glebie przybrzeżnej jeziora Głębokie, ale zmiany aktywności enzymatycznej gleb przybrzeżnych miały podobny charakter w przypadku zlewni obydwu badanych jezior. W latach 2001-2006 aktywność enzymatyczna badanych gleb utrzymywała się na zbliżonym poziomie, wykazując niewielkie tendencje wzrostowe. Natomiast w kolejnych cyklach pomiarowych (2011 i 2016) zanotowano istotny spadek aktywności analizowanych enzymów, związany ściśle ze wzrastającą z roku na rok zawartością związków azotu i fosforu w glebach strefy przybrzeżnej obydwu jezior. Analizowane wskaźniki biochemiczne i chemiczne jednoznacznie wskazują na postępującą w szybkim tempie eutrofizację siedlisk przybrzeżnych jezior Długie i Głębokie.

Słowa kluczowe: gleby przybrzeżne, jeziora, procesy biochemiczne, eutrofizacja

1. Introduction

The land use structure of lake catchment areas has significant influence on the eutrophication of shoreline habitats and degradation of lake water [7, 13, 16, 17]. Differences in the land use in lake catchment areas determine the amount of biogenic substances in shoreline soils. In consequence, it may cause different eutrophication of lake ecosystems [6, 7, 11].

Like the soil fertility in farmland, the productivity of shoreline habitats is strictly correlated with the physiological activity of microorganisms, which is expressed by in-

tensification of biochemical processes [1, 5, 10]. All transformations of biogenic substances in soil are stimulated by enzymes responsible for their transformation into forms available to plants and microorganisms [15]. Soil enzymes, such as phosphatases, urease and proteases, may be good indicators of the potential for mineralisation of organic phosphorus and nitrogen compounds. The mineralisation of these compounds results in the formation of ions of basic biogenic elements, which accelerate eutrophication processes [3, 9].

Long-term (2001-2016) research on changes in the enzymatic activity of soils surrounding two lakes with consid-

erably diversified land use structure of the catchment areas was conducted in order to find and verify the diagnostic indicators of eutrophication processes and the indicators of trophodynamics of lake ecosystems.

2. Materials and Methods

The catchment areas of Lake Długie and Lake Głębokie were researched. Both lakes are located in the south of the Łęczna-Włodawa Lakeland. Their bottoms are flat and they are not very deep: Lake Długie – about 1 m, Lake Głębokie – about 7 m [7, 19]. As the lakes are small (20-30 ha), they contain relatively small amounts of water. They are classified as polymictic lakes due to their small depth and low dynamics of the water mass [7]. The catchment areas of the lakes are covered by a complex of marshy soils, especially black soils formed from sand and underlain with loamy sand [13]. The land use structure of the catchment areas under study is considerably diversified (Table 1).

Table 1. The land use structure (%) in the lake catchment areas [7]

Tab. 1. Struktura użytkowania gruntu (%) w zlewni jeziora [7]

Land use	Lakes	
	Długie	Głębokie
Lake	6.7	11.7
Forest and shrubs	76.8	1.0
Arable land	5.5	73.5
Other	11.0	13.8

Source: own work / Źródło: opracowanie własne

Between 2001 and 2016 the enzymatic activity of shoreline soils surrounding the lakes was researched in five-year measurement cycles. Simultaneously, the content of mineral forms of nitrogen and assimilable forms of phosphorus in the soils surrounding the lakes was measured. Samples of soil were collected from a depth of 0-20 cm three times a year (in early May, mid-July and late September) in 1996, 2001, 2006, 2011 and 2016. Research stations were located along the surface water flow line, about 4 m from the shore. The sample under analysis was the average of 5 samples collected from each research station. The activity of phosphatases [18], urease [21] and proteases [12] was measured.

Table 2. The enzymatic activity in shoreline soils

Tab. 2. Aktywność enzymatyczna w glebach przybrzeżnych

Year	Month	Phosphatases		Urease		Proteases	
		[mg PNP·kg ⁻¹ ·h ⁻¹]		[mg N-NH ₄ ⁺ ·kg ⁻¹ ·h ⁻¹]		[mg tyrosine·kg ⁻¹ ·h ⁻¹]	
		Lakes					
		Długie	Głębokie	Długie	Głębokie	Długie	Głębokie
2001	V	37.09c	20.84b	29.08c	14.39b	34.12c	16.40b
	VII	47.18c	25.92b	28.31c	14.06b	40.20c	17.22b
	IX	39.97c	22.36b	24.32c	12.21b	38.09c	16.95b
2006	V	42.16c	23.64b	33.19c	15.26b	36.63c	17.54b
	VII	52.36c	27.85b	30.68c	14.49b	41.68c	18.26b
	IX	44.72c	24.03b	26.74c	12.20b	39.71c	18.05b
2011	V	17.62b	9.59a	14.18b	5.94a	16.15b	8.47a
	VII	22.58b	11.85a	13.95b	5.12a	21.02b	9.12a
	IX	19.96b	10.51a	12.01b	4.23a	19.33b	8.69a
2016	V	15.37b	7.91a	12.30b	4.89a	14.59b	7.05a
	VII	16.98b	9.15a	11.82b	4.74a	15.24b	6.28a
	IX	14.65b	8.03a	10.11b	3.91a	14.96b	5.94a

The values followed by the same letter in the column are not significant at $p < 0.05$, 't'- test.

Source: own work / Źródło: opracowanie własne

These enzymes are of key importance to the mineralisation of organic compounds of nitrogen (urease and proteases) and phosphorus (phosphatases). The content of ammonium nitrogen and nitrate nitrogen [ISO 14255] and assimilable forms of phosphorus in the soil samples were measured with the method developed by Egner et al. [6].

The results were statistically analysed with Microsoft Office Excel 2003 spreadsheet and Statistica v. 10PL software. The variability of the results was estimated with the two-way analysis of variance. The significance of differences between the mean values was verified with Tukey's t-test at a significance level of $\alpha \leq 0.05$. For the parameters under investigation, the value of the Pearson correlation coefficient (r) was calculated at $p \leq 0.05$. A maximum 5% dispersion of measurements in the biochemical and chemical analysis was assumed in the study.

3. Results and Discussion

During the entire period of observations the enzymatic activity in the Lake Długie shoreline soil was significantly greater than in the soil surrounding the shore of Lake Głębokie (Table 2). It may have been caused by the diversified land use structure of the catchment areas (Table 1) and different intensity of agricultural pressure. The content of mineral forms of nitrogen in the soil around Lake Głębokie was a few times greater than in the soil around Lake Długie (Table 3). It shows that there was an increased flow of mineral salts of agricultural origin into the soil. Other authors also point to increased trophicity of lakes due to a higher share of arable land in their catchment areas [7, 11, 20].

Over the 15 years of the research the catchments areas of both lakes were characterised by similar changes in the enzymatic activity of shoreline soils (Table 2). Between 2001 and 2006 the enzymatic activity in the soils under study was similar and exhibited a slight increasing tendency. In the consecutive measurement cycles (2011 and 2016) the activity of all the enzymes decreased significantly (Table 2). Between 2011 and 2016 the enzymatic activity was about 3-4 times smaller than between 2001 and 2006 (Table 2). Simultaneously, there was an increase in the content of mineral nitrogen and assimilable forms of phosphorus in the shoreline soils of both lakes (Table 3).

Table 3. The content of particular nitrogen and assimilable phosphorus forms (P) in the soil around the shore of the lakes
 Tab. 3. Zawartość poszczególnych form azotu I przyswajalnego fosforu (P) w glebach otaczających brzegi jezior

Year	Month	N-NH ₄ ⁺		N-NO ₃ ⁻		P	
		[mg·kg ⁻¹]					
		Lakes					
		Długie	Głębokie	Długie	Głębokie	Długie	Głębokie
2001	V	20.1a	39.8b	12.2b	5.4a	22.6a	40.3b
	VII	17.9a	35.1b	9.8b	4.2a	19.8a	38.6b
	IX	18.2a	36.9b	11.6b	4.9a	21.4a	39.2b
2006	V	38.7b	63.2c	20.9c	10.2b	44.5b	78.9c
	VII	35.2b	60.8c	18.1c	8.5b	38.2b	76.1c
	IX	36.9b	61.4c	18.4c	9.6b	41.8b	77.5c
2011	V	62.1c	121.6d	31.9c	28.1c	81.7c	139.4d
	VII	58.4c	106.2d	29.7c	25.5c	79.8c	122.6d
	IX	59.6c	110.8d	31.2c	27.3c	80.6c	124.2d
2016	V	101.4d	196.9e	50.4d	52.6d	135.4d	234.3e
	VII	98.5d	188.4e	48.3d	48.9d	129.3d	226.8e
	IX	99.3d	192.3e	48.9d	50.7d	131.4d	230.1e

The values followed by the same letter in the column are not significant at $p < 0.05$, 't' - test.

Source: own work / Źródło: opracowanie własne

This fact indicates the occurrence of a drift in the habitat due to the excessive amounts of biogenic substances in the soil environment. The negative values of the coefficients of correlation between the enzymatic activity and the high content of mineral nitrogen and assimilable forms of phosphorus confirm the negative influence of the content of these substances in the soil on the biochemical processes under investigation (Table 4).

During the period of observations there were minimal seasonal fluctuations in the enzymatic activity of the soils under study. The highest activity of phosphatases and proteases was observed in July, whereas urease exhibited the highest activity in May. However, these differences were not statistically significant (Table 2). The seasonal variability in the enzymatic activity depends on numerous ecological factors, such as: periodical variation in temperature and soil humidity, periodical inflow of chemical substances into the soil, the demand of the biocenosis for nutrients, differences in the sensitivity and resistance of individual enzymes to environmental stress and the content of substrates in the soil which are specific to enzymatic reactions [5].

As time elapsed, the content of mineral forms of nitrogen and assimilable phosphorus in the shoreline soils of the lakes under study increased significantly (Table 3). It was caused both by the inflow of substances of agricultural origin and the development of tourism and recreation in the ecosystems of the lakes [14]. During the entire period under analysis the content of ammonium nitrogen and assimilable forms of phosphorus in the Lake Długie shoreline soil was significantly smaller than in the soil surrounding the shore of Lake Głębokie (Table 3). This result can be explained by the fact that the share of arable land in the catchment area of Lake Długie is much smaller than in the catchment area of Lake Głębokie. In consequence, there are differences in the flow of biogenic substances of agricultural origin into the soils surrounding the shores of both lakes. Only between 2011 and 2016 the content of nitrate nitrogen in the Lake Głębokie shoreline soil was significantly greater than in the soil surrounding Lake Długie (Table 3). Nitrates (V) are at a much higher risk of loss than ammonium salts due to greater variety of processes resulting in loss. Apart from the loss of gaseous forms (NO, N₂O, N₂), rain water and the ease of diffusive migration also cause considerable amounts of nitrates to be washed from soil.

The activity of the enzymes under study exhibited negative, significant dependence on the content of mineral forms of nitrogen and assimilable phosphorus in the shoreline soils of the lakes (Table 4). The flow of biogenic substances to the soil environment may increase the microbial activity in soil and reduce the activity of some enzymes [2, 5]. The excess of inorganic phosphorus in soil inhibits the synthesis of phosphatases [4], whereas a high content of mineral nitrogen limits the activity of urease and proteases [5].

Table 4. The coefficients of correlation between the enzymatic activity and the concentration of nitrogen (NH₄⁺ and NO₃⁻) and assimilable phosphorus forms (P) in the shoreline soils

Tab. 4. Współczynniki korelacji między aktywnością enzymatyczną a koncentracją form azotu (NH₄⁺ and NO₃⁻) i przyswajalnego fosforu (P) w glebach przybrzeżnych

Enzymes	N-NH ₄ ⁺	N-NO ₃ ⁻	P
Phosphatases	-0.78*	-0.60*	-0.79*
Urease	-0.77*	-0.51*	-0.76*
Proteases	-0.77*	-0.51*	-0.77*

* significant at $p = 0.05$.

Source: own work / Źródło: opracowanie własne

4. Conclusions

1. Over the 15 years (2001-2016) of the study the enzymatic activity in the shoreline soil of Lake Długie was significantly higher than in the soil surrounding Lake Głębokie because of diversified land use structure of the catchment areas and different intensity of agricultural pressure.
2. The comparison of the research results from 2001-2006 and those from 2011-2016 documents a significant decrease in the enzymatic activity and a simultaneous, multiple increase in the content of mineral forms of nitrogen and assimilable phosphorus in the shoreline soils of both lakes. This fact indicates the occurrence of a drift in the habitat due to the excessive amounts of biogenic substances in the soil environment.
3. The increasing enzymatic inactivation and the increasing content of mineral forms of nitrogen and assimilable phosphorus in the soils under study point to rapid eutrophication in the shoreline habitats around Lakes Długie and Głębokie.

4. It is possible to determine the rate of eutrophication of shoreline habitats around lakes by measuring the soil enzymatic activity.

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