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EFFECT OF AGRICULTURAL PRODUCTION ON ORGANIC MATTER ACCUMULATION IN THE BOTTOM DEPOSITS OF PILWA BAY (LAKE DOBSKIE)

WPŁYW PRODUKCJI ROLNEJ NA AKUMULACJĘ MATERII W OSADACH DENNYCH ZATOKI PILWA (JEZIORO DOBSKIE)

Abstract: This study examined selected physical and chemical parameters of bottom deposits in the Pilwa Bay (Lake Dobskie) supplied by watercourses draining intensively farmed areas. The chemical composition of bottom deposits was analyzed in 2007. It was found that long-term exposure to agricultural pollution and vegetation growth in the Bay contributed to the deposition of bottom sediments. The accumulation of biogenic elements in the surface layer of bottom deposits reached 77.0 kgN_{tot}, 11.0 kgP_{tot}, 8.0 kgK, 704 kgCa, 59.6 kgMg, 17.1 kgNa per hectare of catchment area, and it was equivalent to 14-year nitrogen loads, 36-year phosphorus loads, 2-year potassium loads, 8-year calcium loads, 5-year magnesium loads and 2-year sodium loads. The accumulation of biogenic elements in the bottom deposits of Pilwa Bay plays a key role in protecting the lake's environment against pollution under natural conditions. With respect to their accumulation in bottom deposits, the analyzed elements may be arranged in the following descending order: $Ca > N_{tot} > Mg > Na > P_{tot} > K$.

Keywords: bottom deposits, biogenic elements, Pilwa Bay

Introduction

Mineral and organic material of allochthonous and autochthonous origin is deposited at the bottom of water bodies, composed of various rock formations. Similarly to soils on land, bottom deposits are a combination of crystalline and amorphous minerals with a different grain size and a varied content of organic matter as well as colloidal mineral and organic substances [1].

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Bottom deposits are an integral component of the aquatic environment. They play an important role in the biogeochemical cycle, they are the place of deposition and chemical transformation of various compounds supplied to water bodies, and they are the habitat of aquatic organisms [2, 3]. The impact of bottom deposits on the water environment grows with an increase in the accumulated nutrients' availability for aquatic organisms [4]. The chemical composition of deposits is a reliable indicator of surface water purity, and chemical analyses support the determination of changes in heavy metal concentrations in the aquatic environment, even if surface waters are marked by relatively low heavy metal levels [5].

In agricultural catchments, the composition of bottom deposits is determined mostly by the type of land use in a lake's catchment area. Pollutants supplied with surface runoffs from farmland may lead to changes in the composition of bottom deposits.

The objective of this study was to evaluate the effect of intensively farmed areas on the accumulation of bottom deposits in the Pilwa Bay, their differentiation in the horizontal profile and the volume of the accumulated organic matter and biogenic elements.

Materials and methods

The analyzed bottom deposits were sampled in the Pilwa Bay, Lake Dobskie, in the mesoregion comprising the Land of Great Masurian Lakes, Gizycko district. Lake Dobskie constitutes the western part of the Mamry Lake complex, and it has the features of a typical basal moraine lake. The lake occupies a total area of more than 17 km^2. The bay has an area of 52.98 ha, with an average depth of 1.36 m and a well-developed shoreline (k = 1.88). The present bay is a remnant of a former section of Lake Dobskie spanning an area of 100 ha. The western part of Pilwa Bay is supplied by inflows from the lake's catchment comprising semi-intensively farmed areas with an intensive fertilization regime. Selected parts of Lake Dobskie's catchment receive high nitrogen loads from farm fields. The morphometric features of the bay are presented in Table 1.

Table 1

Morphometric parameters of Pilwa Bay

Parameter	Value
Water table surface area [ha]	52.98
Maximum depth [m]	3.66
Average depth [m]	1.36
Volume [m^3]	719288
Maximum length [m]	1733
Maximum width [m]	400
Shoreline length [m]	4847
Shoreline development	1.88
Latitude	54°05′40″
Longitude	21°35′5″

Samples were collected using the ELCMAN sampling kit. In view of the bay's bathymetric features, shape and the varied physical and chemical composition of bottom deposits, the Pilwa Bay was divided into three parts according to the direction of outflows: the western, central and eastern part connected with the main basin of Lake Dobskie. Deposit samples were collected according to the experimental design shown in Fig. 1.

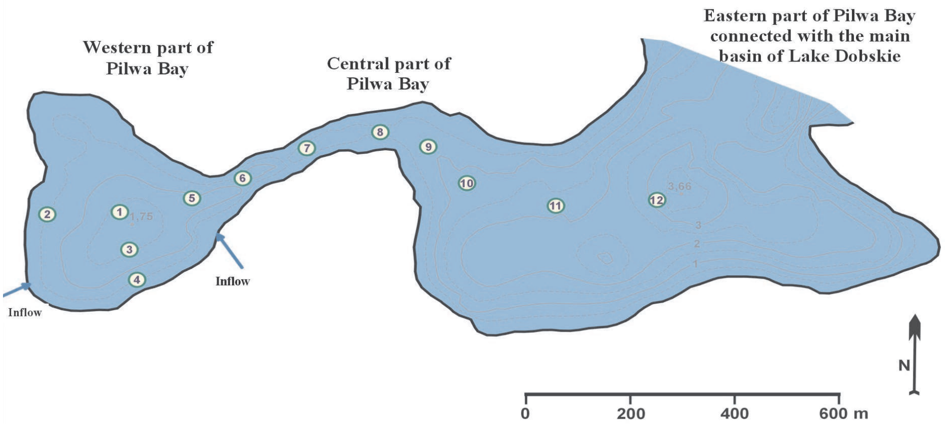

Fig. 1. Bottom deposit sampling sites in Pilwa Bay

Deposit samples were subjected to chemical analyses in the District Analytical and Agricultural Station in Olsztyn, according to Polish Standard PN 88/R-04013. The samples were mineralized in sulfuric acid to determine the content of: total nitrogen (N_{tot}) – by potentiometric titration with sodium bromide, total phosphorus (P_{tot}) – by colorimetry, potassium (K), calcium (Ca), sodium (Na) and magnesium (Mg) – by flame photometry, dry residue – by the gravimetric method (105 ^{o}C), residue after ignition – by the gravimetric method (550 ^{o}C), and pH was determined in a KCl solution.

The Pearson's correlation coefficient was calculated at a significance level of $\alpha = 0.05$ to determine the correlations between the studied parameters.

Results and discussion

The reaction of the investigated bottom deposits was determined in the range of pH_{KCl} 7.15 to pH_{KCl} 7.18, and the average for the entire bay reached pH_{KCl} 7.16 (Table 2).

The average volume density of deposits was leveled throughout the investigated area (1.15 g $\cdot$ cm^{-3}). The studied deposits were characterized by a high degree of hydration and low consolidation. Owing to the bay's relatively small depth, deposits are easily lifted from the bottom, and they are left floating in the water. A high water content of the sampled deposits (86.96 to 89.02 %) indicates that the processes of resuspension and exchange of deposit – water components take place in the examined layer. The least hydrated deposits were found in the central part of the bay where dry matter content reached 13.04 %. In this part of the bay, the collected deposits were marked by a higher content of mineral fractions, as demonstrated by the ash to organic matter ratio of 78.07 % : 21.94 % (Table 2). The highest organic matter concentrations were noted in the eastern part of the bay (40.17 %) characterized by the greatest depth (3.66 m), and the lowest – in its central part (21.94 %). According to Golebiowski and Trojanowski et al [6, 7], deposits sampled at greatest depths are usually marked by the highest accumulation of organic matter. The results of this study support the above findings.

Table 2

Physical properties of the surface layer of bottom deposits in Pilwa Bay

Parameter	Unit	Sampling site			
		Western part of Pilwa Bay	Central part of Pilwa Bay	Eastern part of Pilwa Bay connected with the main basin of Lake Dobskie	Mean
Dry matter	%	10.98	13.04	11.92	11.98
Volume density	$g \cdot cm^{-3}$	1.15	1.15	1.16	1.15
Reaction	pH_{KCl}	7.18	7.15	7.17	7.16
Ash (reside after ignition)	% d.m.	71.98	78.07	59.83	69.96
Organic matter	% d.m.	28.02	21.94	40.17	30.04

Nutrient concentrations varied in the sampled deposits. In the analyzed group of elements, calcium had the highest share with an average of 106.75 $gCa \cdot kg^{-1}$ d.m. for the bay area (Table 3). Calcium concentrations in the analyzed deposit samples ranged from 93.48 to 115.50 $gCa \cdot kg^{-1}$ d.m. According to Januszkiewicz [8], calcium is found in bottom deposits mostly in the form of calcium carbonate. Similarly to other elements, it may be supplied to the water body from the catchment area, mainly during the spring high water stage. Autochthonous matter is yet another source of calcium in bottom deposits.

The studied deposits contained also substantial quantities of nitrogen. The highest amounts of this element were determined in samples from the central part of the bay at 13.28 $gN_{tot} \cdot kg^{-1}$ d.m. on average. The above results suggest that nitrogen is accumulated in this part of the bay, and these findings constitute valuable data for designing protection schemes for the examined lake. The central part of the bay is characterized by the smallest depth and high trophy levels. Mineral deposits feature a powerful system of thick roots which uplift the bottom. The spatterdock had a 50 % to 75 % share of local vegetation rooted in the bottom with leaves floating on the surface. The shallow central part of the bay (depth of around 1 m) contributes to the decomposition of organic matter due to greater exposure to light and higher temperatures. Fertile deposits also support rush growth. The quantities of nitrogen in deposits accumulated nearer the inflows were around two-fold higher than in more distant locations. In this part of the bay, the main source of nitrogen were pollutants and surface runoffs from intensively farmed areas (fertilized with animal slurry). Deposits sampled in the eastern part of the bay were also characterized by higher nitrogen concentrations (Table 3). As noted by Szyperek and Skonieczek [9, 10], the above could result from the fact that nitrogen supplied via surface runoffs migrates to deeper locations where it is accumulated.

The analyzed deposit samples contained significantly lower levels of total phosphorus in comparison with nitrogen. Phosphorus concentrations were also marked by a lower degree of variation (from 1.50 to 2.04 $g \cdot kg^{-1}$ d.m.). Phosphorus levels decreased as the distance from the inflow increased. Similarly to nitrogen, phosphorus was supplied from the catchment, and the above contributed to the accumulation of biogenic elements in bottom deposits. In comparison with calcium and nitrogen, the relatively low phosphorus concentrations in deposits could have resulted from the recirculation of the studied element. Despite a high degree of sedimentation, phosphorus is quickly replenished in water as a result of the exchange between water and bottom deposits. In an environment conducive to resuspension (wave motion in shallow areas) and under oxygen deficiency, high quantities of phosphorus may be released from deposits, especially during the growing season when the studied element is in high demand for primary production needs [11].

Phosphorus is one of the key factors contributing to eutrophication, and it plays a double role in bottom deposits. The quantity of accumulated phosphorus is indicative of bottom deposits' effectiveness as a mechanism for trapping migrating phosphorus, yet high concentrations of this biogenic element may contribute to shallowing processes in the basin of the water body [12].

Potassium is an element with a variety of agricultural applications, and although it does not contribute to water eutrophication, it can be a good indicator of farming intensity in the catchment area. In the analyzed deposits, potassium concentrations ranged from 1.01 to 1.84 $g \cdot kg^{-1}$ d.m. Similar results (0.66 to 1.31 $g \cdot kg^{-1}$ d.m.) were reported by Szyperek [9] who studied a group of water bodies with both agricultural and afforested catchments. Potassium is actively involved in the life processes of ecosystems, and it weakly migrates in water. Among cations, the highest uptake by plants is reported in respect of this nutrient [13].

The magnesium content of the studied deposit samples was relatively leveled, ranging from 8.11 do 9.46 $g \cdot kg^{-1}$ d.m. Magnesium compounds accumulated in bottom deposits do not originate from soil mineral components, and they are supplied mainly by decomposing plants. A similar trend was noted for sodium. With respect to their accumulation in bottom deposits, the analyzed elements may be arranged in the following descending order: $Ca > N_{tot} > Mg > Na > P_{tot} > K$.

The results of this study indicate that agricultural catchments supply substantial biogenic loads. Excess fertilizer nutrients, of both organic and mineral origin, which are not used in farming are distributed in the environment [14].

The volume of nutrients accumulated in the surface layer of bottom deposits points to high dynamics of matter deposition. The level of accumulation is largely determined by the intensity of nutrient supply and the susceptibility of biogenic substances to

Table 3

The content of biogenic elements, ash and organic matter in the surface layer of bottom deposits in Pilwa Bay [g · kg^{-1} d.m.]

Sampling site	Sample no.	N_{tot}	P_{tot}	K	Ca	Mg	Na	Ash (reside after ignition)	Organic matter
Western part of Pilwa Bay	1	6.33	2.20	1.89	115.50	7.40	3.53	654.6	345.4
	2	12.20	2.20	1.98	110.50	8.59	1.83	644.0	356.0
	3	8.03	1.80	1.97	102.50	10.28	2.59	700.8	299.2
	4	12.30	2.20	1.79	108.32	9.96	1.51	758.5	241.5
	5	6.48	1.80	1.57	110.50	11.05	3.15	841.2	158.8
	Mean	**9.07**	**2.04**	**1.84**	**109.46**	**9.46**	**2.52**	**719.8**	**280.2**
Central part of Pilwa Bay	6	13.53	1.80	1.09	118.00	7.51	0.42	598.0	402.0
	7	13.60	1.40	0.95	102.50	8.67	1.26	890.4	109.8
	8	12.70	2.20	1.09	102.50	8.16	3.12	853.6	146.4
	Mean	**13.28**	**1.80**	**1.05**	**107.67**	**8.11**	**1.60**	**780.7**	**219.4**
Eastern part of Pilwa Bay connected with the main basin of Lake Dobskie	9	16.35	1.40	0.85	93.48	6.48	3.62	818.8	181.2
	10	14.35	1.80	0.98	107.00	9.80	2.57	510.6	489.4
	11	10.33	1.40	1.27	108.00	8.50	3.10	563.8	436.2
	12	8.20	1.40	0.93	104.00	9.90	0.94	500.0	500.0
	Mean	**12.27**	**1.50**	**1.01**	**103.12**	**8.67**	**2.56**	**598.3**	**401.7**

permanent sedimentation. The supplied nutrient loads are mostly affected by the type of land use and farming intensity in agricultural catchments [15, 16]. The volume of deposited nutrients is also affected by their concentrations, the thickness and surface area of bottom deposits. The above parameters varied substantially in the bay and, as a result, the estimated values of macronutrient deposition differed significantly

Table 4

The inflow of biogenic load via watercourses feeding into the Pilwa Bay and the accumulation of biogenic elements in the surface layers of bottom deposits

Parameter	Inflow via watercourses	Accumulation in bottom deposits		
	$[kg \cdot ha^{-1} \cdot year^{-1}]$	$[kg \cdot water\ body^{-1}]$	$[kg \cdot m^2$ bay surface area]	$[kg \cdot ha^{-1}$ catchment surface area]
Total N	5.4	163 893	0.309	77.0
Total P	0.3	23 423	0.044	11.0
K	4.7	17 467	0.033	8.0
Ca	89.0	1 498 254	2.83	704.0
Mg	11.6	126 903	0.24	59.6
Na	7.1	36 477	0.07	17.1

The following quantities of nutrients were accumulated in the bay's bottom deposits: 163893 kgN_{tot}, 23423 kgP_{tot}, 17467 kgK, 149825 kgCa, 126903 kgMg and 36477 kgNa. In the group of analyzed elements, the highest accumulation values were reported for calcium. Based on a more objective indicator, *ie* accumulation per unit area, the following nutrient quantities were determined per m^2 of the bay's bottom area: 0.309 kgN, 0.044 kgP, 0.033 kgK, 2.83 kgCa, 0.24 kgMg and 0.07 kgNa. As regards biogenic element deposition relative to the surface area of the catchment, the following quantities of the analyzed elements were determined per hectare of catchment area: 77.0 kgN_{tot}, 11.0 kgP_{tot}, 8.0 kgK, 704.0 kgCa, 59.6 kgMg and 17.1 kgNa. The following annual loads were supplied via drains from the catchment to the western part of the bay: 5.4 $kg \cdot ha^{-1}$ N_{tot}, 0.3 $kg \cdot ha^{-1}$ P_{tot}, 4.7 $kg \cdot ha^{-1}$ K, 89.0 $kg \cdot ha^{-1}$ Ca, 11.6 $kg \cdot ha^{-1}$ Mg and 7.1 $kg \cdot ha^{-1}$ Na.

The Pearson's correlation coefficient was calculated at a significance level of $\alpha = 0.05$ to determine the correlations between the studied parameters (Table 5). The results of a statistical analysis indicate a highly significant correlation between potassium, sodium and nitrogen at $r = 0.60$, between pH, sodium and ash at $r = -0.70$, and between pH and organic matter at $r = 0.72$. The highest value of the correlation coefficient was noted between ash and organic matter at $r = -1.0$. High but statistically non-significant values of the correlation coefficient were observed between Mg, organic matter and pH at $r = 0.49$, and the coefficient of correlation between Mg and ash reached $r = -0.49$. No significant correlations were determined between the remaining parameters.

Table 5

Coefficients of Pearson's correlation between the studied parameters of bottom deposits in the Pilwa Bay

Parameter	N_{tot}	P_{tot}	K	Mg	Ca	Na	Ash	Organic matter
P_{tot}	–0.35							
K	–0.63*	0.66*						
Ca	–0.34	0.47	0.42					
Mg	–0.35	0.04	0.29	0.07				
Na	–0.18	0.27	0.23	–0.34	–0.28			
Ash	0.12	0.21	0.04	–0.49	–0.08	0.37		
Organic matter	–0.12	–0.21	–0.04	0.49	0.08	–0.37	–1.00*	
pH	–0.14	–0.09	0.18	0.56	0.29	–0.70*	–0.72*	0.72*

* Correlation coefficient significant at $\alpha = 0.05$.

Conclusions

The following conclusions can be formulated based on the results of the study analyzing bottom deposits in the Pilwa Bay, Lake Dobskie:

1. Long-term exposure to agricultural pollution and vegetation growth in the Bay contributed to the deposition of bottom sediments. With respect to their accumulation in bottom deposits, the analyzed elements may be arranged in the following descending order: Ca > N_{tot} > Mg > Na > P_{tot} > K.

2. The following quantities of biogenic elements were determined per m^2 of the bay's bottom area: 0.309 kgN_{tot}, 0.044 kgP_{tot}, 0.033 kgK, 2.83 kgCa, 0.24 kgMg and 0.07 kgNa. The quantities of nitrogen in deposits accumulated nearer the inflows were around two-fold higher than in more distant locations. The deposition levels of the remaining nutrients were leveled throughout the bay.

3. The accumulation of biogenic elements in the surface layer of bottom deposits reached 77.0 kgN_{tot}, 11.0 kgP_{tot}, 8.0 kgK, 704 kgCa, 59.6 kgMg and 17.1 kgNa per hectare of catchment area, and it was equivalent to 2–36-year loads. With respect to their accumulation levels, the elements supplied by the inflow may be arranged in the following order: P_{tot} > N_{tot} > Ca > Mg > Na > K.

4. The accumulation of biogenic elements in the bottom deposits of Pilwa Bay plays a key role in protecting the lake's environment against agricultural pollution under natural conditions.

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WPŁYW PRODUKCJI ROLNEJ NA AKUMULACJĘ MATERII W OSADACH DENNYCH ZATOKI PILWA (JEZIORO DOBSKIE)

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Abstrakt: W pracy przedstawiono wyniki badań osadów dennych w zatoce Pilwa jeziora Dobskiego, do której dopływają cieki odwadniające obszary o intensywnej produkcji w aspekcie oceny wybranych parametrów fizykochemicznych tych osadów. Badania składu chemicznego osadów dennych przeprowadzono w 2007 r. Stwierdzono m.in., że wieloletni dopływ zanieczyszczeń pochodzący z intensywnej produkcji rolnej i rozwój roślinności w zatoce spowodował zakumulowanie dużej ilości osadów dennych. Akumulacja biogenów w wierzchniej warstwie osadów wynosiła: 77,0 kgN_{og}, 11,0 kgP_{og}, 8,0 kgK, 704 kgCa, 59,6 kgMg, 17,1 kgNa na jeden ha zlewni, co równało się z 14-letnim dopływem azotu, 36-letnim fosforu, 2-letnim potasu, 8-letnim wapnia, 5-letnim magnezu oraz 2-letnim dopływem sodu. Akumulacja biogenów w osadach zatoki stanowi główny element ochrony jeziora przed zanieczyszczeniami w warunkach naturalnych. Oznaczone składniki, pod względem stężenia w osadach dennych można uszeregować następująco: $Ca > N_{og} > Mg > Na > P_{og} > K$.

Słowa kluczowe: osady denne, składniki biogenne, Zatoka Pilwa