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RELATIONSHIP BETWEEN DYNAMICS OF PHOSPHORUS COMPOUNDS AND NITROGEN RETENTION IN SOME DAM RESERVOIRS FROM PODKARPACIE (SE POLAND)

Mass balance of nitrogen and phosphorus was studied in two ecosystems: the Rzeszów reservoir and the Solina reservoir in a period of 1999–2001. The influence of phosphorus as a N:P ratio on nitrogen retention (N_{ret}) was specified for both waterbodies. An average value of nitrogen retention in the Solina reservoir was 134 mg N m^{-2} d^{-1} and that in the Rzeszów reservoir 833 mg N m^{-2} d^{-1}. The highest retention of both nitrogen and phosphorus was observed in summer. In the Rzeszów reservoir ecosystem, phosphorus was a limiting factor. If the N:P ratio decreased, the concentration of the nitrogen subjected to retention also decreased. In the Solina reservoir ecosystem, nitrogen was a limiting factor for a considerable period of research. The relation between N:P ratio and N_{ret} indicates that nitrogen assimilation is considered to be a significant mechanism of its retention.

1. INTRODUCTION

The term *nitrogen retention* means a difference between the loads of nitrogen that flow in water-body (pond, lake, reservoir, bay, estuary and even sea) and the loads that run off it. In the case of oligotrophic lakes loaded with balanced loads, nitrogen is available in a suitably oxygenated hypolimnion. Despite the fact that available amount of nitrogen is high enough, water organisms consume it in such a minimal degree that nitrogen retention may therefore be negligible (BERGE et al. [2] and WURTSBAUGH et al. [19]).

There are many factors determining the process. Nitrogen retention is a result of three phenomena taking place in water: sedimentation, assimilation by plants and denitrification (AHLGREN et al. [1], HEISKANEN et al. [5], JOSEFSON and RASMUSSEN [6], MAGUER et al. [10], NIELSEN et al. [12], PALMIERI et al. [13], TOMASZEK and CZERWIENIEC [15] and WINDOLF et al. [18]). There is no case that one of them dominates over the others. They mutually complement each other, and one of them can be

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transformed into the other, for example, water plants die and undergo biogegradation, giving the organic matter that is settling and creating conditions suitable for denitrification. Nitrogen retention may be dependent on the morphometry of waterbodies and also their loading with biogenic elements (KOSZELNIK and TOMASZEK [8] and LIN et al. [9]).

Discussing the reasons for nitrogen retention we cannot forget that this process is influenced by phosphorus whose transformations are being considered simultaneously. Based on the mechanism of eutrophication we conclude that nitrogen and phosphorus are interdependent, limiting often disadvantageous growth of water organisms. An indicator that describes this relationship is the N:P ratio. It may ranged from 100 for oligotrophic lakes and reservoirs to less than 10 for eutrophic ones. A stoichiometric N:P ratio approaches 15. Generally, if N:P ratio is higher than 15, phosphorus limits the process of of lake eutrophication. If this ratio is lower than 7, nitrogen limits the process. It can be assumed that if this ratio ranges between 7 and 15, both macronutrients are equally uptaken (MANDAVILLE [11]).

The value of N:P ratio influences some of the processes affecting nitrogen retention. GIBSON et al. [4] described the phenomenon of nitrogen release from bottom sediments which took place much easier when the N:P ratio of bottom sediment was higher than 29. High ratio of total nitrogen to total phosphorus for superficial waters indicates that only this part of nitrogen that is proportional to the above ratio can be subjected to retention due to biological transformations (ELSER et al. [3] and LIN et al. [9]).

2. METHODS OF INVESTIGATIONS

The tests were carried out on two dam reservoirs from the Podkarpacie Province (SE Poland): a large and deep Solina reservoir and a shallow and eutrophicated

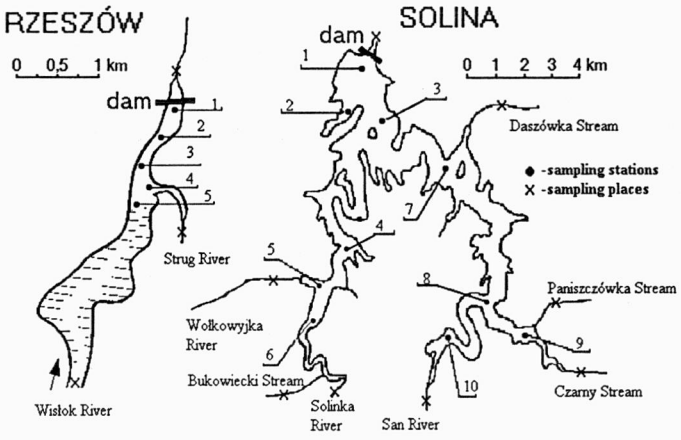

Fig. 1. Shape of the Rzeszów and the Solina reservoirs, with location of sampling stations and places

Rzeszów reservoir. The mass balances of nitrogen and phosphorus were established between March 1999 and March 2001. Samples were collected in estuarine sections of two tributaries to the Rzeszów reservoir, seven tributaries to the Solina reservoir, at outflows and at some points of the surface of water-body (figure 1). The investigations and calculations were made according to the methods described in [16].

3. RESULTS AND DISSCUSION

3.1. NITROGEN RETENTION

Summary results of the experiment are presented in the table. Nitrogen retention in both the Solina and the Rzeszów reservoirs was discussed in detail in the papers by KOSZELNIK and TOMASZEK [7], [8], TOMASZEK et al. [16], and TOMASZEK and KOSZELNIK [17]. Over the period analyzed 35%, on an average, of the nitrogen flowing in the Solina reservoir were retained. The highest value, i.e. of 2127 mg N $m^{-2} d^{-1}$, which was almost 73% of the nitrogen supplied, was measured on 20 July, 1999, while the lowest, 23 mg N $m^{-2} d^{-1}$, as soon as two months later. Over all periods examined the retention was on the similar levels. Its highest values were measured in summer, excluding the turn of the summer and autumn 1999 when the drought was responsible for minimal hydraulic loading of the reservoir, thus for the minimal nitrogen retention. Moreover, much of the element was in the reservoir in winter as well. Local minima occurred in spring and autumn.

Table

Range and mean values of nitrogen retention and ranges of both nitrogen and phosphorus concentrations and a corresponding N:P ratio

Reservoir	N_{ret} [mg N $m^{-2} d^{-1}$]	$N_{ret\%}$ [% of load]	Water from	N_{tot} [mg dm^{-3}]	P_{tot} [mg dm^{-3}]	N:P
The Solina	–23–411	–15–73	reservoir	1.34–3.30	0.04–0.32	7–70
reservoir	134	35	tributaries	1.76–6.22	0.01–0.62	6–146
The Rzeszów	178–2127	6–43	reservoir	0.78–3.09	0.03–3.39	1–59
reservoir	833	22	tributaries	2.03–4.56	0.1–1.0	3–29

The nitrogen retention calculated for the Rzeszów reservoir is higher than that predicted on the basis of literature data. The expected retention in such a small and shallow reservoir should be as high as 20%, maximally 30% of the load supplied. Meanwhile, an average value over the research period was 22%, and its maximum slightly exceeded 43%. Moreover, the values of nitrogen retention were relatively high and varied from 178 to 2127 mg N $m^{-2} d^{-1}$, with mean value of 833 mg N $m^{-2} d^{-1}$. Seasonal changes in the retention in both reservoirs were the same.

3.2. RELATIONS BETWEEN NITROGEN AND PHOSPHORUS

Based on the value of N:P ratio, it can be concluded that in the Solina reservoir, phosphorus content appeared to be the factor limiting the eutrophication process. However, in September and October the nitrogen was the limiting factor. The least values of N:P ratio were measured in the Bukowiecki stream and the Daszówka stream. They were considered to be the most polluted tributaries to the reservoir. Our observations showed that the N:P ratio in almost all rivers and streams and also in the reservoir decreased significantly over the last fifteen years (PŁUŻAŃSKI [14]).

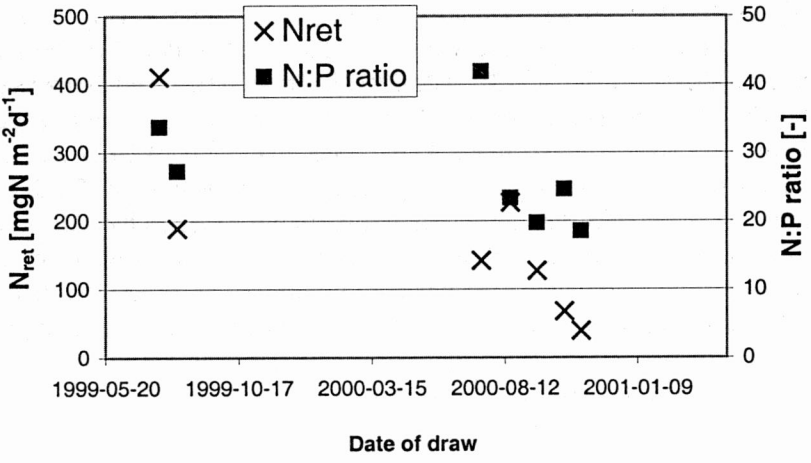

Fig. 2. Comparison of the seasonal changes in nitrogen retention and the N:P ratio in the Solina reservoir

Figure 2 shows changes in the N:P ratio against a background of changes in nitrogen retention in an analogical period. The distribution of values allows only observation of a decrease in nitrogen retention along with a decrease in the value of N:P ratio. This relationship encouraged us to develop a mathematical model representing both parameters, but we succeeded only partially (figure 3). For all the variables being correlated the regression was insignificant, and Pearson's correlation coefficient (R) reached only 0.44 ($n = 7$). However, after omitting one point (June 2000), representing low nitrogen retention and high N:P ratio, the correlation significantly improved (to $R = 0.85$), and the relationship became statistically significant at $p < 0.01$ with $n = 6$.

A sufficiently good correlation between nitrogen retention and phosphorus retention was also found (figure 4), but it should be mentioned that both parameters are expressed as moduli ($R = 0.75$, $n = 22$, $p < 0.001$). Therefore this is only a theoretical relationship which has not any practical application.

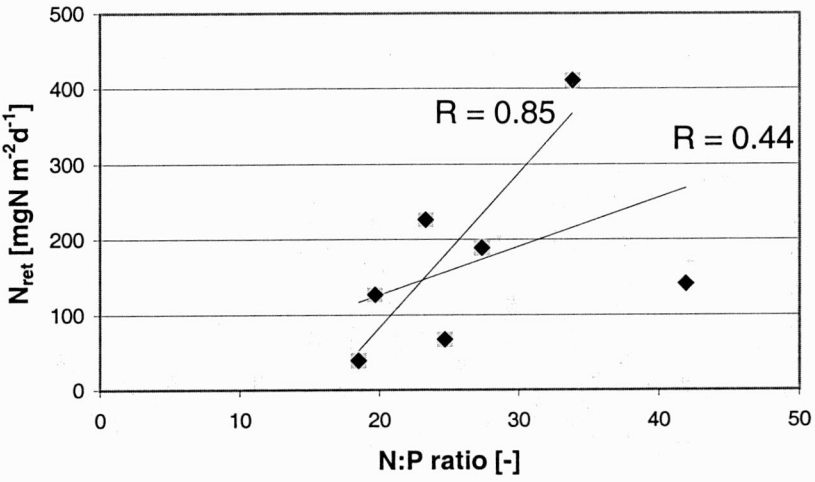

Fig. 3. Nitrogen retention versus N:P ratio in the Solina reservoir

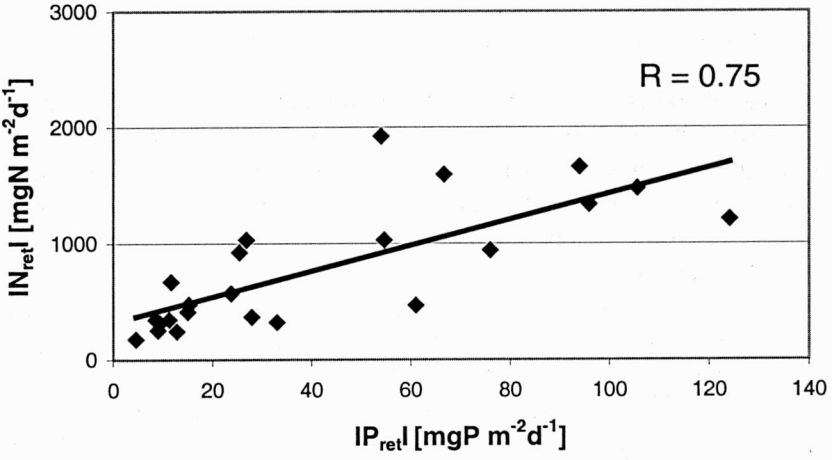

Fig. 4. The modulus of nitrogen retention versus the modulus of phosphorus retention in the Solina reservoir

The average values of the N:P ratio lower than 10 indicate that nitrogen is the limiting factor of eutrophicationin in the Rzeszów reservoir. Besides, the ratio has decreased with the age of the reservoir (PŁUŻAŃSKI [16]). At the beginning of the reservoir exploitation (1973–1975) phosphorus was the factor limiting the growth of

algae – N:P ratio ranged between 70–50:1. In the early eighties, a steady exhaustion of both biogens consistent with a stoichiometric N:P ratio of about 20:1 was observed. In 1997, the ratio was 15:1, whereas at present it is lower than 10:1.

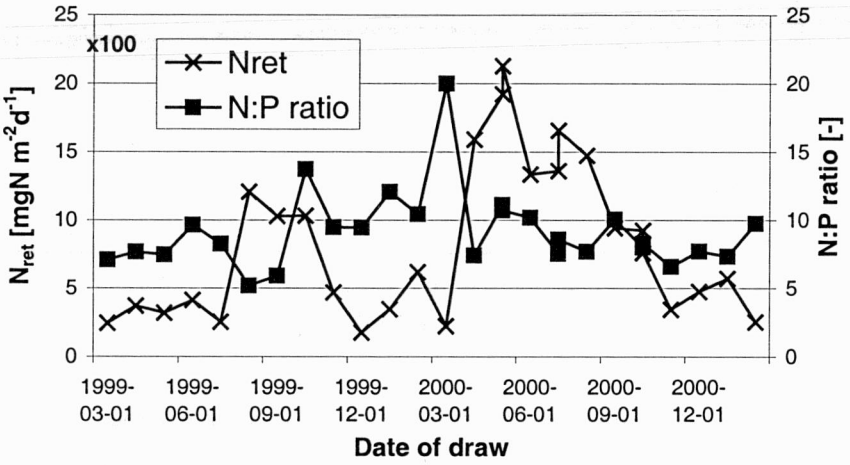

Fig. 5. Comparison of the changes in nitrogen concentration with N:P ratio in the Rzeszów reservoir

Figure 5 shows the changes in nitrogen retention and the N:P ratio over the period of investigations. Until October 2000 a decrease in the N:P ratio was closely associated with an increase in nitrogen retention. After that time this relationship was no longer observed. On the other hand this was observed for more than 75% of the period analyzed, thus it can be concluded that such a tendency may be attributed to the whole Rzeszów reservoir ecosystem.

As mentioned above, due to low values of the N:P ratio, nitrogen is a factor limiting the growth of the algae, while phosphorus is surplus. Large nitrogen loads in the reservoir's area (KOSZELNIK and TOMASZEK [7]) may have an effect on low values of the N:P ratio. Moreover, the low N:P ratio values may be caused by phosphorus removal from water as a result of: (a) sedimentation in shallow reservoir, (b) export outside the water-body, (c) accumulation in water organisms. The influence of phosphorus on the nitrogen retention in the Rzeszów reservoir is mainly shown in the fact that the N:P ratios determine faster depletion of nitrogen from water column, hence they accelerate the element retention. Comparison of N:P ratios with nitrogen retention and establishing their relationships over the seasons investigated allow us to recognize the nitrogen retention due to assimilation of this element by water plants as significant.

When the value of N:P ratio was decreasing which was probably connected with the reduction of total nitrogen concentration, there was observed a rise in the con-

centration of the element being retained. Taking this into account we can conclude that nitrogen retention was a the result of its assimilation. Direct and significant correlations between nitrogen retention and N-concentration as well as between N-load and retention of phosphorus were not observed. In all cases, the coefficient R did not exceed the value of 0.2. Phosphorus retention in the Rzeszów reservoir was greatly differentiated and independent of the season which can be explained by a shallowness of the reservoir and its flowing water body. In such reservoirs, suspended and biogen-containing particles can readily sediment but also resuspention may be of importance.

4. SUMMARY

In the Solina reservoir ecosystem, the phosphorus content was found to be the factor limiting eutrophication during a major part of year. Satisfactory correlation between the nitrogen retention and the phosphorus retention was found. When the N:P ratio decreased, the amount of nitrogen being retained decreased as well.

In the Rzeszów reservoir, the nitrogen content was identified to be the factor limiting eutrophication over the period analyzed. Low values of the N:P ratio can probably affect a faster depletion of available nitrogen from water column, thus they stimulate the growth of water organisms.

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RELACJA MIĘDZY STĘŻENIEM FOSFORU A RETENCJĄ AZOTU W WYBRANYCH ZBIORNIKACH ZAPOROWYCH PODKARPACIA (POLSKA POŁUDNIOWO-WSCHODNIA)

W ekosystemach dwóch zbiorników zaporowych Podkarpacia: solińskiego i rzeszowskiego w okresie 1999–2001 robiono bilans masowy azotu i fosforu. Określono wpływ fosforu w postaci ilorazu N:P na retencję azotu w obydwu zbiornikach. Średnia wartość retencji azotu wynosiła 134 mg N m^{-2} d^{-1} dla zbiornika solińskiego oraz 833 mg N m^{-2} d^{-1} dla zbiornika rzeszowskiego. W obydwu przypadkach najwyższe wartości zmierzono latem. W ekosystemie zbiornika solińskiego czynnikiem limitującym był fosfor. Obserwowano, że zmniejszaniu się ilości retencjonowanego azotu towarzyszy zmniejszanie się wartości stosunku N:P. W ekosystemie zbiornika rzeszowskiego przez większą część analizowanego okresu eutrofizację limitował azot. Relacja między wartością N:P a retencją azotu w tym zbiorniku wskazuje na asymilację azotu jako znaczący mechanizm retencji.