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Phosphorus retention in lake sections of Struga Siedmiu Jezior

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Abstract: In young glacial areas surface drainage system is formed by a river-lake network, i.e. such that consists of lakes connected by usually short river sections. Biogenic matter (both that getting from the catchment and that produced in it) transported in the river-lake system with water, is retained both in the lake as well as river sections of the system. Within one river-lake system lakes can be both a phosphorus trap as well as its source for lakes situated below. This problem is presented on the example of the Struga Siedmiu Jezior – the main stream of the "Bory Tucholskie" National Park.

Key words: river-lake network, phosphorus circulation, river continuum

Introduction

Drainage network in lakeland areas consists of lakes connected by short river sections. These are either II-III order streams flowing through small and shallow lakes draining areas of over ten to several dozen km^2, or large V-VI order systems with catchments of several hundred km^2 flowing through many small and shallow lakes as well as large and deep ones. Such a network is called a river-lake network (Bajkiewicz-Grabowska, 2002). It is a spatial system of alternately distributed two types of ecosystems, connected by water transport, i.e. rivers and lakes (Forman, Gordon, 1986; Hilbricht-Ilkowska, Węgleńska, 1995). In this system there is not only dynamic water exchange but also transformation and retention of matter carried by it and exchange of biomass and organisms.

Conditions of water circulation in a river-lake network are determined by physical-geographical features of the catchment (including its size, shape, relief, surface drainage system, surface formations, type of use); they also stimulate the rate of natural eutrophication of waters. Anthropogenic pressure on the catchment introduces additional energy and matter into water ecosystems thus posing a threat to the maintenance of stability of their natural trophic state.

River ecosystems within a river-lake network receive biogenic matter through: spread inflow from catchment, point sources (e.g. draining pipes), channel erosion, decomposition of matter accumulated in channel, and as a result of export from a lake situated above. In the stream channel and the zones of contact with surrounding land ecosystems, so-called ecotones, there are processes of transformation, retention and removal from circulation of transported biogenes, which lead to diminishing of their absolute load or limitation of their inorganic soluble forms (Hilbricht-Ilkowska, Kostrzewska-Szlakowska, 1996; Kufel, 1996; Wiśniewski, Rzepecki, 1996).

The functioning of a lake ecosystem within a river-lake network is slightly different. Lake ecosystem has a great ability to catch and trap (at least periodically) matter migrating from the catchment. It also produces large quantities of organic matter itself. The river flowing into the lake brings chemical compound and suspensions with water, and they influence the quality of lake waters directly, often causing excessive concentrations in water, and indirectly by initiating or hastening processes that worsen water quality and the functioning of the lake ecosystem. Since lakes in a river-lake network form a cascade system, it seems that due to the accumulation of the load of biogenes in the higher situated lake, the water of the reservoir situated lower should contain a smaller biogene load, unless it has an additional source of biogenes.

A river-lake system is thus a coherent and functionally interrelated system in which water as well as biogenic matter getting into the system (from the catchment and produced in it) is transported and transformed in subsequent lake and river fragments (Hilbricht-Ilkowska, 1999; Hilbricht-Ilkowska, Węgleńska, 1995). Lake "insertions" in a river-lake network disturb the so-called river continuum (Vannote et al. 1980) by changing outflow conditions of the river that flows through them (Bajkiewicz-Grabowska, 1996, 2002) and significantly modifying the transported matter load. This is so because the lake is a place of accumulation of matter both produced in this ecosystem and supplied from the catchment, mainly through the tributary. It can also be the source of biogenic matter which supplies the lower lying fragments of the river-lake network (Hilbricht-Ilkowska, 1999).

In the river-lake network in which lakes disturb the river continuum (Vannote et al., 1980; Minshall et al., 1985), the transport and transformations of mineral substances depend on the character of chemical compounds. Only the transport of water soluble and biologically inactive compounds (sodium, chlorides) proceeds as a continuous process – with the course of the river concentrations of these compounds diminish (e.g. Krutynia) (Hilbricht-Ilkowska, Kostrzewska-Szlakowska, 1996; Hilbricht-Ilkowska, 1999). Water transport of the remaining chemical compounds is dependent on the character of lake sections of the river. Lakes modify river transport of ions that form hardly soluble compounds (calcium) or, whose solubility depends on the redox potential (iron). These compounds are accumulated in lake sediments or released from them according to variable physical-chemical conditions.

Water transport of biogenic compounds is very complex. Biogenes that get into the river-lake network are quickly included in the biotic circulation of matter and also form many bonds of which, in the case of phosphorus, some are soluble and some hardly soluble.

This article presents the transport of biogenic matter in the river-lake system of the Struga Siedmiu Jezior and demonstrates which ecosystems of the network function as accumulating systems and which ones as exporting trophic compounds to ecosystems situated below. The results are based on research performed in May and August 2000.

Study area

The Struga Siedmiu Jezior drains into Lake Charzykowskie, situated on the course of the flow of the Brda, left-side lakeland tributary of the Vistula. This stream of 14 km of length drains an area of 41.5 km^2 that is a fragment of the Charzykowska Plain, which belongs to South Pomeranian Lakelands (Kondracki, 2000).

Almost the whole catchment of the Struga Siedmiu Jezior (85% of area) is situated within the "Bory Tucholskie" National Park. Like other rivers of this region, the Struga Siedmiu Jezior drains an outwash plain called the Great Brda Outwash, formed as a result of the erosive-accumulative action of melt waters of the Pomeranian phase of the Baltic glaciation. The outwash surface, more or less flat, is cut by postglacial channels of various orientations (Nowaczyk, 1994) and is rich in numerous melt-out hollows of varying size, depth and shape. At the bottoms of postglacial channels and hollows there are lakes, many of which are included in the system of surface outflow by streams that join them. In the catchment of the Struga Siedmiu Jezior, melt-out hollows without outflow are generally dry and cover 61% of the area (Nowicka, 2003). The catchment is covered in 96% by forest, whose species composition is dominated by the Scots pine.

The Struga Siedmiu Jezior is an example of a small river-lake network. It connects eight lakes of an area from 0.25 to 2.71 km^2 and mean depth from 0.5 to 11.1 m (table 1) into one coherent outflow system through short river sections (of a length from 43 m to 400 m). These lakes are situated in two channels: one with a longitudinal orientation – Lakes Ostrowite and Zielone – and other one with a latitudinal orientation – Lakes Jeleń, Bełczak, Główka, Płęsno, Skrzynka and Mielnica (fig. 1). The highest situated one is Lake Ostrowite (altitude 124 m a.s.l.), the lowest: Lake Mielnica and Skrzynka (altitude 120.4 m). The lakes of the Struga Siedmiu Jezior belong to two morphometric types. One type includes shallow polymictic lakes, represented by Lakes Jeleń, Bełczak, Główka, Płęsno, Skrzynka and Mielnica. Another type includes deep lakes, permanently stratified in summer of dymictic type: Lake Ostrowite and Zielone. Short river sections connecting the lakes have the character of overflows, as their functioning consists in water excess overflowing from one into another.

In majority the lakes have a passive hydrological regime (very small water exchange) and relatively

Table 1. Morphometric characteristics of lakes included in the outflow system by the Struga Siedmiu Jezior

Lake	Lake area [ha]	Lake capacity [tys. m^3]	Mean depth [m]	Lake catchment area [km^2]	Annual outflow [tys. m^3]	Susceptibility group*	Resistance category*	Threat category**
Ostrowite	280.7	29989.8	10.7	17.298	569	1	I	I
Zielone	25.5	2293.4	9.0	18.614	1019	2	II	III
Jeleń	48.8	2067.3	4.2	23.063	2148	2	III	IV
Bełczak	4.3	147.2	3.4	23.378	2158	3	II	IV
Główka	8.0	299.5	3.7	24.791	3184	2	II	IV
Płęsno Pilskie	47.8	2254.1	4.7	29.905	5296	2	II	IV
Skrzynka	21.1	369.8	1.8	38.101	5279	2	IV	IV
Mielnica	11.3	82.7	0.7	41.500	5313	2	IV	IV

* according to evaluation Bajkiewicz-Grabowskiej (1981)

**according to criterion Vollenweidera (1968, 1976)

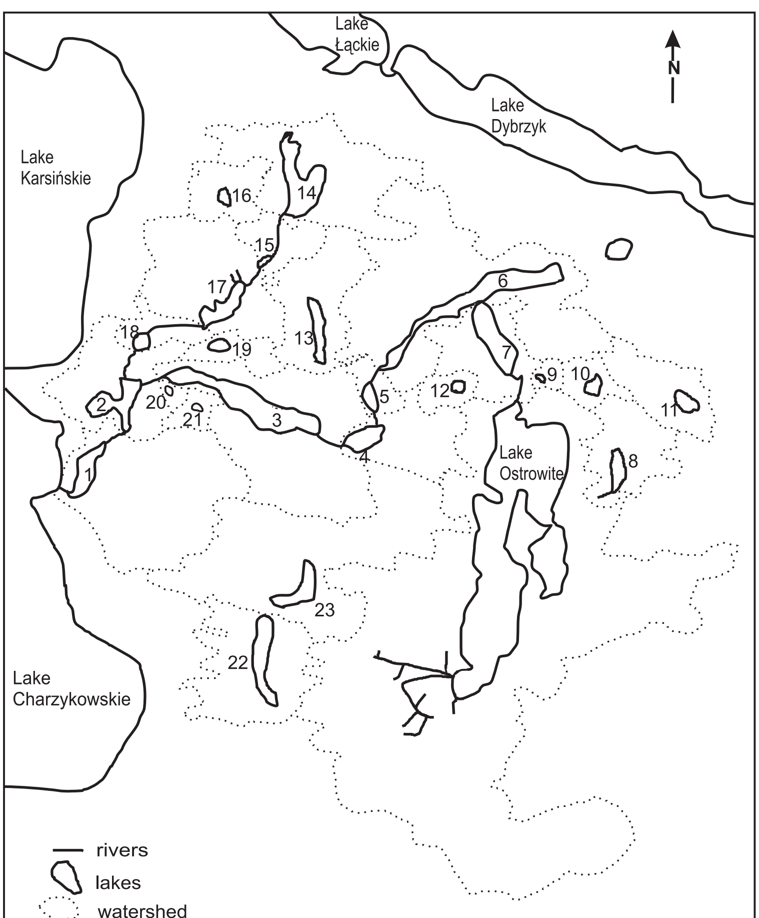

Fig. 1. Location sketch of investgated lakes.

large area of active bottom, which is favourable for internal supply with biogenic elements. Applying the evaluation of the natural eutrophication rate of lakes suggested by Bajkiewicz-Grabowska (1981, 2004) the reservoirs of the system of the Struga Siedmiu Jezior together with their catchments constitute three ecological systems of varying natural eutrophication rate (table 1).

The ecological system of catchment-lake of the first type has the lowest rate of natural eutrophication. Due to favourable catchment conditions (susceptibility group 1 or 2) and natural features of the reservoir (resistance category I or II) such a system is formed by the following lakes with their catchments: Ostrowite, Zielone, Główka and Płęsno. These reservoirs have the chance to preserve their trophy at a low level. A moderate natural rate of eutrophication of waters (ecological system of catchment-lake of second type) occurs in Lake Bełczak. It has resistance category II, and its catchment has susceptibility group 3. The third type, also with moderate natural eutrophication, but with the possibility of hastening when catchment conditions change includes Lake Jeleń, Skrzynka and Mielnica.

Results

The material collected within the scope of research on the preparation of a protection project of the Bory Tucholskie National Park indicated, among others, the role of lakes in phosphorus transport in the river-lake system of the Struga Siedmiu Jezior.

The determined annual supply of total phosphorus to the eight lakes of the studied Struga is from 0.05 to 4.41 g·m^{-2} of lake (Zdanowski, Stawecki, 2004). Lake Ostrowite, situated in a watershed zone, starting the sequence of the lakes drained by the Struga Siedmiu Jezior, receives from external sources very low loads of biophilous elements (0.05 gP·m^{-2} of lake annually), which stabilises its low productivity and oligotrophic status (Zdanowski, Stawecki, 2004).

The second lake in the sequence of the system of the Struga Siedmiu Jezior – Lake Zielone receives annually from external sources a load of phosphorus of 0.32 g·m^{-2} of lake; this is already a higher load than the dangerous one, according to Vollenweider's criteria (Zdanowski, Stawecki, 2004). Despite the high eutrophication threat (category III of threat), favourable catchment and morphometric conditions of the lake (table 1) help it preserve an oligotrophic status.

The annual phosphorus supply to the third lake in the system of the Struga Siedmiu Jezior – Lake Jeleń is 0.39 gP·m^{-2} of lake; this value is two times higher than the dangerous load calculated according to Vollenweider's criteria. Despite high eutrophication threat (category IV of threat, Zdanowski, Stawecki, 2004) the ecological system of catchment-lake still ensures a mesotrophic state of this reservoir

The following lakes of the system of the Struga Siedmiu Jezior: Bełczak, Główka, Płęsno Pilskie, Skrzynka and Mielnica annually receive a phosphorus load two or three times higher than the dangerous one according to Vollenweider's criteria, which gives the lakes category IV of threat (Zdanowski, Stawecki, 2004). Lake Bełczak receives annually 3.59 gP·m^{-2} of lake, Główka 2.79 gP·m^{-2} of lake, Płęsno 0.8 gP·m^{-2} of lake, Skrzynka 2.12 gP·m^{-2} of lake, and Mielnica 4.41 gP·m^{-2} of lake. Lakes Bełczak, Główka and Płęsno still have the status of mesotrophic lakes, whereas shallow and frequently mixed Lakes Skrzynia and Mielnica are already eutrophic lakes.

In the supply of total phosphorus into lakes, the dominating role is played by the stream that flows through them. Its participation in the whole supply of the lakes with this biogene is over 90%, only in Lake Ostrowite 20%.

The Struga Siedmiu Jezior carries little water: unit outflow in the catchment to the outflow from Lake Bełczak rises from 0.9l to 1.96 l/skm^2, whereas below this lake it ranges from 3.15 to 4.42 l/skm^2. The research performed in May and August 2000 (Zdanowski, Stawecki, 2004) revealed that concentrations of total phosphorus in river sections of the

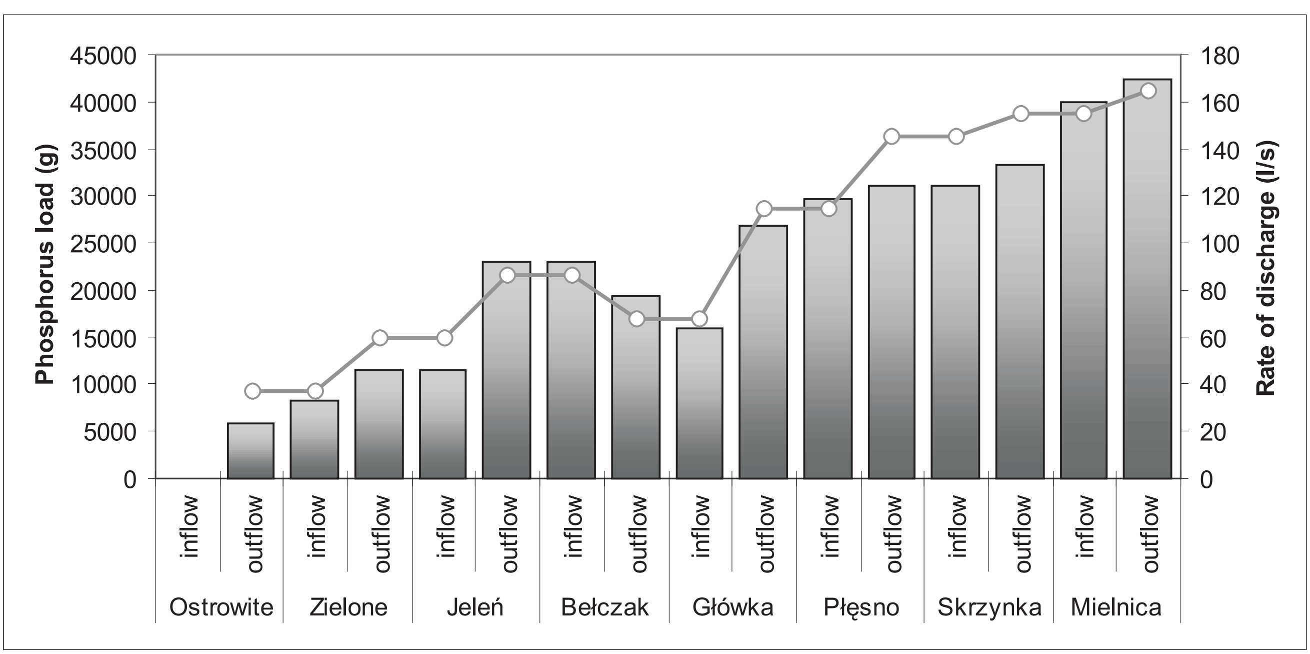

Fig. 2. Phosphorus transport with the course of the Struga Siedmiu Jezior against mean monthly discharge of the river (May, 2000)

Struga Siedmiu Jezior had an increasing tendency with the course of the stream, which means that the stream flowing through subsequent lakes introduced into them a growing load of total phosphorus (fig. 2, fig. 3). An exception in both investigated seasons was the river section between Lakes Bełczak and Główka, in which a noticeable reduction of phosphorus occurred (by 27-28%). A similar role was played in August 2000 also by river sections between Lakes Główka and Płęsno and Lakes Skrzynia and Melnica (observed reduction of phosphorus load by 5-6%). The lake sections of this stream increased the pools of the transported phosphorus; thus they were an additional source of this biogene for the stream.

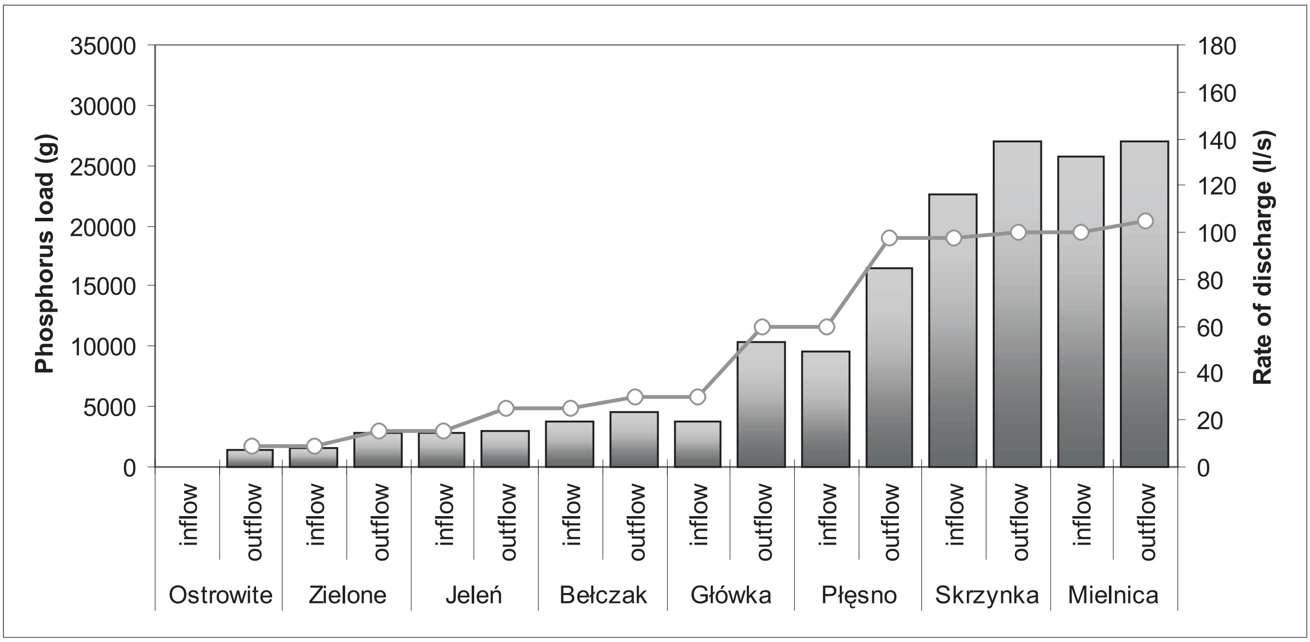

Fig. 3. Phosphorus transport with the course of the Struga Siedmiu Jezior against mean monthly discharge of the river (August 2000)

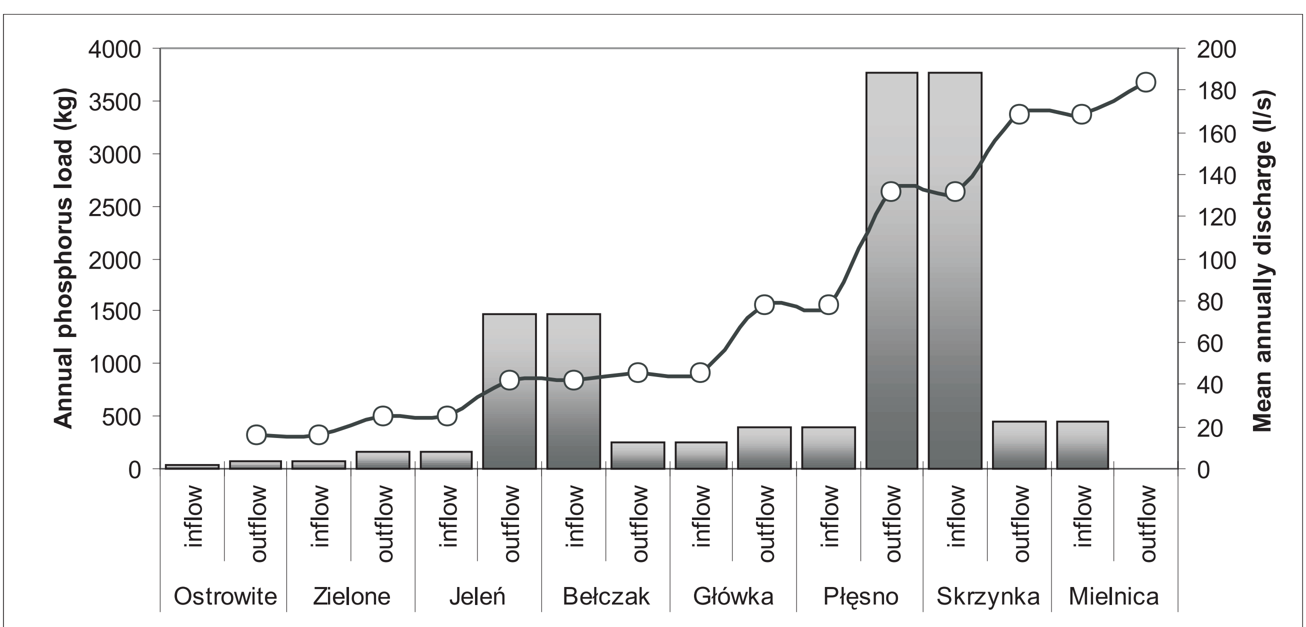

Fig. 4. Phosphorus transport with the course of the Struga Siedmiu Jezior against mean monthly discharge of the river in 2000

The annual load of total phosphorus transported into the lakes by the Struga Siedmiu Jezior was calculated on the basis of the data found in the paper by Zdanowski, Hutorowicz and Białokoz (2004). The tendency of continuous increase in phosphorus load in river waters with the growth of catchment is disturbed in the system of the Struga Siedmiu Jezior by some reservoirs either by increasing the phosphorus supply into the river section: insignificantly as Lake Ostrowite, Zielone and Główka or significantly as Lake Jeleń and Płęsno; or by limiting it as Lake Bełczak and Skrzynka (fig. 4).

In 2000 the lakes of the river-lake system of the Struga Siedmiu Jezior usually "exported" phosphorus outside the ecosystem. The main phosphorus "exporters" were Lakes Jeleń and Płęsno; the annual phosphorus load transported out of these lakes through the stream was almost ten times higher than the annual supply of this biogene to the lakes (fig. 4). In 2000 the river carried 1474 kg of phosphorus out of Lake Jeleń and 3775 kg out of Lake Płęsno. Phosphorus transported by the river was only reduced in Lake Bełczak and Skrzynka. These lakes in 2000 trapped over 80% of the load carried into them from the outside: Lake Bełczak "trapped" 1229 kg of phosphorus and Lake Skrzynka 3334 kg in the discussed year.

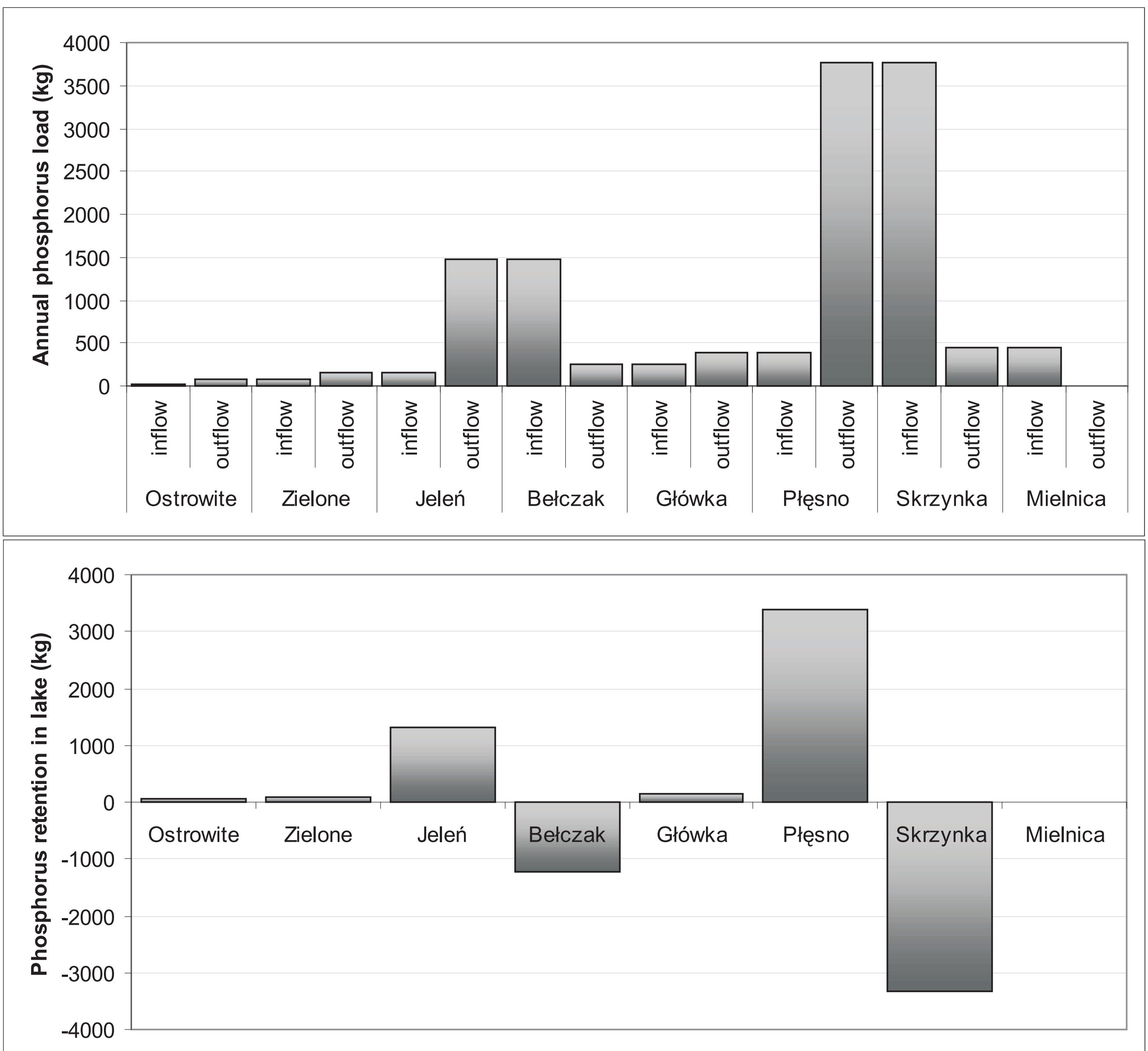

Fig. 5. Role of lakes in phosphorus transport with the course of the Struga Siedmiu Jezior

Discussion

The obtained results confirm the thesis that in the hydrographic network of young glacial areas, river continuum is disturbed by lakes. They change both the conditions of outflow of the river flowing through them and significantly modify the load of biogenic matter transported by the river. During transport the matter undergoes retention both in river and lake sections of the system.

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Streszczenie

Na obszarach młodoglacjalnych system drenażu powierzchniowego stanowi sieć rzeczno-jeziorna. Transportowana w tym systemie wraz z wodą materia biogeniczna (i ta która trafia do niego ze zlewni, i ta która jest w nim produkowana) podlegała retencji zarówno w odcinkach jeziornych, jak i rzecznych systemu. W ramach jednego systemu rzeczno-jeziornego jeziora mogą być zarówno pułapką fosforu, jak też jego źródłem dla jezior leżących poniżej. Problem ten przedstawiono na przykładzie małego systemu rzeczno-jeziornego – Strugi Siedmiu Jezior, głównego cieku Parku Narodowego „Bory Tucholskie". Ciek ten uchodzi do Jez. Charzykowskiego, leżącego na trasie przepływu Brdy, lewego pojeziernego dopływu Wisły. Na długości 14 km drenuje on obszar 41,5 km^2, stanowiący fragment Równiny Charzykowskiej wchodzącej w skład Pojezierzy Południowopomorskich.

Struga Siedmiu Jezior łączy krótkimi (o długości od 43 m do 400 m) odcinkami w jeden spójny system odpływu osiem jezior o powierzchni od 0,25 do 2,71 km^2 i głębokości średniej od 0,5 do 11,1 m (tab. 1). Jeziora te są usytuowane w dwóch rynnach: jednej o przebiegu południkowym – jeziora Ostrowite i Zielone – i drugiej o przebiegu równoleżnikowym – jeziora: Jeleń, Bełczak, Główka, Płęsno, Skrzynka i Mielnica (ryc. 1). Jeziora Strugi Siedmiu Jezior stanowią dwa typy morfometryczne. Jeden typ to jeziora płytkie, polimiktyczne (Jeleń, Bełczak, Główka, Płęsno, Skrzynka i Mielnica), a drugi to jeziora głębokie, trwale stratyfikowane latem, typy dymiktycznego (Ostrowite i Zielone). Krótkie odcinki rzeczne łączące jeziora mają charakter przelewów. W większości jeziora te mają pasywny ustrój hydrologiczny (bardzo mała wymiana wody) i stosunkowo dużą powierzchnię dna czynnego, co sprzyja wewnętrznemu zasilaniu w pierwiastki biogeniczne. Stosując zaproponowaną przez Bajkiewicz-Grabowską (1981, 2004) ocenę naturalnego tempa eutrofizacji jezior zbiorniki systemu Strugi Siedmiu Jezior wraz ze swymi zlewniami stanowią trzy układy ekologiczne o różnym tempie naturalnej eutrofizacji (tab. 1).

Z przeprowadzonych w maju i sierpniu 2000 r. badań wynika, że roczna dostawa fosforu ogólnego do ośmiu jezior odwadnianych przez Strugę wynosi od 0,05 do 4,41 g·m^{-2} jeziora (Zdanowski, Stawecki, 2004). W dostawie fosforu ogólnego do jezior dominuje przepływająca przez nie struga. Jej udział w całkowitym zasilaniu jezior tym biogenem wynosi ponad 90%, jedynie w jez. Ostrowite 20%.

Struga Siedmiu Jezior prowadzi niewiele wody: odpływ jednostkowy w zlewni do wypływu z jez. Bełczak rośnie od 0,91 do 1,96 l/skm^2, natomiast poniżej tego jeziora kształtuje się na poziomie 3,15-4,42 l/skm^2. W maju i sierpniu 2000 r. stężenia fosforu ogólnego w rzecznych odcinkach Strugi Siedmiu Jezior wykazywały tendencję wzrostową wraz z biegiem cieku, co oznacza, że przepływająca przez kolejne jeziora struga wprowadzała do nich coraz to większy ładunek fosforu ogólnego (ryc. 2, ryc. 3). Wyjątek stanowił w obu badanych sezonach odcinek rzeczny między jeziorami Bełczak i Główka, na którym następowała zauważalna redukcja fosforu (o 27-28%). Podobną rolę w sierpniu 2000 r. pełniły też odcinki rzeczne między jeziorami Główka i Płęsno oraz Skrzynka i Mielnica (stwierdzono redukcję ładunku fosforu o 5-6%). Jeziorne odcinki tej strugi zwiększały pule transportowanego fosforu; były więc dla cieku dodatkowym źródłem tego biogenu.

Tendencję ciągłego wzrostu ładunku fosforu w wodach rzecznych wraz z przyrostem dorzecza zakłócają w systemie Strugi Siedmiu Jezior niektóre zbiorniki, albo zwiększając dostawę fosforu do odcinka rzecznego, nieznacznie jak: Ostrowite, Zielone i Główka, lub znacząco jak: Jeleń, i Płęsno, albo znacznie ją ograniczając jak: Bełczak i Skrzynka (ryc. 4).

W 2000 r. jeziora systemu rzeczno-jeziornego Strugi Siedmiu Jezior na ogół „eksportowaly" fosfor poza ekosystem. Głównymi „eksporterami" fosforu były jeziora Jeleń i Płęsno; roczny ładunek fosforu wyprowadzony z tych jezior ciekiem prawie dziesięciokrotnie przekroczył roczną dostawę tego biogenu do jezior (ryc. 4). W 2000 r. z jeziora Jeleń rzeka wyniosła 1474 kg fosforu, a z jeziora Płęsno 3775 kg. Redukcja fosforu transportowanego rzeką zachodziła jedynie w jeziorach Bełczak i Skrzynka. Jeziora te w 2000 r. zatrzymały powyżej 80% ładunku wnoszonego do nich z zewnątrz: jez. Bełczak „zatrzymało" w omawianym roku 1229 kg fosforu, natomiast jezioro Skrzynka 3334 kg.