Teka Kom. Ochr. Kszt. Środ. Przyr. – OL PAN, 2014, 11, 22–35

THE EFFECT OF ENVIRONMENTALLY DIFFERENT LAKES ON THE CHANGES OF PHYSICOCHEMICAL VARIABLES IN THE RIVERS OF THE DRAWIEŃSKI NATIONAL PARK

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Summary. The Drawieński National Park (DNP) is a nature preservation area focused on the protection of water ecosystems, particularly rivers which are a unique part of the landscape. However, flow-through lakes located in the course of rivers flowing through the buffer zone of the DNP are exposed to unfavourable anthropogenic effects leading to their degradation and to the degradation of rivers flowing through the lakes. The aim of this study was to define the degree to which the river-lake systems in the buffer zone of DNP manage the retention of organic matter and answer the question: what may be the effect of these systems on the proper ecological function of the waters of the DNP rivers? Samples for physicochemical trials were collected from the inlet and outlet of lakes are located in the buffer zone of the DNP: Dubie, Tuczno, Korytnica, Lake Adamowo and Dominikowo. It can be claimed that lakes Dubie, Korytnica and Adamowo currently pose a threat to the rivers flowing through them and flowing into the waters in the DNP area. Tuczno does not pose a threat at present, but some variables indicate its incremental trophy that may have a negative impact on the DNP waters in the future. Dominikowo does not pose a threat to the DNP waters due to the favourable morphological conditions and the favourable catchment area.

Key words: river-lake systems, eutrophication, Drawieński National Park, Drawa river

INTRODUCTION

Eutrophication of waters intensified by human activity is a common issue concerning an increasing number of lakes and flowing waters, also those regarded as clean and resistant to degradation [Allan 1998, Lampert and Sommer 2007]. Recently we have observed significant acceleration of the process, which even lasts for several thousand years in natural conditions. The most frequent cause of this kind of eutrophication is the runoff of untreated sewage directly into the waters of lakes and rivers or the excessive runoff of biogenic compounds from agricultural catchment areas [Smal *et al*. 2005]. Moreover, unfavourable morphometric and hydrological conditions of water reservoirs which reduce vertical mixing of waters, which in turn leads to a significant increase in primary production, are also conducive to excessive eutrophication [Sługocki *et al*. 2012]. A crucial factor affecting the rate of eutrophication is the characteristics of the catchment area of lakes [Smal *et al*. 2005]. The most visible result of excessive eutrophication is rapidly deteriorating transparency of waters in the summer which is caused by rapid development of planktonic algae [Gołdyn and Kowalczewska-Madura 2008]. Another symptom of this process is gradual overgrowth of water reservoirs and watercourses by macrophytes [Stephen *et al*. 1997].

A crucial role in the function of rivers is played by lakes in river-lake-river systems [Hillbricht-Ilkowska 1993, Czerniawski and Domagała 2011, Czerniawski and Pilecka-Rapacz 2012]. They are specific sedimentation tanks for organic matter carried by a river [Wiśniewski and Rzepecki 1996]. In theory, lakes with a low trophic state ought to accumulate in sediments or mineralise a large part of inflowing organic matter, owing to which the amount of matter transported from the lake on the outlet is consequently smaller than on the inlet [Kufel 1993, Wiśniewski and Rzepecki 1996, Wotton 1988]. Such lakes play a significant role in the processes of self-purification of rivers. However, beyond all doubt, flow-through lakes upset the natural order of the river as clear changes in their many physicochemical and biological variables typical of stagnant waters are observed below their outlet [Minschal *et al*. 1985, Hilbricht-Ilkowska 1999]. However, lakes with a high status of eutrophication theoretically ought to discharge more organic matter on the outlet than they receive on the inlet. Such lakes, which accumulate significant amounts of detritus in their sediments, do not mineralise sediments as a result of oxygen deficiency and, in consequence, release inorganic biogenic compounds which induce rapid growth of phytoplankton [Lampert and Sommer 2007]. Thus, outlets of such lakes also alter the trophic structures of the river itself through the introduction of organic and inorganic nutrients into the river. As mentioned above, human activity affects the deterioration of abiotic conditions of lakes, also the flow-through ones. Flow-through lakes exposed to human activity significantly shorten the time of their function as sedimentation basins for organic matter from rivers flowing through them. It appears to be important to maintain flow-through lakes in the best possible ecological condition so that they can fulfil their role of sedimentation basins for organic matter, which will result in more efficient purification of rivers flowing through such lakes.

In this respect, particularly important flow-through lakes in terms of river protection are lakes located in nature preservation areas or in their buffer zones. The Drawieński National Park (DNP) is a nature preservation area focused on the protection of water ecosystems, particularly rivers which are a unique part of the landscape. However, flow-through lakes located in the course of rivers flowing through the buffer zone of the DNP are exposed to unfavourable anthropogenic effects leading to their degradation and to the degradation of rivers flowing through the lakes. Therefore, it is important to define the degree to which the lakes manage the retention of organic matter and answer the question: what may be the effect on the proper ecological function of the waters of the DNP rivers? The purpose of the tests was to determine the influence of lake waters on the condition of waters in the watercourses of the Drawieński National Park.

STUDY AREA

Samples for physicochemical trials were collected once a month from May to September 2012 at the inlets and at the outlets of the selected rivers from the five selected lakes in the drainage of the Drawa River: 1) lake Dubie lies in the drainage of the Cieszynka River, 2) lake Tuczno – Młynówka river, 3) lake Korytnica – Korytnica river, 4) Lake Adamowo – Drawa river, 5) lake Dominikowo – Słopica river. The lakes are located in the buffer zone of the Drawieński National Park. A rivers flows through each of these lakes and then flows into the Drawa river in the DNP area. The drainage of each lake, except of Lake Korytnica is from 70 to 90% agricultural area. Moreover, these lakes lie close to an urban agglomeration. Only Korytnica lake is surrounded by forest, however in upper drainage of river Korytnica occur agricultural areas. Basic characteristics of lakes examined are in the Table 1 [Filipiak and Raczyński 2010].

METHODS

The measurements of temperature, pH, conductivity and concentration of dissolved oxygen were performed using a multifunctional device manufactured by Elmetron (Poland). Determinations of $N\text{-}NH_3$, $N\text{-}NO_2$, $N\text{-}NO_3$, N_{tot}, PO_4, P_{tot} were performed using a Hach Lange photometer (USA). To nutrient analyses before the final photometrical measurements the method from Datalogging Colorimeter Handbook by Hach Lange was used. At each site the velocity, width and depth were measured with an electromagnetic water flow sensor OTT (Germany) to determine the discharge of water. The stream channel cross section was divided into five vertical subsections. In each subsection, the area was obtained by measuring the width and depth of the subsection, and the water velocity was determined using a current meter. The discharge in each subsection was computed by multiplying the subsection area by the measured velocity. The total discharge was then computed by summing the discharge of each subsection.

Table 1. Basic characteristics of lakes examined

Lake	Area, ha	Depth max., m	Depth mean, m	Trophic status	Mixing type	Schindler index, m^2/m^3	Altitude, m a.s.l.	Volume, $\times 10^3$ m^3
Adamowo	112	34.4	7.3	eutrophy	dimictic	216	77.3	8137.3
Dominikowo	78.6	16.5	9.3	mesotrophy	dimictic	5.3	79	7326.6
Dubie	19.2	5.1	1.9	mesotrophy	polymictic	96	59.5	373.8
Korytnica	111.3	4.7	2.4	polytrophy	polymictic	15	77.8	2636.5
Tuczno	128.9	20.2	9.1	mesotrophy	dimictic	1.3	75.4	11668.9

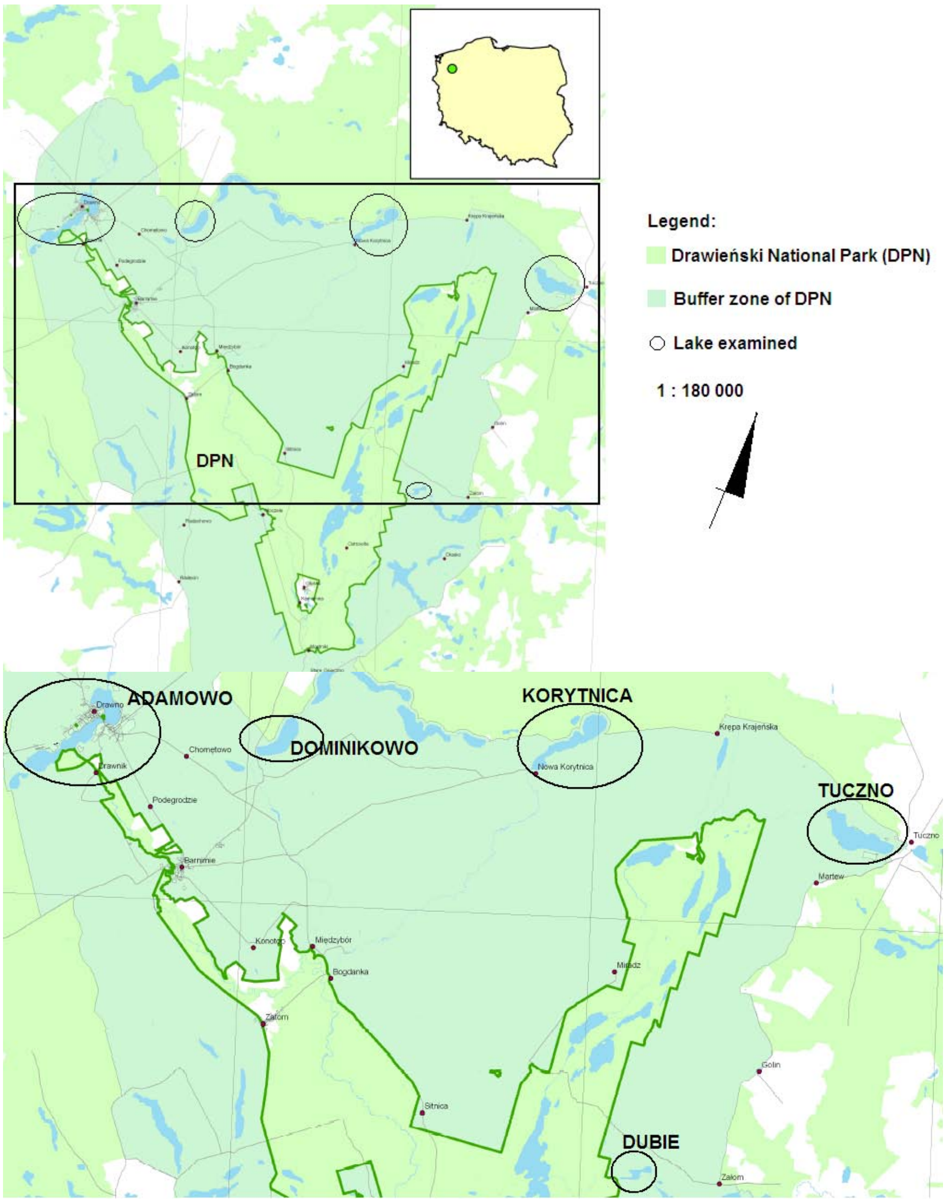

Fig. 1. Study area

The significance of differences in the values of individual physicochemical variables between the inlet and the outlet were analysed using a Mann-Wittney U test ($P < 0.05$) in STATISTICA 10 software.

RESULTS

In each of the tested lakes, the flow rate on the outlet was higher than on the inlet (Fig. 2). The highest flow rate was observed in Lake Adamowo whereas the lowest flow rate was observed in Lake Dominikowo. Monthly changes in the flow rate on the inlet and the outlet of each lake were similar.

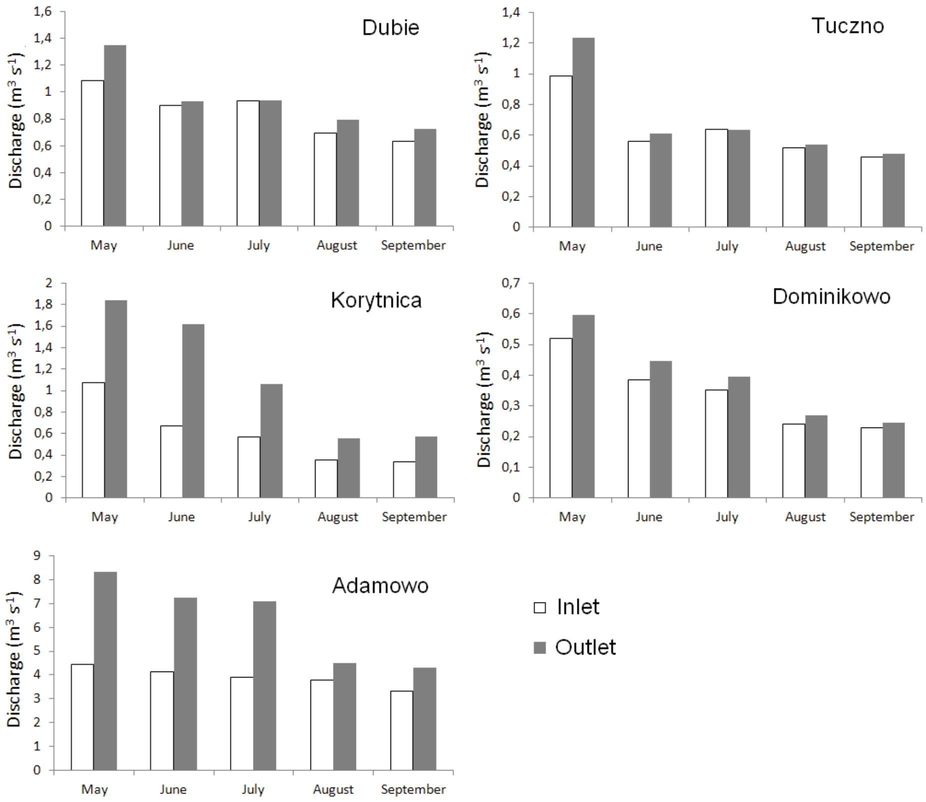

Fig. 2. Monthly changes of discharge in inlet and outlet of lakes examined

Higher values of all the physicochemical variables were observed on the outlet of each lake than on the inlet (Tab. 2). Moreover, in four of the lakes examined the values of some variables were significantly higher on the outlets than on the inlets ($P < 0.05$), namely in lakes Dubie, Korytnica and Adamowo. Significant differences between the inlet and the outlet were observed in the concentration of the following variables: dissolved oxygen content (Dubie, Adamowo), conductivity (Korytnica), $N\text{-}NO_3$ (Korytnica, Adamowo), $N\text{-}NO_2$ (Korytnica), $N\text{-}NH_3$ (Dubie, Tuczno, Korytnica, Adamowo), N_{TOT} (Korytnica, Adamowo), PO_4 (Tuczno,

Tabela 2. Mean values of physico-chemical variables in inlet and outlets of lakes examined

	Temperature ºC	O_2 mg l^{-1}	pH	Conductivity µS cm^{-1}	N-NO_3 mg l^{-1}	N-NO_2 mg l^{-1}	N-NH_3 mg l^{-1}	N TOT mg l^{-1}	PO_4 mg l^{-1}	P TOT mg l^{-1}	Suspended solids mg l^{-1}
Dubie Lake – River Cieszynka											
Inlet	19.1	**8.32**	8.27	328.0	0.2	0.003	***0.06***	1.2	0.17	**0.44**	**6**
Outlet	19.7	**9.47**	8.66	365.2	0.2	0.003	***0.19***	2.4	0.32	**1.73**	**13**
Tuczno Lake – River Młynówka											
Inlet	19.3	8.49	8.22	329.2	0.3	0.005	**0.12**	1.6	**0.18**	**0.37**	**6**
Outlet	18.8	9.37	8.48	340.4	0.2	0.007	**0.17**	1.8	**0.25**	**0.61**	**9**
Korytnica Lake – River Korytnica											
Inlet	13.5	9.06	8.16	**355.0**	***0.2***	***0.003***	***0.06***	***1.2***	0.17	**0.44**	***3***
Outlet	19.5	9.71	8.30	**380.1**	***0.6***	***0.014***	***0.19***	***5.1***	0.44	**1.77**	***16***
Dominikowo Lake – River Słopica											
Inlet	18.1	8.38	8.45	282.7	0.5	0.006	0.07	2.4	0.20	0.55	6
Outlet	18.3	8.55	8.61	288.4	0.5	0.007	0.08	2.7	0.21	0.57	7
Adamowo Lake – River Drawa											
Inlet	18.7	**8.24**	7.94	**313.2**	**0.1**	0.006	***0.15***	**1.4**	**0.16**	**0.25**	**7**
Outlet	19.5	**9.57**	8.89	**367.9**	**0.3**	0.004	***0.24***	**2.4**	**0.23**	**0.60**	**15**

Significant difference between inlet and outlet are marked with: Bold < 0.05; Italic < 0.01; No marked – not significant

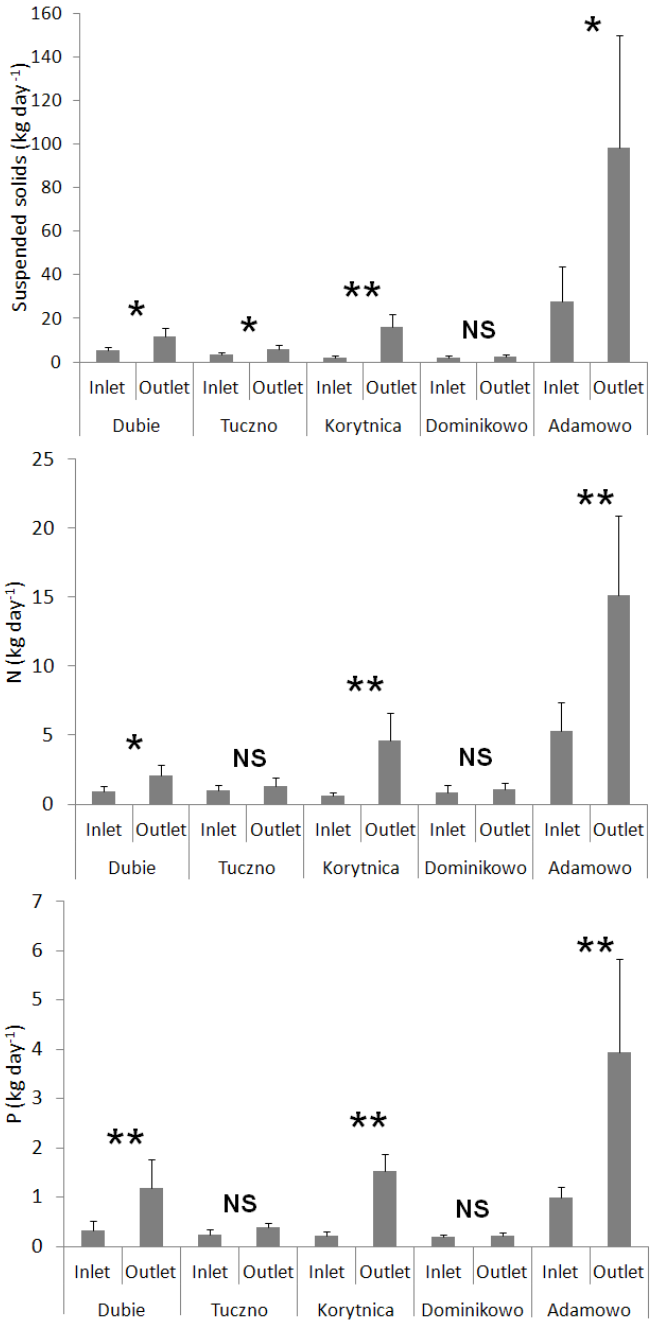

Fig. 3. Loading of suspended solids, total nitrogen and total phosphorus (kg day^{-1}) in inlet and outlet of lakes examined (mean + SD). Significant differences between inlet and outlet are marked with asterix: * $P < 0.05$; ** $P < 0.01$, NS – not significant

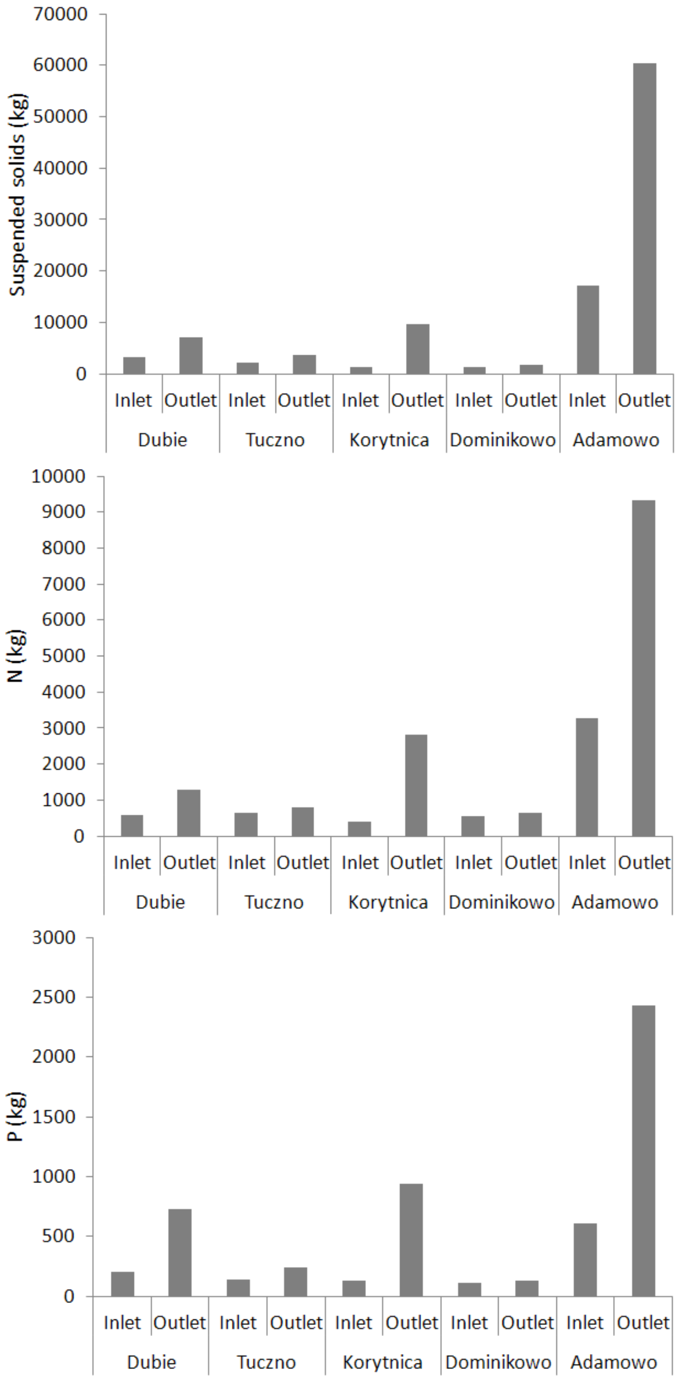

Fig. 4. Total loading observed from May to September of suspended solids, total nitrogen and total phosphorus in inlet and outlets of lakes examined

Adamowo), P_{TOT} (Dubie, Tuczno, Korytnica, Adamowo), suspended solids (Dubie, Tuczno, Korytnica, Adamowo). The only lake in which no significant differences in the values of the physicochemical variables between the inlet and the outlet were observed was Lake Dominikowo ($P > 0.05$).

Taking into consideration the mean daily mass of suspended solids, N_{tot} and P_{tot}, the most significant differences between the inlet and the outlet of the examined lakes were observed in: Lake Dubie, Lake Korytnica and Lake Adamowo (Fig. 3). Moreover, a significantly bigger mass of suspended solids was observed on the outlet of Lake Tuczno than on its inlet ($P = 0.016$).

During the whole period of tests, the biggest mass of suspended solids, N_{tot} and P_{tot} was transported into and out of Lake Adamowo (Fig. 4). The smallest amount of compounds was transported into and out of Lake Dominikowo.

DISCUSSION

The analysis of the results showed that three out of the examined lakes constitute a real threat to the waters of the Drawieński National Park. These are Lake Dubie on the Cieszynka River, Lake Korytnica on the Korytnica River and Lake Adamowo on the Drawa River. The content of phosphorus and nitrogen compounds on the outlets of these lakes is approximately twice as high as on their inlets. Similar changes concern the amounts of suspended solids. Attention should also be drawn to a significant difference in temperatures that occurs between the inlet and the outlet of Lake Korytnica and on average amounts to as much as 6°C. The value of conductivity on the outlets of these lakes is also significantly higher than on the inlets. Also, the concentration of oxygen and the pH value on the outlets of these lakes are significantly higher, which supposedly results from phytoplankton bloom in the vegetation period. The phenomena occurring in these lakes are accompanied by permanent changes in the species content, both in flora and fauna, e.g. in the ichthyofauna (our own observations and oral feedback from anglers and fishermen). In some cases, even disappearance of some fish species occurs due to too rapid changes in their environment that take place under the influence of biotic, abiotic and, predominantly, anthropogenic factors [Lampert and Sommer 2007].

It can be stipulated that the aforementioned lakes (Dubie, Korytnica and Adamowo) are in an advanced stage of eutrophication and do not function as sedimentation basins for the rivers that flow through them. The lakes are subjected to secondary contamination and thus cause a permanent increase in the amount of nutrients that are conducive to progressive eutrophication, which constitutes a threat to the waters of the Drawieński National Park. Moreover, Lake Dubie and Lake Adamowo lie close to urban agglomerations. Additionally, part of their drainage belongs to the agricultural area. According to Wiśniewski

[2007] lakes near towns and lakes in the agricultural drainage area are particularly susceptible to degradation, which is caused by the runoff of untreated wastewater as well as by the runoff of local impurities. Runoffs of treated and untreated wastewater, excessive exploitation of agricultural areas, rainwater outfalls in the sewage systems, and even the vicinity of allotments contribute to the occurrence of unfavourable conditions in these lakes [Smal *et al.* 2005] which directly affect the ecological balance as well as the rate of self-purification of waters. Lake Adamowo and Lake Dubie could have been recipients of untreated wastewater for many years, which may be related to the times of the People's Republic of Poland. Their current unfavourable condition is certainly a consequence of actions performed for many years before. However, sites of discharge of untreated wastewater in the vicinity of these lakes can still be found in villages or even in the centres of bigger places [Czerniawski *et al.* 2008, Domagała *et al.* 2010].

A particularly peculiar case is relatively big Lake Korytnica which lies far from urban agglomerations and whose direct catchment area is a forest. Therefore, it seems the lake should be characterised by a relatively good trophic condition. Excessive tides of alga *Ceratium hirudinella* is observed in the lake from spring to autumn as well as the outflow of significant amounts of zooplankton from the lake [Czerniawski and Domagała 2010, 2012]. The cause of such unfavourable conditions in Lake Korytnica is the presence before the inlet, in the course of the same river, of a very shallow lake (max. depth 0.5 m) called Lake Studnickie. This eutrophic water reservoir which heats up to over 28°C in the summer is characterised by a significant amount of detritus which releases organic and inorganic nutrients into the Korytnica River which transports them to Lake Korytnica. It has to be emphasised at this point that Lake Studnickie drastically affects the physiochemical and biological character of the Korytnica River. The lake is a critical point of changes in the Korytnica River. In the summer, the difference in temperature between the inlet and the outlet of this lake may even exceed 10°C.

Lake Adamowo is relatively deep (37 m) and the increase in the depth of lakes has a positive effect on purification of waters and the decrease in the rate of eutrophication [Gołdyn and Kowalczewska-Madura 2008, Czerniawski *et al.* 2010]. However, despite the significant depth, the lake has no favourable trophic condition, which has resulted from anthropogenic activity. As far as the aforementioned changes are concerned, it can be stipulated that Lake Dubie, Lake Korytnica and Lake Adamowo are not capable of functioning as sedimentation tanks for organic matter inflowing in the waters of the rivers due to the current anthropogenic effect.

Lake Tuczno ought to be regarded as a medium threat to the DPN waters. As a matter of fact, no significant differences on the inlet and the outlet are observed in the values of physicochemical variables, but almost a double increase in the amount of phosphorus compounds on the outlet is disquieting. Despite the fact that Lake Tuczno is located near a town Tuczno, it is not exposed to the runoff of nutrients, unlike Lake Adamowo. First and foremost, no discharge of untreated wastewater is observed here. Secondly, the direct catchment area of the lake is a forest. Moreover, Lake Tuczno is characterised by the largest area and a high mean depth and, as mentioned before, the correlation between these variables and the rate of eutrophication is negative [Seip *et al*. 1991]. Czerniawski *et al*. [2010] also claimed that lakes with the biggest depth in the drainage of the Drawa River are characterised by better trophic conditions than shallow lakes. In its whole area, Lake Tuczno has a typically thermal stratification in the summer. Its morphology and the characteristics of the catchment area cause slight susceptibility to degradation. Therefore, it can be stipulated that Lake Tuczno does not pose a threat to the DPN waters because it discharges in the Młynówka River a relatively smaller amount of nutrients in comparison to its inlet and in comparison to Lake Dubie, Lake Korytnica and Lake Adamowo. However, in the case of Lake Tuczno, some variables (e.g. suspended solids and phosphorus content) indicate a need to take proper action to protect the Młynówka River below the lake.

The only lake whose waters are not subjected to rapid eutrophication is Lake Dominikowo through which the Słopica River flows. A minimal increase in the physicochemical variables was observed on the outlet in comparison to the inlet into this lake. Therefore, it should be considered that Lake Dominikowo is a sedimentation basin for organic matter and plays a crucial role in the purification of the Słopica River flowing through it. Moreover, it has to be emphasised clearly that Lake Dominikowo lies in a favourable location of the Słopica River and the majority of its direct and indirect drainage is comprised of a forest. Above this lake, there are two deep lakes with a similar area which are also characterised by a mesotrophic status of the waters. Thus, they constitute a perfect sedimentation basin for organic matter from the Słopica River before it reaches Lake Dominikowo. The only threat to the Słopica River in the DNP area may be recreational fishing ponds located below the outlet of the Słopica River from Lake Dominikowo. These are ponds which derive water from and discharge water into the Słopica River, which causes an increase in the temperature of its water and biological changes in the river [Czerniawski *et al*. 2010]

Generally, the DNP waters are not directly in danger [Czerniawski *et al*. 2010] which is certainly affected by active care of the DNP functionary and the drainage systems for wastewater that are constantly developed and lower agricultural activity than in the previous year. It is therefore expectable that the quality of the waters examined by us will slowly improve. However, the present threats must not be ignored. We are also aware that our research does not reflect the full capability of purification of river waters in lakes, because we collected only one sample a month. But it constitutes a good prerequisite for further research in the physicochemical condition not only of waters, but also of sediments, paying special attention to their sorptive characteristics. The current condition of the lakes examined must be the consequence of human activity lasting for decades in the times of the People's Republic of Poland. Therefore, majority of attempts to protect the lakes as sedimentation basins for organic matter are induced by human activity from the past, not in the present time. However do not discontinue the use of appropriate protective treatments to restoration and preservation of these waters and to minimizing current threats.

CONCLUSIONS

1. Among all of the examined lakes the Lake Dubie, Lake Korytnica and Lake Adamowo currently pose a threat to the rivers flowing through them and flowing into the waters in the DNP area.
2. Lake Tuczno does not pose a threat at present, but some variables indicate its incremental trophy that may have a negative impact on the DNP waters in the future.
3. Lake Dominikowo does not pose a threat to the DNP waters due to the favourable morphological conditions and the favourable catchment area covered by forest. However, below the outlet from the lake, the Słopica River receives runoffs of nutrients from small ponds that are a threat to the ecological balance of this river.

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WPŁYW ZRÓŻNICOWANYCH ŚRODOWISKOWO JEZIOR NA ZMIANY PARAMETRÓW FIZYKOCHEMICZNYCH W RZEKACH DRAWIEŃSKIEGO PARKU NARODOWEGO

Strzeszczenie. Jeziora przepływowe leżące w biegu rzek płynących przez obszar otuliny Drawieńskiego Parku Narodowego (DPN) narażone są na niekorzystny wpływ antropogeniczny prowadzący do ich degradacji oraz do degradacji rzek poniżej ich odpływów. Badaniom poddano dopływy i odpływy jezior przepływowych znajdujących się przed DPN, w którym sprawdzano stan fizykochemiczny wód. Analiza wyników wykazała, że jeziora Dubie, na cieku Cieszynka, Korytnica, na cieku Korytnica i Adamowo, na cieku Drawa stanowią realne zagrożenie dla wód DPN. Natomiast jezioro Tuczno obecnie zagrożenia nie stanowi, ale niektóre wskaźniki świadczą o jego zwiększającej się trofii mogącej w przyszłości negatywnie oddziaływać na wody DPN. Jezioro Dominikowo ze względu na korzystne warunki morfologiczne i zlewniowe nie stanowi dla wód DPN zagrożenia.

Słowa kluczowe: systemy rzeczno-jeziorne, eutrofizacja, Drawieński Park Narodowy, rzeka Drawa