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Elżbieta Bajkiewicz-Grabowska

RESISTANCE OF LAKES OF THE KRUTYNIA RIVER-LAKE SYSTEM (MASURIAN LAKELAND) AND SUSCEPTIBILITY OF THEIR DRAINAGE BASINS TO DEGRADATION

A drainage basin constitutes a natural landscape system in which water constitutes the basic transport carrier and the vehicle of exchange of the various forms of matter between such ecosystems as forest, field, meadow, bog and lake. An especially interesting landscape system is the one formed by the lakes connected via a common course of a river. In this system the lenthic objects (lakes) and the lothic ones (rivers) appear in the natural space intermittently, and constant transport, exchange and cumulation of matter takes place, including biogenic matter, responsible for eutrophication of lakes. The rate of this process is influenced, in particular, by the physico-geographical structure of the drainage basin, advantageous or disadvantageous for the supply of the biogenic substances to the reservoir, and by the set of natural features of the lake.

THE PHYSICO-GEOGRAPHICAL ENVIRONMENT OF THE STUDY AREA

The watershed of Krutynia river, the "tourist zone" with a known sailing and rowing route, traced along the lakes and the river, with numerous areas of rural and tourist settlement types, constitutes a typical example of the hydrographic system, characteristic for the rolling lakeland landscape of northern Poland.

Krutynia river drains 700 sq.kms located within the Masurian Lakeland, forming the bow-shaped area turning towards the South (Fig. 1). In the western arm of the bow the river flows towards South–East, while in the eastern arm — towards North–East. The change of direction takes place in Spychowskie Lake (Fig. 1), located in the southernmost part of the basin.

The morphology of the Krutynia basin, similarly as of the whole Masurian Lakeland, is genetically connected with the accumulative and erosive activity of the continental glacier of the last glaciation period. Thus, we are dealing here with the young glacial landscape, featuring very diversified

relief, significant altitude differences, large number of (primarily finger-) lakes, many no-outflow lows, and the weakly developed natural drainage of flowing waters. The northern part of the basin has a rolling lakeland landscape, while the southern part — the outwash lakeland landscape (Kondracki, Mikulski, 1958).

The main geomorphological units in the drainage basin of Krutynia are the moraine uplands, lake gullies and outwash plains. Secondary relief forms appear within the confines of these units, including hills and mounds

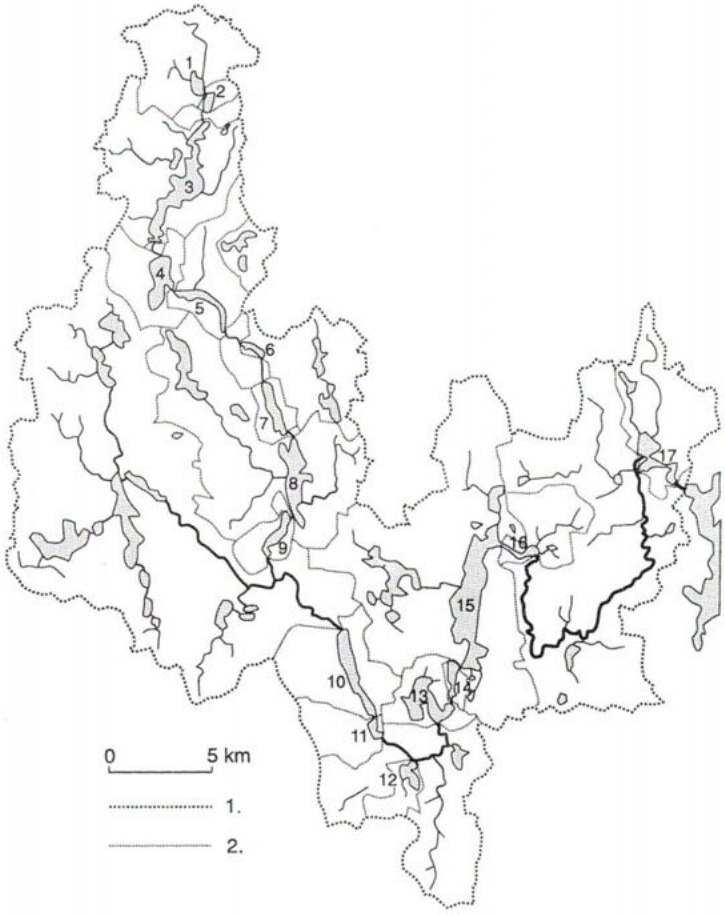

Fig. 1. The drainage basin of Krutynia river — the river network and the hydrographical divisions: 1. the Krutynia watershed, 2. watersheds of the lakes, through which Krutynia flows; the names of the lakes: 1 — Warpuńskie, 2 — Zyndackie, 3 — Gielądzkie, 4 — Lampackie, 5 — Lampasz, 6 — Kujno, 7 — Dłużec, 8 — Białe, 9 — Gant, 10 — Zyzdrój Wlk., 11 — Zyzdrój Mały, 12 — Spychowskie, 13 — Zdrużno, 14 — Uplik, 15 — Mokre, 16 — Krutyńskie, 17 — Gardyńskie.

of the accumulation moraines, as well as bank up moraines, kems, glacial pot- holes, and erosion cut-ins of various origin.

With respect to altitudes the area of Krutynia is quite differentiated. The western part of the basin is located on the average at the altitude by a dozen meters higher than the eastern part.

Among the surface formations of the Krutynia river basin the fluvioglacial and boulder material dominates. The sandy and gravel areas (the Masovian Plain, the outwash patches on the moraine upland) have very good permeability. The gravel-sand areas of frontal moraines display similar features. On the other hand the clay areas, taking the form of patches, have low permeability.

Brown and brown-podzolic soils dominate. Podzolic soils as such appear solely on the outwash plain. Important surfaces are also occupied by peats and silt soils.

One third of the area of Krutynia river basin is forested, the remaining part is under agricultural use.

THE HYDROGRAPHIC NETWORK

The main characteristic feature of the river basin of Krutynia is domination of lakes over other hydrographic objects. Lakes occupy 9% of total surface of the drainage basin (Fig. 1). There are 46 lakes of more than 5 hectares of area each. They are usually small, with up to 100 hectares of surface area (69% of all lakes), among which the very small ones dominate, of up to 50 hectares of surface. There are only six lakes (14% in terms of numbers) with more than 250 hectares of surface. The lakes of the Krutynia drainage basin are usually shallow: 50% of them do not exceed 10 metres of depth, and only five (11%) reach deeper than 30 metres. The total volume of these lakes is 420 million cu.m. There are 76% of lakes with less than 10 million cu. m of volume each, and 20% with volumes between 10 and 50 million cu.m.

The largest lakes of the basin are interconnected with the surface outflow system through Krutynia and Babant rivers and their confluents (Fig. 1). The lesser lakes do usually have no outflow.

The main river of the area considered is Krutynia, the confluent of Pisa (Vistula river drainage basin). It is a young river, composed of the intermittently appearing lothic (fluvial) and limnic (lake) segments. The limnic character of this river is well seen through the value of the ratio of the length of lake segments to the total length of the river, reaching 0.47. The length of the river is approximately 100 km, and the average slope is 0.28‰. Along its whole length the river flows through 17 lakes (Fig. 1), mainly finger lakes, differentiated as to their morphometric features. The surfaces of these lakes range between 24 and 841 hectares, their volumes — between 684.3 thousand cu.m and 107.3 million cu.m, and their maximum

depths — between 3.2 m and 51.0 m. The lakes through which Krutynia flows differ also in terms of the magnitude of basins drained, their cover, land use and hydrological characteristics, including water retention.

EVALUATION OF THE LAKE BASINS AND THEIR NATURAL SUSCEPTIBILITY TO DEGRADATION — THE METHOD AND THE RESULTS

The natural susceptibility of lakes and their basins to changes related to anthropopressure can be expressed through classification into groups of susceptibility (basins) and categories of resilience (lakes) according to the specific classification system proposed by the present author (Bajkiewicz-Grabowska, 1981, 1987).

The intensity of impact of the basin on the lake is assessed on the basis of features characterizing both the overall basin of the lake, and its direct basin (i.e. after having subtracted the part corresponding to the main inflow). These features for the whole basin are: the limnological coefficient (the ratio of the area of the whole basin of the lake to the lake surface), and the balance type of the lake (throughflow, outflow or no-outflow), informing of the inclusion of the reservoir into the system of surface flows. In case of a direct basin (from which the matter load is brought to the lake), we consider the following properties:

— the magnitude of the basin taking effectively part in the supply of the matter (it is measured with the degree of lack of outflow),

— the average slope of the basin, which constitutes the main condition for the area runoff,

— the density of the river network, providing the routes of the direct and quick transport of the matter,

— the permeability of the ground, which is decisive for the transport of the biogenic matter to the groundwaters,

— the land use, which influences the quantity and the form of the bio-elements in the surface runoff.

The above characteristics were empirically determined on the basis of topographical and soil-and-agricultural maps of the scale of 1:25 000 (Table 1).

The influence exerted by the basin on the intensity of supply of the matter to the lake is estimated by rating each of the properties listed before on the scale of 0 to 3 points, with 0 denoting a very weak influence on the supply of the matter and in fact lack of possibility that it reaches the lake, while 3 — strong influence and quick supply of the matter to the reservoir. The final assessment is obtained in the form of the arithmetic average of the ratings obtained for the individual properties (Table 2), which allows to classify the basins into four susceptibility groups:

group 1 — the average rating is not greater than 1; the basin strongly limits the surface flow and displays a virtual lack of capacity of supplying matter to the lake;

Table 1

Selected physico-geographical characteristics of the total and the direct basins of the lakes belonging to the river- and-lakes system of Krutynia

No	Lake	Total surface of the basin A_c (km^2)	Limnological coefficient A_c/A_j	Surface of the direct basin A_b (km^2)	No-outflow areas in the direct basin (%)	Density of the river direct basin (%)	Aerage slope of the direct basin (%)	Land use in % of area of the direct basin				
								Forests	Arable land	Meadows and pastures	Water bodies	Overbuilt areas
1.	Warpuńskie	21.6	44	21.6	11	0.48	15	10	77	8	0	5
2.	Zyndackie	22.8	58	1.2	0	0	39	8	89	2	0	1
3.	Gielądzkie	64.0	13	36.9	0	0.56	12	40	57	3	0	0
4.	Lampackie	78.6	40	14.6	9	0.78	15	11	84	4	0	1
5.	Lampasz	101.9	116	23.3	15	0.98	11	30	58	12	0	0
6.	Kujno	105.5	440	2.1	30	0.62	33	30	50	20	0	0
7.	Dłużec	114.5	93	5.7	0	0.76	13	3	89	4	0	4
8.	Białe	202.9	60	20.8	9	0.54	4	32	60	8	0	0
9.	Gant	209.3	278	5.6	0	0.32	9	98	0	2	0	0
10.	Zyzdrój Wlk.	402.5	192	20.6	46	0.36	6	76	20	2	0	2
11.	Zyzdrój Mały	412.6	814	10.1	0	0	8	98	0	2	0	0
12.	Spychowskie	431.1	883	5.1	0	1.30	6	68	10	12	0	10
13.	Zdrużno	468.1	187	9.7	0	0.26	5	94	1	4	1	0
14.	Uplik	470.5	776	2.4	66	0.48	28	53	40	6	1	0
15.	Mokre	568.7	68	47.6	27	0.20	6	63	28	6	2	1
16.	Krutyńskie	581.9	1058	13.2	6	0.66	7	95	0	4	1	0
17.	Gardyńskie	696.6	843	23.0	0	0.84	8	68	12	19	1	0

group 2 — the average rating is between 1.1 and 1.4; the basin is characterized by low susceptibility to triggering the motion of the load deposited on its area and by low possibility that it reaches the reservoir;

group 3 — the average rating is between 1.5 and 1.9; the basin features an average susceptibility, i.e. moderate capacities of supplying matter;

group 4 — the average rating is equal at least 2.0; the basin displays the high capacity of supplying the matter to the lake.

Table 2

Ratings of individual physico-geographical features of the basins of the Krutynia river-lake system and classification of the drainage basins of the lakes according to groups of susceptibility to suplly of the matter

Lake	Limnologoca coefficient		Degree of no-outflow	Density of the river network	Average slope of the basin	Geological type of the basin	Land use in the basin	Average rating
IIIrd susceptibility group — average susceptibility (between 1.5 and 1.9)								
Gielądzkie	1	3	3	1	2	2	1	1.9
Lampackie	2	3	3	1	2	1	0	1.7
Białe	2	3	3	1	0	2	1	1.7
Gant	3	3	3	0	1	2	0	1.7
Zyzdrój Wlk.	3	3	3	0	1	3	0	1.6
Zyzdrój Mały	3	3	3	0	1	3	0	1.9
Uplik	3	3	0	0	3	3	0	1.7
Zdrużno	3	3	3	0	0	3	0	1.7
Mokre	2	3	3	0	1	3	0	1.7
IVth susceptibility group — high susceptibility (at least 2.0)								
Warpuńskie	2	3	3	0	2	2	2	2.0
Zyndackie	2	3	3	0	3	2	2	2.1
Lampasz	2	3	3	1	2	2	1	2.0
Kujno	3	3	3	1	3	2	1	2.1
Dłużec	2	3	3	1	2	2	2	2.1
Spychowskie	3	3	3	2	1	3	2	2.4
Krutyńskie	3	3	3	1	1	3	0	2.0
Gardyńskie	3	3	3	1	1	3	1	2.1

The respective assessment indicates also which of the properties considered is conducive to the supply of the matter to the lake, and which of them hamper this process.

The lakes of the Krutynia river system have the drainage basins susceptible to setting in motion the area loads (Table 2). This fact is first of all due to such characteristics as througflow nature of lakes, geological structure of the basins, and their low degree of no-outflow.

The features conditioning the resistance of the lakes to the influence of

the basins — assessed, as well, on the scale of 0 through 3 points — are: the average depth of the lake, the ratio of the lake volume and the length of the coastline, the percentage of stratification of waters, i.e. percentage share of the layer of meta- and hypo-limnion in the whole mass of water, the ratio of the surface of the bottom within the reach of epilimnion and the volume of epilimnion, the annual average intensity of water exchange in the lake — that is, the ratio of the annual outflow and the volume of the lake, as well as the Schindler coefficient, namely the ratio of the surface receiving pollutants and the quantity of water diluting them (Bajkiewicz-Grabowska, 1987; Kudelska et al., 1983).

The necessary characteristics were calculated on the basis of batymetric plans of the lakes, elaborated by the Freshwater Fishery Institute, while the magnitude of outflow from the lakes was calculated on the basis of own measurements (Table 3).

Table 3

Values of the coefficients of natural resistance of the lakes to external influence

No	Lake	Average depth (m)	Ratio of lake volume to coastline length	Percentage of stratification of waters[1]	Ratio of the area of active bottom to the volume of epilimnion[2]	Intensity of water exchange in the lake[3]	Schindler's coefficient[4]
1.	Warpuńskie	2.6	036	28	0.39	2.8–4.0	17
2.	Zyndackie	4.0	0.50	19	0.18	2.4–3.4	14
3.	Gielądzkie	6.8	1.72	19	0.11	0.3–0.4	2
4.	Lampackie	11.1	2.40	47	0.07	0.6–0.8	4
5.	Lampasz	4.9	0.40	29	0.18	3.8–5.4	24
6.	Kujno	2.8	0.25	1	0.41	24.4–35.5	154
7.	Dłużec	6.3	0.97	40	0.17	2.4–3.4	15
8.	Białe	7.0	1.72	46	0.13	1.4–1.9	8
9.	Gant	9.5	1.20	33	0.10	5.3–8.9	29
10.	Zyzdrój Wlk.	4.9	0.89	24	0.15	7.5–9.6	39
11.	Zyzdrój Mały	3.9	0.48	20	0.26	40.1–51.5	210
12.	Spychowskie	2.3	0.33	2	0.44	72.4–93.6	382
13.	Zdrużno	5.4	1.03	16	0.16	6.8–8.6	35
14.	Uplik	2.8	0.26	9	0.33	53.9–68.1	276
15.	Mokre	12.7	4.56	40	0.07	1.1–1.3	5
16.	Krutyńskie	1.7	0.13	0	0.60	127.9–160.1	638
17.	Gardyńskie	2.4	0.50	11	0.36	65.7–83.8	340

[1]Percentage share of meta- and hypo-limnion in the whole mass of lake water,
[2] Ratio of the surface of the bottom within the reach of the epilimnion and the volume of epilimnion,
[3] Ratio of the annual outflow and the lake volume (1987–1989),
[4] Ratio of the total surface of the lakeŀs drainage basin and its volume.

The ultimate assessment is constituted by the arithmetic average of the ratings resulting from the evaluation of the influence of particular resilience features of the lakes. The average rating taking values up to 0.8 indicates that the given lake belongs to category I (highly resistant to external influences), when it is between 0.9 and 1.6, the lake belongs to category II (medium resistant), for values between 1.7 and 2.4 — to category III (little resistant), and above 2.4 — to category IV (non-resistant, i.e. strongly vulnerable to the external influences). As can be concluded from Table 4, the highest resistance to external impact characterizes two deepest lakes of the system of Krutynia river (Lampackie and Mokre), while the lowest resistance is displayed by the most shallow and smallest of these lakes (Kujno, Spychowskie, Uplik and Krutyńskie).

Table 4

Ratings of individual resistance features of the lakes belonging to the Krutynia system and classification of lakes according to the categories of natural resistance

Lake	Average depth (m)	Ratio of lake volume to coastline length	Percentage of stratification of waters	Ratio of the area of active bottom to the volume of epilimnion	Intensity of water exchange in the lake	Schindler's coefficient	Resulting rating
Ist category — high resistance (rating of at lest 0.8)							
Lampackie	0	2	0	0	3	0	0.8
Mokre	0	1	0	0	2	0	0.5
IInd category — medium resistance (rating between 0.9 and 1.6)							
Gielądzkie	1	2	2	1	3	0	1.5
Dłużec	1	3	0	1	2	1	1.3
Białe	1	2	0	1	2	0	1.0
Gant	1	2	1	0	1	1	1.0
IIIrd category — low resistance (rating between 1.7 and 2.4)							
Warpuńskie	3	3	1	3	2	1	2.2
Zyndackie	2	3	2	2	2	1	2.0
Lampasz	2	3	1	2	2	1	1.8
Zyzdrój Wlk.	2	3	1	1	1	2	1.7
Zyzdrój Mały	2	3	1	2	0	3	1.8
Zdrużno	1	3	2	2	1	2	1.7
Gardyńskie	3	3	2	3	0	3	2.3
IVth category — non-resistance (rating exceeding 2.4)							
Kujno	3	3	3	3	0	3	2.5
Spychowskie	3	3	3	3	0	3	2.5
Uplik	3	3	3	3	0	3	2.5
Krutyńskie	3	3	3	3	0	3	2.5

By combining the groups of susceptibility of the basins and the categories of resilience of the lakes we can distinguish four basic types of ecological basin-lake settings with differentiated rate of natural eutrophication (Table 5).

Table 5

Ecological lake-drainage basin settings according to their intensity of natural eutrophication (groups correspond to susceptibility of the basins to the supply of the matter, while categories — to lake resistance)

Type 2			Type 4		
Moderate eutrophication			Quick eutrophication		
Lake	Group	Category	Lake	Group	Category
Dimictic			Polymictc		
Białe	III	II	Warpuńskie	IV	III
			Zyndackie	IV	III
Polymictic			Lampasz	IV	III
Gielądzkie	III	II	Kujno	IV	IV
Lampackie	III	I	Zyzdrój Wlk.	III	III
Gant	III	II	Zyzdrój Mały	III	III
Dłużec	IV	II	Spychowskie	IV	IV
Mokre	III	I	Zdrużno	III	III
			Uplik	III	IV
			Krutyńskie	IV	IV
			Gardyńskie	IV	III

The first type represents such an ecological basin-lake setting in which both the natural properties of the reservoir (Ist or IInd category of resistance) and of the basin (1st or 2nd group of susceptibility) are not conducive to eutrophication of the lake waters; the lake is resistant to the influences from the outside, and its basin — little active in the supply of area loads to the lake. Such a setting is therefore capable of maintaining a low level of eutrophication. There are, however, no such reservoirs in the system of Krutynia river.

The second group is constituted by such an ecological setting in which the basin properties which are disadvantageous for the lake (high capacity of supplying solid matter to the lake — 3rd or 4th susceptibility group) are being compensated for by the high resistance of the lake to external influences (Ist or IInd resistance category). Consequently, the resulting rate of eutrophication should be moderate. This setting is represented by six lakes of the Krutynia system, including one polymictic lake (a shallow lake with stratification often disturbed during summer), i.e. Białe Lake, and five dimiktic lakes (deep ones, permanently stratified during summer), i.e. Mokre, Lampackie, Gielądzkie, Gant and Dłużec lakes (see Table 5).

The third type represents the basin-lake setting in which the advantageous basin conditions exist (the basin is little active in putting in motion

the area loads — 1st or 2nd susceptibility group), but the lake itself is vulnerable to external influence (IIIrd or IVth resilience category). Eutrophication of the lakes in this group progresses moderately, but an intervention in the basin conditions (like development of tourism, changes in land use, or land improvement operations), may result quite quickly in the increase of eutrophication of the lake waters. There is no representative of this group among the lakes of Krutynia system.

The fourth group is constituted by such ecological settings in which the natural conditions are disadvantageous for the quality of lake waters. The lakes are characterized by the IIIrd or IVthe category of resistance, and the basins by 3rd or 4th group of susceptibility. The natural features of the basin are conducive to area outflow, and the lake itself is highly vulnerable to external influence. Consequently, quick eutrophication of the lake waters follows. This type characterizes the remaining lakes of the Krutynia system, i.e. Warpuńskie, Zyndackie, Lampasz, Kujno, Large and Small Zyzdrój lakes, Spychowskie, Zdrużno, Uplik, Krutyńskie and Gardyńskie. These are polimictic lakes, often not stratified (e.g. Kujno, Uplik, Krutyńskie, Gardyńskie), see Table 5.

Out of 17 lakes being parts of the Krutynia system only six are characterized by the moderate eutrophication of their waters. These are the deep, permenently stratified lakes, resilient to external impacts; an exception here is constituted by the already mentioned Białe Lake.

The remaining 11 lakes of the Krutynia system feature quick eutrophication of their waters. They are polymictic lakes, little resistant to the influence of their respective basins, which, given high susceptibility of these basins to the supply of the matter, is conducive to cumulation of the outflows from the basin, and hence further eutrophication.

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