KOMITET EKOLOGICZNY-POLSKA AKADEMIA NAUK

EKOLOGIA POLSKA – SERIA A

Tom XIII | Warszawa 1965 | Nr 20

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THERMAL CONDITIONS IN MOUNTAIN WATERS AND THEIR INFLUENCE ON THE DISTRIBUTION OF *PLECOPTERA* AND *EPHEMEROPTERA* LARVAE*

The following thermal characteristics of mountain pools and streams were investigated: their mean daily temperature, their daily thermal astatism and the occurrence of vertical and horizontal temperature differences. The influence on the water temperature of prevailing meteorological conditions, the degree of shading, the surface flow and the amount of contact with subterranean water is discussed. Five types of water bodies were distinguished according to their daily mean temperature and degree of thermal astatism. A good correlation was obtained between the types of temperature changes occurring in a water body and the composition of its plecopteran and ephemeropteran fauna.

The aim of the present work is to extend our information on thermal conditions in mountain waters. The problem was chosen in order not only to compare, on a vide scale, the degrees of thermal astatism existing in these waters but also to examine their biological consequences.

In general, temperature conditions in Polish mountain waters are not well known. Best known are the Tatry lakes which already have a long history of investigation; some temperature observations on these lakes were made by Świerz (1894), Birkenmajer (1901), Lityński (1914, 1917) and Olszewski (1937, 1948); the latter (Olszewski 1951) summarised this information by dividing the lakes into thermal groups. A more recent study by Gliwicz, as yet unpublished, contains some temperature observations on Tatry lakes.

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Compared with the lakes, much less is known about temperature conditions in Tatry streams; Świerz (1894, 1897), Romer (1911) and Dyk (1940) contain some temperature records of Tatry streams whereas M. Gieysztor (1951) gives the longitudinal thermal profile along the course of several streams as well as the results of two series of twenty-four hourly observations. Dudziak (1956) records some temperature measurements he made during an ecological investigation on alpine planarians in the Western Tatry. Although little is known of the thermal conditions in Tatry streams compared with its lakes, even less is known about the streams of Bieszczady which have not been investigated systematically until now. Romer (1905) and Pawłowski (1959) have published some temperature observations from the streams Świdrowiec and Czarnohora in the eastern part of Eastern Beskidy.

Temperature conditions of mountain pools are completely unknown, there being only Pesta's (1932, 1935, 1943) work in the Alps.

Larvae of the insect orders *Plecoptera* and *Ephemeroptera* have proved to be useful biological indicators of various types of thermal conditions. Both orders, but especially the *Plecoptera*, are preponderantly cold stenothermal species and, together with trichopteran and chironomid species, form the most important components of the macrofauna of mountain streams. In the streams investigated by Percival and Whitehead (1929), the *Plecoptera* and *Ephemeroptera* constituted between 13–50% of the macrofauna of various types of stony bottom. Macan (1961) found the *Ephemeroptera* particularly useful for characterising streams. Illies (1953) used plecopteran, ephemeropteran, trichopteran and coleopteran species for extending the concept of river regions based on salmonid fish species. In his 1955 paper, he also reports that *Plecoptera* have only a small capacity for dispersal and, because of this, suggests that they are good material for studies on the distribution of organisms of mountain streams. Pleskot (1951) is also of the opinion that *Plecoptera* are good temperature indicators.

I. THE TERRAIN AND METHODS

Two areas in the Carpathian Mountains were investigated, the Tatry which include the highest peaks of the Carpathian chain (2663 m above m.s.l.) and Bieszczady, the western part of Eastern Beskidy (1425 m above m.s.l.). Most of the temperature observations were carried out in Bieszczady and fewer in the Tatry and only in order to compare with previous data.

Twenty five different water bodies were examined, of which eight were large streams, five were small brooks and twelve were pools. No temperature measurements were made in Tatry lakes and Olszewski's (1951) classification of these was adopted. In addition to some temperature measurements made in different years at five large Tatry streams and longitudinal temperature profiles of two streams, the twenty four hourly thermal cycle of twenty one waters at twenty six stations and forty one measuring points was also recorded. Below is listed the situations and characteristics of the waters in which temperature was measured over twenty four hours.

A. Large Tatry streams

1) Olczyski stream, above the mouth of its tributary, Świński, 970 m above m.s.l., observed from 19^{00} on 27th to 19^{00} on 28th August 1963, four hours' sunshine, measurements in the current at half depth where the total depth was 2.5 cm. The stream is 7 m wide, has a maximum depth of 40 cm and flows from south to north, with 90% shading.

B. Small Tatry streams

2) Left tributary of the Olczyski (Świński), above its junction with the Olczyski, 970 m above m.s.l., observed from 19^{00} on 27th to 19^{00} on 28th August 1963, four hours' sunshine, measurements in the current at half depth where the total depth was 5 cm. The stream is 1 m wide, has a maximum depth of 10 cm and flows from west to east through a steep wooded gorge, with 100% shade.

C. Large Bieszczady streams

3) Osława stream near Duszatyn (Fig. 1), 500 m above m.s.l., observed from 15^{00} on 11th to 19^{00} on 12th June 1963, three hours' sunshine, measurements in the current,

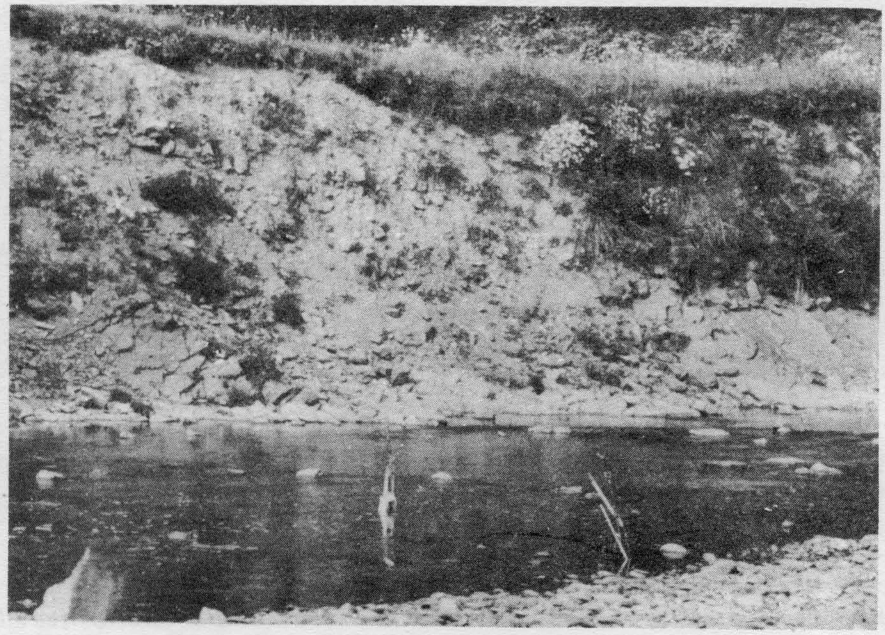

Fig. 1. Osława stream near Duszatyn in Bieszczady

at the surface and above the bottom 26 cm deep, as well as near the bank, also at the surface and above the bottom 8 cm deep. The stream is 15 m wide, has a maximum depth of 30 cm and flows from west to east, unshaded.

4) Kalnica stream near the habitation Kalnica, 500 m above m.s.l., observed from

12^{00} on 14th to 12^{00} on 15th June 1963, eight hours' sunshine, measurements in the current at the surface and above the bottom 8 cm deep as well as in stagnant water, at the surface and above the bottom 40 cm deep. The stream is 4 m wide, has a maximum depth of 40 cm and flows through meadows from south to north, partly shaded by shrubs.

5) Wołosaty stream near Ustrzyki Górne (Upper Ustrzyki), 650 m above m.s.l., observed from 10^{00} on 16th to 10^{00} on 17th June 1963, one hour's sunshine, measurements in the current at the surface and above the bottom 30 cm deep as well as in stagnant water also at the surface and above the bottom 15 cm deep; further observations were made from 9^{00} on 14th to 9^{00} on 15th September 1963, ten hours' sunshine, measurements in the current at the surface and above the bottom 30 cm deep as well as in stagnant water also at the surface and above the bottom 25 cm deep. The stream is 12 m wide, has a maximum depth of 30 cm and flows, unshaded, from west to east.

D. Small Bieszczady streams

6) Right tributary (I) of the Osława stream near Duszatyn (Fig. 2), 500 m above m.s.l., observed from 15^{00} on 11th to 19^{00} on 12th June 1963, three hours' sunshine,

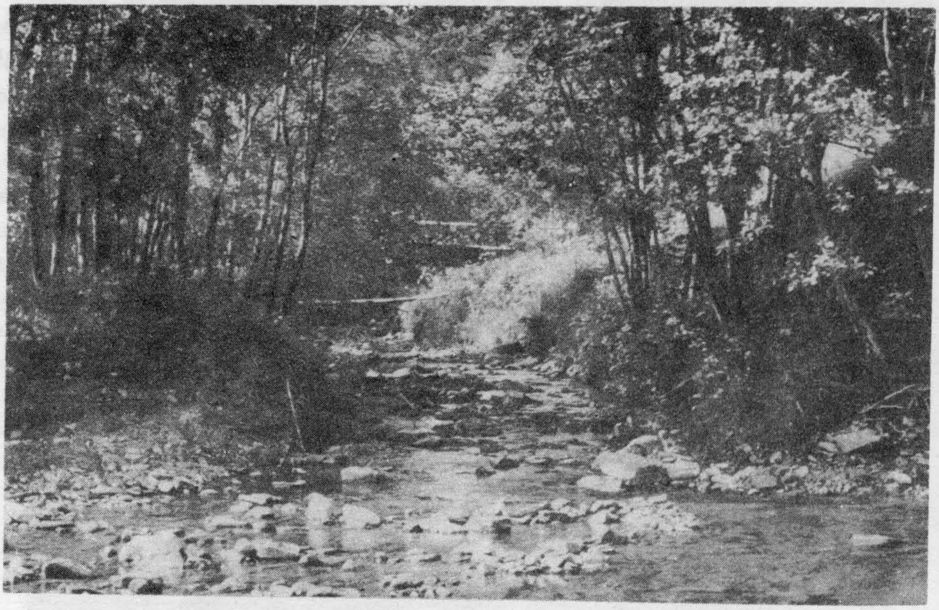

Fig. 2. Right tributary (I) of the Osława stream near Duszatyn in Bieszczady

measurements in the current at the surface and above the bottom 10 cm deep. The stream is 3 m wide, has a maximum depth of 10 cm and flows through a wooded gorge with 95% shading from north to south.

7) Right tributary (II) of the Osława stream near Duszatyn, 500 m above m.s.l., observed from 21^{00} on 11th to 16^{00} on 12th June 1963, three hours' sunshine, measurements made in the current at half depth where the total depth was 1 cm. The stream is 0.2 m wide, has a maximum depth of 2 cm and flows through a steep wooded gorge with 100% shading from north to south.

8) Left tributary of the Wołosaty stream near Ustrzyki Górne, 650 m above m.s.l.,

observed from 9^{00} on 14th to 9^{00} on 15th September 1963, ten hours' sunshine, measurements in the current at the surface and above the bottom 14 cm deep. The stream is 0.5 m wide, has a maximum depth of 14 cm and flows with about 95% shading from north to south.

9) Right tributary of the Wołosaty stream near Ustrzyki Górne, 650 m above m.s.l., observed from 13^{00} on 16th to 12^{00} on 17th September 1963, ten hours' sunshine, measurements in the current at half depth where the total depth was 3.5 cm. The stream is 0.2 m wide, has a maximum depth of 7 cm and flows through meadows from south to north with about 30% shading.

E. Bieszczady pools

10) Pool on first (lower) terrace (on the dry stream bed) of the Osława stream near Duszatyn (Fig. 3), 500 m above m.s.l., observed from 15^{00} on 11th to 19^{00} on 12th June 1963, three hours' sunshine, measurements at deepest point, at the surface and above bottom 10 cm deep. Surface area 22 m^2, sunny, without macrophytes, speed of flow 0.025 m/sec, a stony and mud bottom.

Fig. 3. A pool on the first terrace of the Osława stream near Duszatyn in Bieszczady

11) Pool on second (upper) terrace (on the stream bank) of the Osława stream near Duszatyn, 500 m above m.s.l., observed from 15^{00} on 11th to 19^{00} on 12th June 1963, three hours' sunshine, measurements at the deepest point, at the surface and above the bottom 15 cm deep. Surface area 8 m^2, 10% shading by shrubs, overgrown with macrophytes, with no water flow, black mud on the bottom.

12) Puddle on second terrace of the Osława stream near Duszatyn, 500 m above m.s.l., observed from 15^{00} on 11th to 19^{00} on 12th June 1963, three hours' sunshine,

measurements at the deepest point, at the surface above the bottom 8 cm deep. Surface area 6 m^2, sunny, without macrophytes, with no water flow, black mud on the bottom.

13) Pool near Kalnica, 500 m above m.s.l., observed from 12^{00} on 14th to 12^{00} on 15th June 1963, eight hours' sunshine, measurements at the deepest point, at the surface and above the bottom 10 cm deep. Surface area 200 m^2, 100% shaded by trees and shrubs, without macrophytes, with no water flow, mud and rotting leaves on the bottom (pH = 5.8).

14) Ditch at the roadside near Kalnica, 500 m above m.s.l., observed from 12^{00} on 14th to 12^{00} on 15th June 1963, eight hours' sunshine, measurements at the deepest point, at the surface and above the bottom 7 cm deep. Ditch with width of 0.2 m, sunny, overgrown with macrophytes, with no flow, clayey mud on the bottom.

15) Pool A on first terrace of the Wołosaty stream near Ustrzyki Górne, 650 m above m.s.l., observed from 10^{00} on 16th to 10^{00} on 17th June 1963, one hour's sunshine, measurements at the deepest point, at the surface and above the bottom 12 cm deep. Surface area 2 m^2, sunny, without macrophytes, supplied water from a small spring on the left, wooded bank of the Wołosaty, stones and mud on the bottom.

16) Pool B on first terrace of the Wołosaty stream near Ustrzyki Górne, 650 m above m.s.l., observed from 10^{00} on 16th to 10^{00} on 17th June 1963, one hour's sunshine, measurements at the deepest point, at half depth. Surface area 0.125 m^2, maximum depth 2 cm, sunny, without macrophytes, water supplied from pond A, stones and mud on the bottom.

17) Pool C on first terrace of the Wołosaty stream near Ustrzyki Górne, 650 m above m.s.l., observed from 10^{00} on 16th to 10^{00} on 17th June 1963, one hour's sunshine, measurements at the deepest point, at the surface and above the bottom 37 cm deep. Surface area 6 m^2, sunny, without macrophytes, without any flow, stones and mud on the bottom.

18) Pool D on first terrace of the Wołosaty stream near Ustrzyki Górne, 650 m above m.s.l., observed from 9^{00} on 14th to 9^{00} on 15th September 1963, ten hours' sunshine, measurements at the deepest point (8 cm) at half depth. Surface area 4 m^2, sunny, without macrophytes, without any flow, stones and mud on the bottom.

19) Pool 1 on second terrace of the Wołosaty stream near Ustrzyki Górne, 650 m above m.s.l., observed from 13^{00} on 16th to 12^{00} on 17th September 1963, ten hours' sunshine, measurements at the deepest point (12 cm) at half depth. Surface area 2 m^2, sunny, overgrown with macrophytes, connected with right tributary of the Wołosaty, speed of flow 0.005 m/sec, muddy bottom.

20) Pool 2 on second terrace of the Wołosaty stream near Ustrzyki Górne, 650 m m.s.l., observed from 13^{00} on 16th to 12^{00} on 17th September 1963, ten hours' sunshine, measurements at the deepest point (5cm) at half depth. Surface area 1.2 m^2, 95% shaded by shrubs, without macrophytes, speed of flow 0.016 m/sec, mud and leaves on the bottom.

21) Pool 3 on second terrace of the Wołosaty stream near Ustrzyki Górne, 650 m above m.s.l., observed from 13^{00} on 16th to 12^{00} on 17th September 1963, ten hours' sunshine, measurements at the deepest point (3cm) at half depth. Surface area 2 m^2, sunny, without macrophytes, water changed every 25 minutes, muddy bottom.

Measurements were made with decimal laboratory and soil thermometers whose scales were checked in 2°C steps from − 0.2°C to + 35°C by comparison with a thermometer certified by the Central Office of Measurement.

During one twenty four hourly period of observation, simultaneous measurements of the temperature of between 2 to 6 water bodies lying in an area whose diameter was not more than 400 m were carried out. Two thermometers were set up for the period of observation, one just under the surface of the water, the other just above the bottom; where the water body was very shallow, the temperature at half depth was recorded. In small pools the water temperature was measured at its deepest point whereas, in streams, in the current. In order to determine any small temperature differences occuring in streams, the temperature of the water near the bank and in stagnant water was measured in addition. A thermometer, 1.5 m above the ground, sited in the middle of this area containing the water bodies under investigation recorded the air temperature. In order to compare more easily the temperature variation over twenty four hours in the water bodies listed above, coefficients of daily themal astatism were introduced, similar to those coefficients for irregularity of flow used in hydrology.

The following coefficients were used:
Coefficient of daily thermal astatism of surface water:

$$Kp = \frac{\text{Max } p}{\text{Min } p}, \tag{1}$$

Coefficient of daily thermal astatism of bottom water:

$$Kd = \frac{\text{Max } d}{\text{Min } d}, \tag{2}$$

Coefficient of thermal astatism of a water body:

$$K_1 = \frac{Kp + Kd}{2}. \tag{3}$$

and where the temperature was measured only at half depth, the following coefficient was used:

$$K = \frac{\text{Max}}{\text{Min}} \tag{4}$$

where, Max p is the daily maximum surface temperature, Min p is the daily minimum surface temperature, Max d is the daily maximum bottom water temperature, Min d is the daily minimum bottom water temperature, Max is the daily maximum temperature at half depth and Min is the daily minimum temperature at half depth.

The themometers were protected by paper covers. The themometers used to measure air temperature were sited in a shaded place and, before recording the temperature, it was always checked that the mercury reservoir was dry externally.

Measurement of the longitudinal temperature profile was conducted in two streams in the same way as did M. Gieysztor (1951). The water temperature was recorded along the stream's course, from its spring to its mouth and at its characteristic points, including both above and below the tributary junctions as well as in the tributary itself; the air temperature was measured at the same time. Temperature records made irregularly during the faunistic work in summer and winter in the Tatry have also been included.

Other environmental factors in addition to temperature were investigated. Details of the methods used are described in Kamler and Riedel (1960). In streams the speed of surface flow was measured with floats (applying the methods contained in Klimaszewski, Pietkiewicz, Więckowska 1954), the maximum speed of flow and the time for a complete change of water by using a saturated solution of fluorescent sodium. In all the waters, the following features were noted, namely, the dimensions (width of streams, surface area of pools, depth at the temperature and biological sampling stations), the petrographic character, particle size of substrate and thickness of moss pad; the altitude above mean sea level was read from the map.

Biological samples were collected from the same stations where the temperature was measured. In streams mostly between eight or ten samples, occasionally more or less, were collected from two sections about 500 m long, lying above and below the point where the temperatures were read. In pools several samples were distributed evenly. The capture of the larvae were carried out by different methods depending on the nature of the bottom. A detailed description of these collecting methods is contained in the work of Kamler and Riedel (1960). In large streams, the following habitats occurred: stagnant water, gravel, stones and moss on rocks; in small ones: deep water (that is, bath-shaped depressions in the gravel bottom thus combining the characteristics of stagnant water and gravel habitats), stones and moss. Samples from the stagnant water, deep water or gravel habitats were collected by a bottom sampler pushed into the substratum, the collected material lifted out and seived and the larvae picked out. In the stony habitats, the procedure was as follows: a rectangle was marked out on the stream bottom from which the stony material was twice scooped out by pulling a metal-framed seive the required distance against the current. The stones were washed in a dish and the larvae picked out. In the mossy habitat, samples were collected by cutting a quadrat 10 cm by 10 cm in the moss under the water and later removing the larvae. Larvae from lakes and pools with a muddy bottom were collected in the same way as described above for stagnant water, deep water and gravel; those from lakes and pools with a stony bottom as described for the stony parts of streams. Macrophytes occurred occasionally in the pools investigated and then the larvae were collected by pushing a net through a marked area among the plants. Adults were caught with an entomological net either in the air, from trees on the banks or, the weak fliers, from the bank itself. All collected material was preserved in 75% ethyl alcohol.

II. RESULTS

1. Thermal conditions in streams

a. Mean daily temperature of streams. Table I gives the mean daily water temperatures of the streams and shows that, during the summer period, the large Tatry stream, Olczyski, was the coldest, with a temperature of 6.6°C. The small Tatry streams were warmer; the mean daily temperature of the left tributary of the Olczyski (Świński) was 10.4°C and a lower tributary of this stream was even warmer (Fig. 4A). Temperatures similar or somewhat

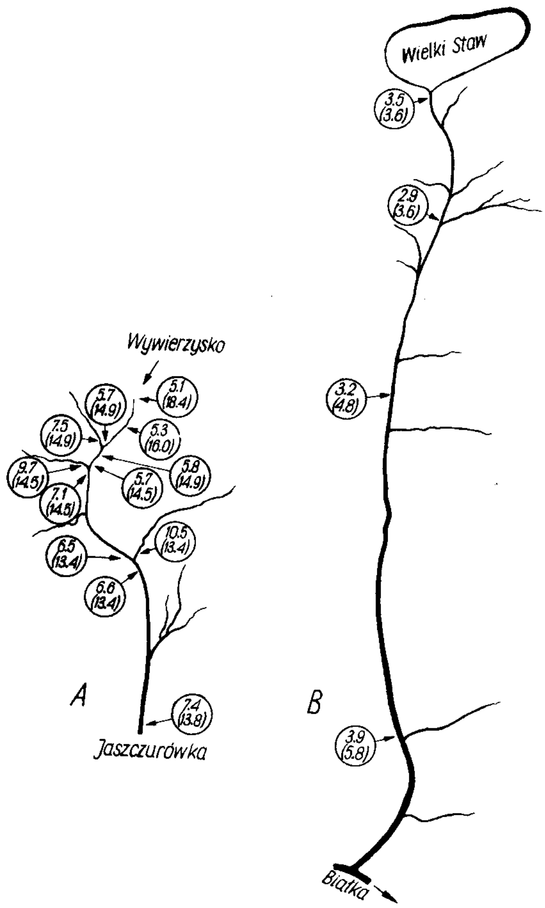

Fig. 4. Longitudinal temperature profiles of streams
A – Olczyski stream (mountain course) in Tatry, 28 VIII 1963 from 17[45] to 19[30], *B* – Roztoka stream in Tatry (Gieysztor 1951), 24 XI 1949 from 16[00] to 19[00]. The unbracketed figures inside the rings refer to water temperature and those in brackets to air temperature (in °C)

Tab. I

Mean twenty four hourly water temperatures in streams in summer 1963

Name of stream	Date	Station	Point	Mean twenty four hourly temperature °C	
				Air	Water
	A. Large Tatry streams				
Olczyski	27/28 VIII	in current	half depth	15.6	6.6
	B. Small Tatry streams				
Left tributary of the Olczyski (Świński)	27/28 VIII	in current	half depth	15.6	10.4
	C. Small Bieszczady streams				
Right tributary (I) of the Osława	11/12 VI	in current	surface	14.3	12.2
			bottom	14.3	12.1
Right tributary (II) of the Osława	11/12 VI	in current	half depth	15.1	11.3
Left tributary of the Wołosaty	14/15 IX	in current	surface	9.1	10.7
			bottom	9.1	10.5
Right tributary of the Wołosaty	16/17 IX	in current	half depth	14.6	13.0

	D. Large Bieszczady streams				
Osława	11/12 VI	in current	surface	14.3	17.5
			bottom	14.3	17.5
		near bank	surface	14.3	17.7
			bottom	14.3	17.7
Kalnica	14/15 VI	in current	surface	16.8	14.2
			bottom	16.8	14.1
		stagnant water	surface	16.8	14.0
			bottom	16.8	13.7
Wołosaty	16/17 VI	in current	surface	12.0	12.5
			bottom	12.0	12.4
		stagnant water	surface	12.0	12.5
			bottom	12.0	12.6
	14/15 IX	in current	surface	9.1	12.7
			bottom	9.1	12.4
		stagnant water	surface	9.1	13.8
			bottom	9.1	13.3

higher to those of small Tatry streams were shown by small shaded Bieszczady streams, the right tributary of the Osława and the left tributary of the Wołosaty (the range of mean daily temperatures being 10.5°C–12.2°C). Wamest of all were the large Bieszczady streams with a range of daily mean temperatures of between 12.4°C and 17.7°C. The right tributary of the Wołosaty, which flowed through open gently sloping country, had thernal characteristics similar, not to the small, but to the large Bieszczady streams and so has been ommitted from further consideration. Figure 5 illustrates the temperature changes throughout

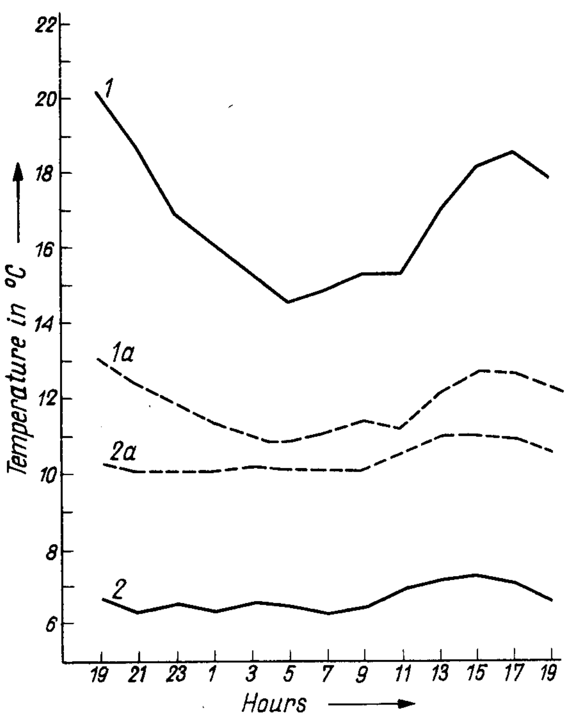

Fig. 5. A comparison of the temperature changes over twenty four hours in main streams and their tributaries

Bieszczady (11th – 12th June 1963): *1* – Osława stream, *1a* – right tributary (*I*) of Osława stream; Tatry (27th – 28th August 1963): *2* – Olczyski stream, *2a* – left tributary of Olczyski stream (Świński)

twenty four hours in streams belonging to different groups, namely, the Olczyski (a large Tatry stream), the Świński-left tributary of the Olczyski (a small Tatry stream), the right tributary (I) of the Osława (a small Bieszczady stream) and the Osława (a large Bieszczady stream).

b. Thermal astatism of streams. These streams differ not only in the level of their mean daily temperature but also in their thermal astatism.

Table II presents the coefficients of daily thermal astatism and the amplitude of air and stream temperatures over twenty four hours. The coefficient of thermal astatism (K_1 or K) of Tatry streams ranged between 1.09 and 1.15, of small shaded Bieszczady streams between 1.09 and 1.53 and of large Bieszczady streams between 1.33 and 2.66. The range of daily amplitude of water temperature showed a similar increase in values, being 0.9°C–1.1°C, 1.0°C–4.5°C and 3.3°C–12.8°C respectively.

The low level of temperature variation in Tatry streams is also revealed by isolated temperature records made in these streams at other times of the year. In the Olczyski on 11 III 1963, the water temperature ranged from +3.8°C to +4.1°C when the air temperature varied from +4.0°C to +5.3°C which reveals only slight differences in water temperature from those during the summer period (Table I), despite the greater differences in air temperatures. A not too great a difference was also observed in the Roztoka stream, where in July (14 VII 1956) the temperature of the water was +8.0°C and of the air +26.7°C, whereas in contrast in March (16 III 1963) these were +1.7°C and –17.0°C respectively.

c. The influence of meteorological conditions on stream temperatures. Meteorological conditions greatly influence the temperature of large Bieszczady streams. A comparison of the temperature changes occurring at the surface and near the bottom, both in the current and in stagnant water, was made for the stream Wołosaty throughout a twenty four hour period during different meteorological conditions. On the first occasion (16/17 VI 1963), the weather was cloudy and windy with one hour of sunshine; on the second occasion (14/15 IX 1963), the wind was very weak and sunshine lasted for ten hours. Figure 6 presents the curve of temperature changes in the current and in stagnant water, given as the mean of the temperatures of the two levels. Windy weather and weak sunshine causes a flattening of this curve and makes more similar the temperature changes over twenty four hours in the current and in stagnant water of the thermally astatic large streams in Bieszczady.

Compared with the large streams, the small streams of Bieszczady showed less temperature variation in different meteorological conditions. The coefficient of thermal astatism (K_1) of the right tributary (I) of the Osława on 11/12 VI 1963 (with three hours of sunshine) was 1.31 and the daily water temperature amplitude was 3.3°C at the surface and 3.5°C near the bottom; on 14/15 IX 1963 (with ten hours of sunshine), the coefficient K_1 was 1.53 and the daily amplitude was 4.5°C and 4.3°C respectively for the left tributary of the Wołosaty. This shows that the temperature of small streams is to a great extent independent of meteorological conditions.

d. Vertical and horizontal temperature differences in streams. Investigations on the vertical thermal micro-differences in streams

Coefficients of thermal astatism and temperature amplitudes over twenty four hours in streams (summer 1963)

Tab. II

Name of stream	Date	Station	Point	Coefficients				Amplitudes in °C	
				Kp	Kd	K_1	K	air	water
A. Large Tatry streams									
Olczyski	27/28 VIII	in current	half depth				1.15	7.1	0.9
B. Small Tatry streams									
Left tributary of the Olczyski (Świński)	27/28 VIII	in current	half depth				1.09	7.1	1.1
C. Small Bieszczady streams									
Right tributary (I) of the Osława	11/12 VI	in current	surface	1.30		1.31		13.1	3.3
			bottom		1.32			13.1	3.5
Right tributary (II) of the Osława	11/12 VI	in current	half depth				1.09	6.7	1.0
Left tributary of the Wołosaty	14/15 IX	in current	surface	1.55		1.53		13.2	4.5
			bottom		1.52			13.2	4.3
Right tributary of the Wołosaty	16/17 IX	in current	half depth				2.23	21.4	9.0

D. Large Bieszczady streams									
Oława	11/12 VI	in current	surface	1.54		1.55		13.1	7.9
			bottom		1.56			13.1	8.0
		near bank	surface	1.58		1.58		13.1	8.5
			bottom		1.59			13.1	8.6
Kalnica	14/15 VI	in current	surface	1.38		1.36		18.3	4.3
			bottom		1.35			18.3	4.1
		stagnant water	surface	1.38		1.33		18.3	4.4
			bottom		1.28			18.3	3.3
Wołosaty	16/17 VI	in current	surface	1.45		1.46		5.5	4.5
			bottom		1.48			5.5	4.7
		stagnant water	surface	1.45		1.44		5.5	4.5
			bottom		1.44			5.5	4.4
	14/15 IX	in current	surface	2.38		2.39		13.2	10.9
			bottom		2.41			13.2	10.7
		stagnant water	surface	2.61		2.66		13.2	12.7
			bottom		2.71			13.2	12.8

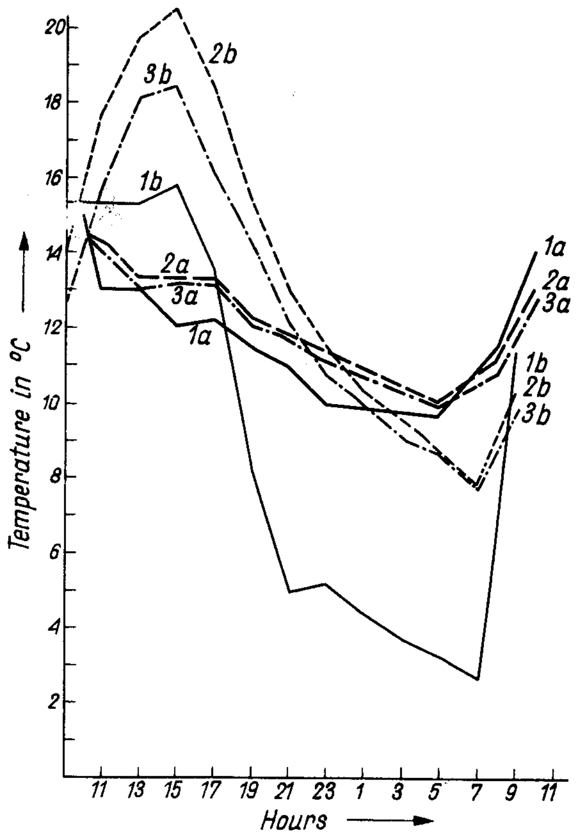

Fig. 6. Temperature changes over twenty four hours in the Wołosaty stream during different meteorological conditions

1 — air temperature, *2* — temperature of stagnant water, *3* — water temperature in the current, *a* — 16th — 17th June 1963, *b* — 14th — 15th September 1963

revealed no differences between the daily temperature cycle occurring near the bottom and at the surface of the water (Tables I and II). Even during very sunny days (14/15 VI 1963 and 14/15 IX 1963) in deep (40cm and 25cm) stagnant waters in the Kalnica and Wołosaty streams, the temperatures over twenty four hours at these two levels were very similar. Apparently even in a weak water flow such as 0.043 and 0.005 m/sec. (maximum flow), when the whole water is changed every 12 and 45 minutes, no temperature stratification was evident. On the other hand, slight thermal micro-differences did occur in different parts of the streams. On 11/12 VI 1963, the temperature near the bank of the Osława was a little higher (17.7°C) than in the current (17.5°C). A somewhat greater thermal variation occurred in the water near the banks (K_1 was 1.58, the temperature amplitude at the surface and near the bottom was 8.5°C and 8.6°C) than in the current (K_1 was 1.55, the temperature amplitude was 7.9°C and 8.0°C respectively). In the Wołosaty, such temperature differences occurred in the current and in stagnant water only during very good weather (14/15 IX 1963, Fig. 6); then the values for the mean daily temperature, the coefficient of thermal astatism and the temperature amplitude were higher in the stagnant water than in the current; the mean water temperature at the surface and near the bottom was 13.8°C and 13.3°C in stagnant water and 12.7°C and 12.4°C in the current; K_1 was 2.66 in stagnant water and 2.39 in the current; the daily temperature amplitude at the surface and near the bottom was 12.7°C and 12.8°C in stagnant water and 10.9°C and 10.7°C in the current.

e. Observations on the formation of an ice cover in Tatry streams. Observation on the covering of Tatry streams with ice were carried out from January to March 1963. Large streams were never completely frozen. Snow accumulates in large amounts on the banks and, on the boulders jutting out of the stream, overhangs the water. Underneath this overhanging snow is a supporting layer of ice formed from splashed water frozen by contact with the air-cooled rocks (Fig. 7). On this, ice settles and more splashed water is frozen until an irregular and thick ice layer is formed which is then melted by contact with the warmer stream water. As a result of this melting and of the usual winter fall in water level (I. Gieysztor 1961), an air gap is formed between the snow-ice mass, and the flowing stream water. New falls of snow, particularly wet snow, causes the break down of these ice-snow overhanging structures, which in any case rarely completely cover the whole stream surface. The extent of the ice-snow cover was examined in more detail in the Olczyski stream. The source of this stream comes from deep layers (Wrzosek 1933). Near the source the stream was not frozen throughout the period of observation. The lower half of the stream's mountainous course had a considerable ice cover (Fig. 8). At the lower limit of this mountainous course, the stream received warm water from the warm spring (Cieplice) at Jaszczurówka and there again the water surface was uncovered (Fig. 9). In contrast to the large Tatry streams, the small ones lose their surface flow in winter and become frozen to the bottom (Fig. 10).

2. Temperature conditions in pools

a. Thermal astatism in pools. The coefficient of thermal astatism of all the examined streams lay within the limits of 1.09 and 2.66; the coefficient for pools was somewhat higher, ranging from 1.34 to 2.79 (Table III).

It is of particular interest that there is a great similarity between the daily temperature cycle of the large Bieszczady streams which are the most astatic group of streams and that of pools:

Fig. 7. The formation of an ice-snow cover on the Czarny stream (1550 m above m.s.l.) in Tatry (29 I 1963)

Fig. 8. Olczyski stream above warm spring (Cieplice) at Jaszczurówka (Tatry), covered in this section with an extensive ice-snow cover (30 I 1963)

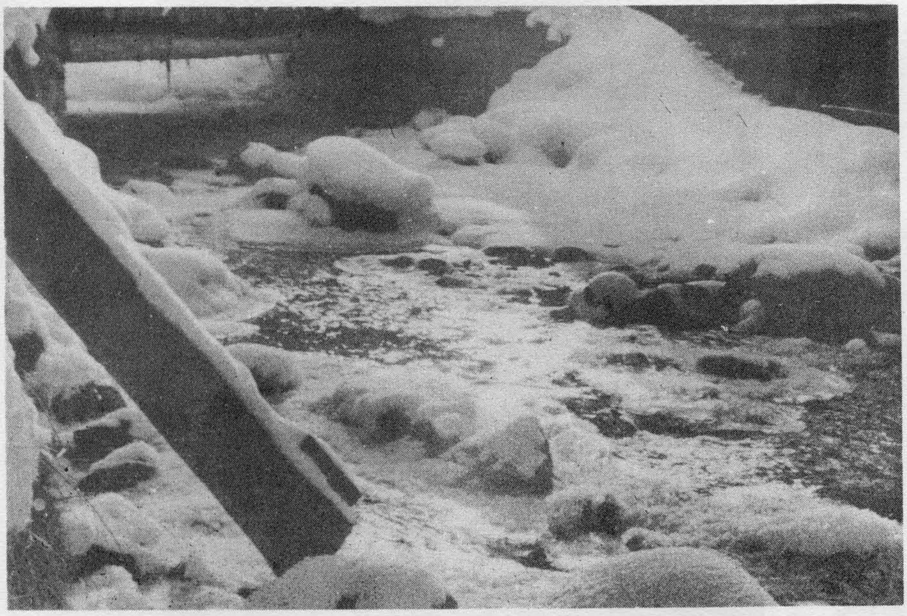

Fig. 9. Olczyski stream below warm spring (Cieplice) at Jaszczurówka (Tatry), without an ice-snow cover in this section (30 I 1963)

	K_1 (or K)	mean daily temperature (in °C)
large Bieszczady streams	1.33–2.66	12.4–17.7
small Bieszczady pools	1.34–2.79	11.6–18.1

b. Temperature stratification in pools. In contrast to streams, the temperature at the surface and near the bottom of pools may be very different. In all the water bodies in which both the surface and near-bottom temperatures were measured, the mean daily temperature and the coefficient of daily thermal astatism are higher for the surface than for the bottom (Table III). In three cases, the characteristic development of stratification was observed: during the day normal stratification occurred, at night an inversed stratification and in the morning and evening homothermal conditions developed (Fig. 11).

c. The influence of the number of hours on sunshine on the daily temperature cycle of pools. As was noted in the earlier descriptions of the investigated pools, temperatures were recorded during days with different periods of sunshine. During one hour's sunshine, the coefficient of thermal astatism (K_1 or K) for pools A, B and C on the first terrace of the Wołosaty changed from 1.34 to 1 59. During three hours' sunshine, the coefficient

Fig. 10. A tributary of the Roztoka stream (Tatry) flowing into the main stream near Wodogrzmoty Mickiewicza completely frozen on 2 II 1963

for the pools on the first and second terraces and the pudle on the second terrace of the Osława changed from 1.56 to 2.09. During eight hours' sunshine, the coefficient for the pool and ditch near Kalnica changed from 1.65 to 2.53. Finally, during ten hours' sunshine, the coefficient of pools 1, 2 and 3 on the second terrace of the Wołosaty and pool D on the first terrace of the Wołosaty changed from 1.87 to 2.79.

Such data, therefore, suggests that long periods of sunshine increases the astatism in the development of temperature in small pools.

d. The influence of shading on the twenty four hour cycle of temperature in pools. Investigations carried out on 11/12 VI 1963 show that the coefficient of daily thermal astatism K_1 for the pool on the second

Mean temperatures, coefficients of thermal astatism and temperature amplitudes over twenty four hours in Bieszczady pools (summer 1963)

Tab. III

Name of pool	Date	Point	Mean temperatures in °C		Coefficients				Amplitude in °C	
			air	water	Kp	Kd	K_1	K	air	water
Pool on first terrace of the Osława stream	11/12 VI	surface	14.3	13.6	2.21	1.98	2.09		13.1	11.9
		bottom		11.7						8.2
Pool on second terrace of the Osława stream	11/12 VI	surface	14.3	18.1	1.63	1.49	1.56		13.1	8.9
		bottom		17.3						7.0
Puddle on second terrace of the Osława stream	11/12 VI	surface	14.3	17.3	2.04	1.42	1.73		13.1	12.8
		bottom		16.8						5.8
Pool near Kalnica	14/15 VI	surface	16.8	14.7	1.82	1.49	1.65		18.3	7.8
		bottom		13.2						4.9
Ditch at the roadside near Kalnica	14/15 VI	surface	16.8	17.7	2.95	2.09	2.53		18.3	16.2
		bottom		16.0						10.8
Pool A on the first terrace of the Wołosaty stream	16/17 VI	surface	12.0	12.3	1.39	1.31	1.35		5.5	4.1
		bottom		12.0						3.3
Pool B on the first terrace of the Wołosaty stream	16/17 VI	half depth	12.0	13.5				1.59	5.5	6.3
Pool C on the first terrace of the Wołosaty stream	16/17 VI	surface	12.0	14.7	1.40	1.29	1.34		5.5	4.9
		bottom		14.0						3.4
Pool D on the first terrace of the Wołosaty stream	14/15 IX	half depth	9.1	13.8				2.20	13.2	10.8
Pool 1 on the second terrace of the Wołosaty stream	16/17 IX	half depth	14.6	11.6				1.87	21.4	6.5
Pool 2 on the second terrace of the Wołosaty stream	16/17 IX	half depth	14.6	14.2				2.48	21.4	10.8
Pool 3 on the second terrace of the Wołosaty stream	16/17 IX	half depth	14.6	15.2				2.79	21.4	13.1

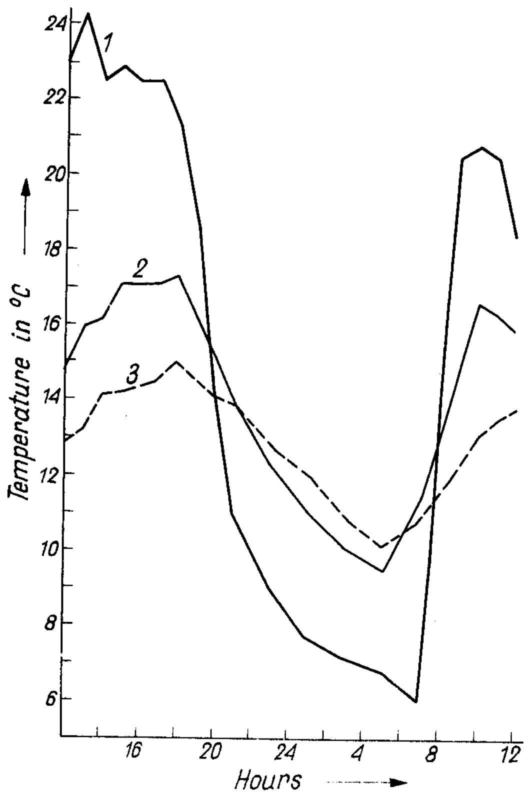

Fig. 11. Temperature changes over twenty four hours in pool near Kalnica (Bieszczady, 14–15 VI 1963)

1 – air temperature, *2* – surface water temperature, *3* – water temperature near the bottom

terrace of the Osława, which was shaded by aquatic macrophytes and surrounding trees and bushes, was lower (1.56) than K_1 for the unshaded puddle on the second terrace of the Osława (1.73).

Similarly, from work carried out on pools of the second terrace of the Wołosaty on 16/17 IX 1963, the coefficients K of pool 1 (shaded by aquatic macrophytes) and of pool 2 (shaded by surrounding trees and bushes) were lower (1.87 and 2.48) than the coefficient K of the unshaded pool 3 (2.79).

The resulting data seems to show that the twenty four hour temperature cycle in shaded pools is less variable than in simultaneously examined pools exposed to sunshine.

e. The role of the surface flow on the temperature of small pools. On 16/17 VI 1963, temperature observations were carried out for twenty four hours on three small pools lying close together on the first terrace of the stream Wołosaty. Into pool A flowed a slight stream of water from a cold spring lying on the steep left wooded slope of the Wołosaty; from A water slowly flowed into pool B but there appeared to be no surface flow in the remaining pool C. The mean daily temperature of these pools were 12.3°C at the surface and 12.0°C at the bottom in pool A, 13.5°C at half depth in B and 14.7°C at the surface and 14.0°C at the bottom in C. The mean daily temperature of pool A into which water from the cold spring flows directly was lower than in poll B. The temperature of pools A and B were lower than pool C which had no surface flow at all. Such results indicate that surface flow can influence the temperature of pools.

f. The significance of contact with subterranean water on the development of thermal stratification in pools. The occurrence of inverse stratification at night was observed in three pools which were all situated on the second terraces of streams. On the other hand, all the pools lying on the first terraces, that is on the dry stream bed itself, in which the surface and near-bottom temperatures were investigated separately, had a normal temperature stratification during the whole twenty four hours. It is suggested that the flowing subterranean water of the stream produced this effect by cooling the bottom layer of water in those pools lying on the dry stream bed and so prevented the formation of inverse stratification.

3. Biological consequences of thermal astatism

On the basis of their thermal differences already described, the five groups of waters can be arranged in the following order of increasing astatism: large Tatry streams, small Tatry streams, small Bieszczady streams, large Bieszczady streams and Bieszczady pools. The latter two groups in certain respects show very similar thermal characteristics even though they are very different hydrologically.

Table IV has assembled together the thermal characteristics of the different groups of water bodies together with their *Plecoptera* and *Ephemeroptera* faunas. It shows very clearly that the number of species and density of *Plecoptera* species is reduced as the thermal astatism rises. The most astatic water bodies are inhabited exclusively by eurythermal species. *Ephemeroptera* are most abundant in the thermally variable large Bieszczady streams. The ratio between *Plecoptera* and *Ephemeroptera* in terms of number of species and density diminishes with increased astatism. Despite the "replacement" of *Plecoptera* by *Ephemeroptera* in waters which were warm and very astatic, in general, a fall in the number of species was observed in such waters.

Occurrence of *Plecoptera* and *Ephemeroptera* in thermally different streams and pools

Tab. IV

Type of water body	Large Tatry streams	Small Tatry streams	Small Bieszczady streams	Large Bieszczady streams	Bieszczady pools
No. of investigated water bodies	1	1	3	3	12
Coefficients of daily thermal astatism (K_1 or K)	1.15	1.09	1.09–1.53	1.33–2.66	1.34–2.79
Mean daily temperatures of water (in °C)	6.6	10.4	10.5–12.2	12.4–17.7	11.6–18.1
Number of *Plecoptera species* in one water body	19	13	2–8	0–5	0–1
Plecoptera density per m² in one water body	1126	36	56–383	0–137	0–39
% of eurythermal species	0	15	18	50	100
Plecoptera					
Diura bicaudata (Linné)	+				
Perlodes intricata (Pictet)	+				
Leuctra major Brinck	+				
Isoperla obscura (Zetterstedt)	+				
Brachyptera seticornis (Klapálek)	+				
Rhabdiopteryx neglecta (Albarda)	+				
Protonemura nimborum Ris	+				
Leuctra rosinae Kempny	+				
Leuctra moselyi Morton	+				
Dinocras cephalotes (Curtis)	+				
Leuctra rauscheri Aubert	+				
Nemoura marginata (Pictet) Ris	+				
Perlodes jurassica Aubert	+				
Isoperla grammatica (Poda)	+				

Leuctra nigra Kempny	+	+			
Protonemura brevistyla Ris	+	+			
Leuctra inermis Kempny	+	+			
Isoperla sudetica (Kolenati)	+	+			
Leuctra armata Kempny	+	+			
Chloroperla tripunctata (Scopoli)	+	+			
Protonemura krabĕi Raušer	+		+		
Protonemura lateralis (Pictet) Ris	+		+		
Isoperla görtzi Illies	+		+		
Protonemura nitida (Pictet) Ris	+		+		
Leuctra braueri Kempny	+	+	+		
Amphinemura sulcicollis (Stephens)	+	+	+		
Protonemura auberti Illies	+	+	+		
Protonemura intricata Ris	+			+	
Protonemura sp (*montana?*) Kimmins	+	+		+	
Chloroperla neglecta (Rostock)		+			
Nemurella picteti Klapálek		+			
Leuctra autumnalis Aubert			+		
Perla marginata (Panzer)			+	+	
Perla burmeisteriana Classen				+	
Nemoura cinerea (Retzius)		+			+
Leuctra fusca (Linné)			+	+	+
Nemoura sp.			+	+	+
Number of *Ephemeroptera* species in one water body	5	7	1–5	1–12	0–7
Ephemeroptera density per m^2 in one water body	63	18	33–77	29–1529	0–255
Ephemeroptera					
Baëtis carpaticus Morton	+	+			
Ameletus inopinatus Eaton	+	+			

Tab. IV con.

Type of water body		Large Tatry streams	Small Tatry streams	Small Bieszczady streams	Large Bieszczady streams	Bieszczady pools
Ecdyonurus subalpinus Klapálek		+	+			
Baëtis bioculatus (Linné)			+			
Habroleptoides modesta (Hagen)			+	+	+	
Rhithrogena semicolorata (Curtis)		+	+	+	+	
Ecdyonurus venosus (Fabricius)		+	+	+	+	+
Baëtis vernus Curtis				+		
Torleya major (Klapálek)				+	+	
Ecdyonurus lateralis (Curtis)				+	+	+
Habrophlebia fusca (Curtis)				+	+	+
Baëtis scambus Eaton					+	
Baëtis rhodani (Pictet)					+	
Baëtis pumilus (Burmeister)					+	
Procloëon pseudorufulum Kimmins					+	
Caenis rivulorum Eaton?					+	
Baëtis sinaicus (Bogoescu)					+	
Oligoneuriella rhenana Imhoff					+	
Ephemerella ignita (Poda)					+	+
Caenis macrura Stephens					+	+
Ephemera danica Müller					+	+
Centroptilum luteolum (Müller)						+
Centroptilum pennulatum Eaton						+
Siphlonurus aestivalis Eaton						+
Mean ratio[1] of *Plecoptera* to *Ephemeroptera*:	no. of spp.	5.8	1.9	1.3	0.4	0.2
	density	17.9	2.0	4.0	0.1	0.1

[1] in those cases where a thermal group contained more than one water body, the ratio of *Plecoptera* to *Ephemeroptera* was calculated for each and from these the mean obtained.

Temperature differences in different parts of the streams separates out the fauna along the lines revealed above. In the more thermally astatic water near the bank of the Osława, the ratio of *Plecoptera* species to *Ephemeroptera* (0.17) was lower than in the current (0.22); the ratio based on densities of the two groups was also lower near the bank (0.05) than in the current (0.13). A much clear fall in density and number of species of *Plecoptera* was observed in stagnant water. In the Kalnica stream, the ratio of *Plecoptera* to *Ephemeroptera* densities was 1.21 in the current and 0.08 in the stagnant water; the ratio in terms of species number was 1.66 in the current and 0.50 in the stagnant water. In the stagnant water of the Wołosaty, *Plecoptera* were completely absent.

Table V presents the *Plecoptera* and *Ephemeroptera* occurring in thermally different groups of lakes. In the highest lake, the lake in the Dolina Pięciu Stawów Spiskich, only one boreo-alpine species, *Ameletus inopinatus* Eaton, was found; it may be that other species cannot exist throughout the long period of freezing. Although in general the fauna of the different groups of lakes is somewhat similar, some differences can be seen. In lakes in which the annual maximum temperature is low (less than 8°C and 14°C) only one or two species occurred. In lakes in which the maximum temperature lies between 14°C and 17°C, rather more species appeared (between one and four in particular lakes). In lakes with a higher maximum temperature (20.0°C and 22.5°C) only one species was found. It is noteworthy that *Cloëon dipterum* (Linné), a species characteristic of lowland small water bodies, was recorded from the very warm lake Toporowy Staw.

III. DISCUSSION

Tatry and Bieszczady streams and pools were chosen are terrain for thermal observations. The temperature of Tatry lakes was not studied because these are already well known to a large extent. However, the results of other authors, cited in Table V, have been used and, especially, the division of Tatry lakes into thermal groups from Olszewski's (1951) work. The use of such information for comparison with the distribution of *Plecoptera* and *Ephemeroptera* should be treated with reserve; the larvae caught came only from the narrow "littoral" zone. Moreover, thermal information from this zone is usually lacking from the cited works. This whole problem demands much more extensive and detailed investigation. It would be reasonable to apply the already existing thermal classification of Tatry lakes which takes into account not only the maximum annual temperature but also the dimensions of lakes, their altitude and the character of their surroundings. These are factors which are certainly not without influence on the temperature of those parts of the lake where *Plecoptera* and *Ephemeroptera* occur, namely the "littoral" zone. The results obtained, namely that a somewhat greater number of species occur in the large and in the low--lying lakes compared with the colder and warmer lakes appears to confirm this suggestion.

Occurrence of *Plecoptera* and *Ephemeroptera* in thermally different Tatry lakes

Tab. V

Name of lake	m above m.s.l.	Surface area in ha	Max. depth in m	Thermal group[1]	Max. annual water temperature in °C	*Ephemeroptera* a	b	c	*Plecoptera* d	e	f	g	h
Lake in Dolina Pięciu Stawów Spiskich	2039.0	2.43	9.6	Cold lake	8[3]	+							
Zadni Staw in Dolina Pięciu Stawów Polskich	1889.6	6.47	31.6	Lakes in high situations	14[4]	+			+				
Długi Staw in Dolina Staroleśna	1886.0	1.12	6.8									+	
Długi Staw Gąsienicowy at Świnica	1783.5	1.58	10.6									+	
Czarny Staw in Dolina Pięciu Stawów Polskich	1722.1	12.69	50.4	Larger lakes	14[4]	+			+				
Przedni Staw in Dolina Pięciu Stawów Polskich	1668.3	7.71	34.6			+			+			+	+
Wielki Staw in Dolina Pięciu Stawów Polskich	1664.6	34.35	79.3			+						+	
Morskie Oko	1392.8	34.93	50.8	[2]	15.8[5]		+						
Kurtkowy Stawek Gąsienicowy (Kurtkowiec)	1686.0	1.56	4.8	Lakes in low situations	17.0[3]	+					+		+
Zielony Staw Gąsienicowy at Świnica	1671.7	3.84	15.1		16.9[6]							+	
Czerwony Stawek Gąsienicowy Zachodni	1694.6	0.27	1.4	Lakelets	20.0[4]					+			
Mały Staw in Dolina Pięciu Stawów Polskich	1667.6	0.18	2.1										+
Sobkowy Stawek Gąsienicowy (Litworowy)	1618.0	0.48	1.1									+	
Toporowy Staw Niżni	1089.0	0.617	5.9	Forest lake	22.5[3]			+					

[1] lakes sub-divided according to Olszewski's (1951) thermal grouping,
[2] a lake falling between the group of sub-mountain lakes (because of its altitude) and the group of large lakes (because of the character of its basin and surroundings),
[3] acc. to Szaflarski (1932),
[4] acc. to Olszewski (1951),
[5] acc. to Birkenmajer (1901),
[6] acc. to Lityński (1914) *a-Ameletus inopinatus* Eaton *b-Ecdyonurus venosus* (Fabricius) *c-Cloëon dipterum* (Linné) *d-Diura bicaudata* (Linné) *e-Protonemura brevistyla* Ris *f-Protonemura meyeri* (Pictet) *g-Nemurella picteti* Klapálek *h-Nemoura cinerea* (Retzius).

The greatest attention was devoted to thermal observations of the Bieszczady streams and pools because the temperature of these waters has not until now been systematically investigated. A few observations were carried out on Tatry streams in order to compare them with existing information on this subject.

The water temperature of Tatry streams investigated in August 1963 was lower than that of Bieszczady streams examined in June and September 1963. On the other hand, air temperatures in August in the Tatry were in general higher than in June and September in Bieszczady as is shown in Table I as well as from the following PIHM means: mean air temperature in Zakopane for August 1963 was 15.2°C; in Ustrzyki Górne(Bieszczady) for June and September 1963 was 13.6°C and 11.8°C respectively. The fact that Tatry streams had lower water temperatures than Bieszczady streams despite a higher air temperature allows one to define the temperature of Tatry streams as low, in agreement with the results of other authors. These temperatures fluctuated only slightly both throughout the year and throughout twenty four hours. According to M. Gieysztor (1962), this property is fundamental to Tatry streams. However, small Tatry streams flowing from springs arising from shallow subterranean layers in the forest zone have higher temperatures than the large valley streams arising from high mountain lakes or from deeper lying springs but are equally thermally stable. These warmer small streams are one of the factors which increase the temperature of the main streams in summer. Dyk (1940) also drew attention to the thermal differences between these two types of stream. It is interesting that the small Tatry streams of the Olczyski valley and the small Bieszczady streams are similar not only in the character of their springs and nature of their courses, which are short, steep and pass through wooded slopes, but also in their thermal and biological characteristics.

The differences in temperature conditions and fauna between the small streams in Tatry and Bieszczady, with about 400m difference in altitude, are no greater than the differences between small and large Bieszczady streams flowing at the same altitude. This shows that sunshine and the origin of the stream exerts a considerable influence on its temperature conditions. Romer (1905, 1911), Dyk (1940), Dudziak (1956) and Pawłowski (1959) also drew attention to the importance of sunshine on temperature conditions in streams. Raušer (1962) found an impoverished *Plecoptera* fauna in the large sunny valley streams of Jesioniki compared with the small streamlets flowing through wooded ravines. However, lacking until now was any comparable work documenting throughout twenty four hours the thermal constancy of these small forest streams; now it is possible to compare these with the large streams of the lower mountains and to show in these wooded streams the greater independence of the daily thermal cycle from meteorological conditions.

It was found that differences in the daily temperature cycle occurred in the various habitats in the large Bieszczady streams but these differences between the temperature in the current and near the bank, or between the current and stagnant water, are not very great and occur only during sunny weather. According to Macan (1959) stream temperatures measured at the same time in different places can be considerably different. The occurrence of higher temperatures in stagnant waters compared with the current in large streams during the summer has already been recorded by Dudziak (1956) and Pawłowski (1959), and Dudziak (1956) observed higher temperatures near the bank than in the current. The temperature differences observed by Dudziak in the Kościeliski stream (Tatry) were smaller than those recorded in the present work for large Bieszczady streams. In addition, he mentioned that vertical temperature differences existed in streams. The results in the present work obtained from ten twenty four observations of the stream temperature at the surface and near the bottom failed to show any vertical thermal stratification in streams. Such slight differences in temperature near the bottom and at the surface which did occur were not present throughout twenty four hours and could be the result of errors of measurement or from a brief flow of warmer or colder water from other parts of the stream.

Faunal collections were carried out at the same time as the thermal observations and reveal that, near the bank and in stagnant waters, the ratio of *Plecoptera* to *Ephemeroptera*, both in terms of density of individuals and number of species, is somewhat lower than in the current, which seems to indicate that the increased astatism of these parts of the stream influences the fauna. However, apart from temperature, other factors may be influencial, namely the slower flow of water and/or the very fine deposits occurring near the bank and in stagnant waters but in the current. With the methods used, it is difficult to estimate to what extent each of these factors contributes to the development of the observed differences in faunal composition.

Very interesting is the similarity revealed between certain aspects of the daily thermal cycle of the pools and large streams of Bieszczady. The coefficient of thermal astatism (K_1 or K), the amplitude and the mean daily temperature are all similar. It appears that the prevailing conviction that pools posses their own specific temperature conditions which are in contrast to the thermal stability of streams is not true in the case of the large streams of the lower Bieszczady mountain and their neighbouring pools. However, any analogy drawn between these two types of waters is limited by the presence of thermal stratification in pools and its absence in streams.

The twenty four hour cycle of thermal stratification in pools as well as the occurrence of temperature differences between shaded and unshaded pools are phenomena known for a long time from work carried out on lowland pools by M. Gieysztor (1934), Kreuzer (1940), Paschalski (1959a) and Chodorowski (1961). The present work reveals the occurrence of these phenomena in mountain waters also but in the literature no attention has been paid to the influence of surface flow and contact with subterranean water on the temperature of pools.

Despite their very southerly situation in Poland (about 49° latitude) Bieszczady pools do not warm up to such high temperatures as lowland pools. The highest temperature recorded in a Bieszczady pool was 25.1°C in June. Styczyńska-Jurewicz (1962) recorded a surface temperature of 29°C in pools in the forest Puszcza Kampinoska (about 52° 30') and in the Wigry region (about 54° latitude) M. Gieysztor (1934) a temperature of 30.6°C in a pool near the bank. This difference is most certainly due to the greater altitude of the Bieszczady pools.

A second property of these pools, also connected with their high altitude, is the greater degree of thermal astatism. Using other authors' results, the coefficients of daily thermal astatism (K_1 or K) was obtained for pools situated at different altitudes. For lowland pools the values obtain were as follows: Wigry region 1.14–1.74 (M. Gieysztor 1934), Puszcza Kampinoska 1.35–1.55 (Styczyńska-Jurewicz 1962), Cairo 1.30 (Klimowicz 1961), Spitzbergen 1.06–1.75 (Rakusa-Suszczewski 1963). For the investigated Bieszczady pools with an altitude of 500–650m above m.s.l. these values are 1.34–2.79. Using Pesta's (1935) data for a pool in the Austrian Alps lying at an altitude of 160m above m.s.l., the value obtained for K was 3.17. According to Romer (1911), great daily temperature fluctuations are a particular feature of mountain waters; he suggest that these result from the great water transparency which allows the bottom and so indirectly the water to be strongly heated during sunny periods.

A list of species occurring in thermally different types of water is presented in Tables IV and V. Among the specimens of *Dinocras cephalotes* (Curtis) cited in Table IV as occurring in the large Tatry stream, Olczyski, was one female imago without anal cross-veins in the hind wings. This character is given in the keys as a basis for distinguishing the genus *Marthamea* (without cross-veins) from the genus *Dinocras* (with cross-veins). Because of this character, this specimen and also another female found at the stream flowing into the Wielki Staw in the Dolina Pięciu Stawów Polskich were identified in an earlier work of the author's (Kamler 1964) as *Marthamea vitripennis* (Pictet). However, Dr. Sowa kindly drew attention to other characters in these two specimens (the head pattern, the form of the sub-genital plates and the tenth sternum) which suggest that they belong to the species *Dinocras cephalotes*. Moreover, specimens identified erroneaously as *M. vitripennis* in Kamler (1964) also belong to the species *D. cephalotes*. It appears that the character, absence of anal cross-veins in the hind wings, is unreliable as a generic difference between *Dinocras* and *Marthamea*.

The order of presentation of species in Tables IV and V in general outline corresponds to the thermal requirements of these species. The few eurythermal

Plecoptera are assembled together at the bottom of the tables: these are *Nemurella picteti*, *Perla burmeisteriana*, *Nemoura cinerea* and *Leuctra fusca*. The tolerance of *Ephemeroptera* from streams and ponds to high temperatures has been investigated by Whitney (1939). The temperature at which 50% mortality occurred was successively higher in the following order of species, *Baëtis rhodani*, *Rhitrogena semicolorata*, *Ecdyonurus venosus*, *Caenis sp.* and *Cloëon dipterum*. The order of species presented in Table IV coincides with Whitney's results, with the exception of *Baëtis rhodani*. The influence of temperature on the distribution of *Ephemeroptera* larvae has also been investigated by Pleskot (1951) and Macan (1960a, 1960b).

The results of these investigations show that together with increase in temperature and temperature fluctuation there is a decrease in the number of *Plecoptera* plus *Ephemeroptera* species. However attention must be drawn to the rapid fall in density and number of species, their replacement by *Ephemeroptera*, whose maximum occurrence is attained in large Bieszczady streams[1] and then the disappearance of the *Ephemeroptera*, all these taking place as the temperature increases. This is the result of different developmental temperatures which for a number of *Plecoptera* species is around 0°C whereas it is in general higher in the *Ephemeroptera* (Brinck 1949, Illies 1952). It appears that it is quite possible to characterise sufficiently precisely mountain waters using the ratio of *Plecoptera* to *Ephemeroptera* in terms of densities and number of species.

The discussed changes in distribution of *Plecoptera* and *Ephemeroptera* under the influence of temperature increase and fluctuation shows that these factors are very important. Kamler (1964) discussed the influence of a low and constant temperature of the spring, Źródło Lodowe, in the Tatry on the occurrence and morphological character of the boreo-alpine species, *Arcynopteryx compacta* (Mac Lachan). In this low lying spring, about 500m lower than the upper limit of the forest zone, this species maintains itself continuously and shows a strong shortening of the wings. Shortening of wings occurs also in *Plecoptera* from very high lying or very northerly areas under the influence of extreme conditions, such as temperature, among others.

From the above considerations, it would seem to be possible, on a broad scale, to incorporate the degree of daily astatism of the thermal cycle into a classification of streams. In many works attempting to classify mountain streams from a thermal point of view (Hesse 1924, Brehm and Ruttner 1926, Thienemann 1936, Illies 1952, Botosaneanu 1959, Illies and Botosaneanu 1963) what was mainly considered were the maximum summer temperatures, the annual amplitudes and the monthly mean amplitudes of the water

[1]Macan (1957) comparing a small stream with a stony river observed that in the river appeared species of *Ephemeroptera* which were missing from the stream: *B. scambus*, *C. luteolum*, *C. pennulatum*, *P. pseudorufulum*; see Table IV.

temperature. The height of the maximum summer temperature is not a good index. It has been shown that many cold-living animals can survive this period, disadvantageous for them, in a state of resistance to temperature. Daily thermal changes occur with great frequency. M. Gieysztor (1934) and Pleskot (1951) indicate the importance of such daily changes in water temperatures and Dyk (1940) and Madsen (1962) included this feature in their classification. The application of data on the variability of the daily thermal cycle to evaluating different waters is supported by biological evidence.

An interesting attempt to produce a single thermal characteristic for water bodies was made by Paschalski (1959b, 1963). He characterised the annual temperature cycle of lakes by means of a curve illustrating the temperature difference between the surface and near the bottom; this curve he called a 'curve of temperature difference'. As Paschalski (1964) suggests such "curves of temperature difference" may be useful to evaluate also the periodic thermal variability of pools during their daily cycle. However, in the case of streams, where vertical stratification does not occur, such 'curves of difference' cannot be used. For periodic thermal variability so great as in the various types of streams and pools, the coefficients of daily astatism of the thermal cycle proposed in the present work seem to be particularly useful. They permit a precise comparative grasp of such a biologically important property as temperature conditions.

The phenomenon of freezing in mountain streams has scarcely been investigated until now. The last authors occupied with this problem were Macan (1959) and D. H. H. Kühlmann and I. Kühlmann (1963). The latter authors observed a stream in the Erzgebirge mountains (flowing from an altitude of 940m to 680m) during not too frosty weather between February and March. Their results are in general agreement with the present work. The authors confirmed the lowering of the temperature and increase in ice-cover in the lower course of the stream. However the observations carried out at the Olczyski where the warm spring (Cieplice) at Jaszczurówka caused renewed melting show that the development of freezing is not identical throughout the stream's course but instead depends on hydrological conditions reigning in particular sections. D. H. H. Kühlmann and I. Kühlmann (1963) emphasised the role in ice formation of the cooling down by cold air of the bank and boulders in water (the German term, Kerneis) and of splashed water (the German term, Spritzeis). They also discussed the winter fall in water level and the formation of layered ice as well as the formation of ice from snow with soaked up water later frozen. But it is not correct to erect too strong a barrier between the formation of "nuclear" ice (Kerneis) and "splashed" ice (Spritzeis) for these processes probably occur simultaneously.

Observation of winter phenomena in streams shows that small streams become frozen to a greater degree than large. Freezing limits the fauna quantitatively and in numbers of species. As Kamler (1964) showed, the *Plecoptera* and *Ephemeroptera* fauna is more diversified and more abundant in large Tatry streams than in their tributaries, the small streams. It seems likely that freezing limits particularly those species whose winter growth is most intense. That such species exist among the *Plecoptera* and *Ephemeroptera* has been mentioned by Brinck (1949), Macan (1960b), Hynes (1961, 1962) and Thorup (1963). This is confirmed in that the following early spring forms were not found in small streams: *Brachyptera seticornis* (Klapálek), *Rhabdiopteryx neglecta* (Albarda) and *Protonemura nimborum* Ris.

The present work contains data which appears to indicate the variability of thermal phenomena occurring in Tatry streams at different seasons of the year. In summer (Fig. 4A, Tables IA and B) the water temperature is lower than the air temperature. The water temperature in the Tatry stream, Olczyski on 28 VIII 1963, after flowing about 2 km, was about 2.3°C higher than the water temperature at its source. In winter, on 16 III 1963, the water temperature in the Tatry stream, Roztoka, was about 18.7°C higher than the air temperature. A greater and greater ice cover in the downstream the Olczyski, above the warm inflow from the warm spring, indicates a lowering of the water temperature. In figure 4B some autumnal measurements by M. Gieysztor (1951) are presented: the water temperature of the Roztoka stream was similar to the air temperature and increased only 0.4°C over a distance of 4.5 km. This fragmentary information corroborates data by Pleskot (1951) regarding the general character of the thermal cycle occurring throughout the year in mountain streams, which is as follows: in summer, the water temperature is lower than the air temperature and the less the distance from the source, the lower is the temperature; in winter, the relationship is reversed whereas in spring and autumn homothermy is established.

I warmly thank my colleagues from the Department of Experimental Hydrobiology, Nencki Institute of Experimental Biology, for their critical attention and valuable suggestions. I am also greatly obliged to M.Sc. W. Chodorowska for her help in carrying out the thermal observations in Bieszczady.

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WARUNKI TERMICZNE W WODACH GÓRSKICH I ICH WPŁYW NA ROZMIESZCZENIE LARW *PLECOPTERA* I *EPHEMEROPTERA*

Streszczenie

Celem pracy było pogłębienie znajomości termiki wód górskich, a zwłaszcza porównanie stopnia astatyzmu termicznego badanych wód oraz prześledzenie jego biologicznych konsekwencji.

W czerwcu, sierpniu i wrześniu 1963 r. przeprowadzono dobowe obserwacje termiki tatrzańskich i bieszczadzkich potoków i małych zbiorników, uzupełniono je pomiarami temperatur potoków tatrzańskich w różnych porach roku, obserwacjami zamarzania oraz pomiarem termicznych profilów podłużnych 2 potoków. Dokonano także pomiaru innych czynników środowiskowych. Jako obiektem porównań biologicznych posłużono się *Plecoptera* i *Ephemeroptera*, które zbierano w potokach, małych zbiornikach, a także w tatrzańskich jeziorach, których termiczną charakterystykę zaczerpnięto z piśmiennictwa.

W okresie letnim najchłodniejsze są duże potoki tatrzańskie, najcieplejsze – duże potoki bieszczadzkie. Źródłowe, zacienione małe potoczki tatrzańskie i bieszczadzkie mają temperaturę zbliżoną (te ostatnie nieco wyższą) (tab. I, fig. 5). Potoki cieplejsze wykazują większy astatyzm dobowego przebiegu temperatury (tab. II). Temperatura potoków tatrzanskich wykazuje niewielką zmienność również w różnych porach roku. Warunki meteorologiczne silniej wpływają na termikę bieszczadzkich dużych potoków niż małych. Zróżnicowań termicznych między warstwą powierzchniową a przydenną w potokach nie obserwuje się. Mikrozróżnicowania termiczne w poprzecznym przekroju dużych potoków bieszczadzkich (nurt – brzeg i nurt – zastoisko) obserwowano jedynie w dni o silnym usłonecznieniu. Wówczas w strefie przybrzeżnej i w zastoiskach obserwowano wieksza zmienność termiczną niż w nurcie (fig. 6). Małe potoki tatrzańskie zimą przemarzają w większym stopniu niż potoki duże (fig. 10). W dużych potokach tatrzańskich nie obserwowano całkowitego zamarznięcia (fig. 7, 8, 9). Tworzenie się na nich pokrywy lodowo-śnieżnej zależy od warunków hydrologicznych, panujących w poszczególnych odcinkach potoku.

W małych zbiornikach astatyzm dobowego przebiegu termicznego zaznacza się silniej niż w potokach. Temperatury powierzchniowe są bardziej zmienne niż przydenne (tab. III). Niekiedy obserwowano charakterystyczny przebieg uwarstwień: w ciągu dnia – proste, w nocy – odwrócone, rano i wieczorem – homotermia (fig. 11). Na termikę małych zbiorników wydają się wpływać warunki meteorologiczne (usłonecznienie, zacienienie), przepływ powierzchniowy i wody spływu podziemnego.

Wyróżniono 5 grup zbiorników według wzrastającego astatyzmu ich termiki: duże potoki tatrzańskie, małe potoki tatrzańskie, małe potoki bieszczadzkie, duże potoki bieszczadzkie i małe zbiorniki bieszczadzkie. Stwierdzono redukcję zagęszczenia osobników i liczby gatunków *Plecoptera* wraz ze wzrostem astatyzmu termicznego zbiorników. Maksimum występowania *Ephemeroptera* przypada na duże potoki bieszczadzkie. W grupach zbiorników cieplejszych i bardziej astatycznych obserwowano ogólny spadek liczby gatunków obu rzędów owadów oraz obniżenie się stosunku zagęszczenia osobników i liczby gatunków *Plecoptera* do *Ephemeroptera* (tab. IV). W podobny sposób działają na faunę cieplejsze i bardziej astatyczne wody partii przybrzeżnych i zastoisk dużych potoków bieszczadzkich.

W najwyżej z badanych jezior położonym zbiorniku znaleziono jedynie boreoalpejski gatunek *Ameletus inopinatus* (*Ephemeroptera*). Stosunkowo największą liczbę gatunków badanych grup stwierdzono w wielkich jeziorach i jeziorach nisko położonych (według klasyfikacji Olszewskiego 1951). W najniżej położonym, silnie nagrzewającym się jeziorze złowiono jedynie charakterystyczny dla niżowych małych zbiorników gatunek *Cloëon dipterum* (*Ephemeroptera*) (tab. V).

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Sekretariat Redakcji
Warszawa, ul. Nowy Świat 72

Redaktor pracy — E. Pieczyński

Printed in Poland

Państwowe Wydawnictwo Naukowe
Oddział w Łodzi 1965

Wydanie I. Nakład 975 + 100 egz. Ark. wyd. 3, ark. druk. 2.5.
Papier offsetowy kl. III 80 g. 70 × 100. Oddano do druku. 29. IX. 1965 r.
Druk ukończono w październiku 1965 r. Zam. 217. N-4. Cena zł 12,—

Zakład Graficzny PWN
Łódź, ul. Gdańska 162

Cena zł 12,—