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Benthic Invertebrates and Metabolism of West Carpathian (Slovakia) Rivers

key words: allochthonous, organic matter, periphyton, trophic guilds, secondary production

Abstract

We examined benthic invertebrates and metabolism on the basis of the annual sampling of 9 types of running waters in the West Carpathians. Headwaters in general represent typical heterotrophic systems, except where they are high mountain streams, which are autotrophic. Lower down, the upper reaches of brooks are transition zones between heterotrophic and autotrophic systems. After the transition to an autotrophic system (which depends mainly on the primary producers) there is a considerable decrease in secondary production. Production is higher in the rivers of the Carpathian basin, as well as lower down the valley (submontane rivers and lower tributaries of submontane streams) where, within the autotrophic systems, there is a shift of metabolism from the bottom to the water column. The temperature days, altitude and slope of the stream and concentration of calcium influence production of macrozoobenthos.

1. Introduction

Running waters are open aquatic ecosystems, closely connected to terrestrial biotopes through their long riparian zones. VANNOTE et al. (1980) regards them as ancient systems but very dynamically responsive to changing environmental conditions. These systems are more often limited by abiotic then by biotic inputs (REICE, 1985). The greatest diversity of aquatic species is found in reaches of streams where the natural oscillation of environmental factors exceeds the mean value of the intensity of their impact (STANFORD and WARD, 1983). STATZNER (1987) reports five essential factors affecting lotic ecosystems: 1) temperature regime, 2) discharge regime and character of the substratum (affected by the discharge regime), its stability, interactions between aquatic environment and organisms, atmosphere, hyporheal and turbidity, 3) light regime, 4) nutrients affecting primary production, and 5) input of allochtonous organic matter. All of these factors are modified by the geographic location and longitudinal position along the river continuum and by hydraulic stress (VANNOTE et al., 1980; STATZNER and HIGLER, 1986). BENKE et al. (1988) regard the main environmental conditions which influence the bioenergetics of water ecosystems as, climate (temperature, light and rainfall), geology (soil and substratum), geomorphology (topography, slope of stream, riparian vegetation), hydrology (stream velocity, hydrological regime), chemistry of waters (nutrients, toxic matter, pH), trophic structure, food webs, the biomass, assimilation and production efficiency of its components, P/B coefficients, mortality, stage of autotrophy or heterotrophy of streams. Running water ecosystems are sharply dependent on the supply of matter from the terrestrial environment and from ground waters. Secondary production of macrozoobenthos in streams is directly dependent on the substratum (GURTZ and WALLACE, 1986), quantity and quality of food supply (HAWKINS et al., 1982), temperature (SWEENEY, 1984), chemistry of waters and pressure of predators.
In the present study we focussed on hydrobiological research in mountain torrents, brooks and submontane rivers. It concerns catchments which are relatively unperturbed or disrupted, but there are also some with anthropogenic impacts on them. Our main aim was to extend knowledge of the diverse ecological relationships (autecological, synecological and production) within these ecosystems. We concentrate on diversity, structure, and seasonal and longitudinal dynamics of macrozoobenthos. Our investigations are principally examining the River Continuum Concept (VANNOTE et al., 1980) which was based on biomass values (standing crop), while our investigations were focused on the production aspects of both the krenal and rhithral of the West Carpathian streams.

2. Material and Methods

Samples were taken with two types of methods. From all nine sites (Fig. 1), quantitative samples were taken monthly using “Kubiček’s benthometer” (area of 450 cm², Hess type of sampler with mesh size of 0.5 mm) during the years 1976–1997 from various types of running waters (headwaters, torrents, brooks, downstream to submontane rivers) in the Carpathians. From each site during the yearly period four samples from riffles and two from macrophyte pools were taken. The biomass of macrozoobenthos was determined directly as wet formalin mass. Dry biomass of macroinvertebrates was derived from wet mass according to CUMMINS and WUYCHECK (1971). The secondary production of zoobenthos was evaluated by size-frequency methods (MENZIE, 1980) or by annual P/B ratios – for permanent fauna (WATERS, 1977) and Chironomidae (BEHMER and HAWKINS, 1986).

At five sites, Javorník (7), Hincov potok (1), Hučava (4) and Turiec (5) and Turiec (8), plant and benthic organic material were sampled. Plant material (periphyton) adhering to stones was removed with a nylon brush from 7–10 (stones, rocks) and the size of the stone’s surface was measured with aluminium foil (PUNČOCHÁR, 1986). Coarse particulate organic matter (CPOM) was collected from the benthometer, fine particulate (FPOM) and ultrafine particulate organic matter (UFPOM) were isolated by using a sharply edged tube inserted 10–15 cm into the substratum. After replacement of stones the bottom was thoroughly whirled several times to a depth of about 5 cm. 0.5 l of water was taken from the column and this procedure was repeated 2–3 times. For assessing the transported organic matter (TOM) 2–3 litres were taken from the stream flow.

Particulate organic matter (POM) was separated through nested sieves (1.0 mm, 50 µm) and finally through 0.5 µm glass microfibre filters (Whatman GF/C). Material trapped on each sieve or filter corresponded to coarse, fine and ultrafine particulate organic matter. Wet biomass was recalculated as Dry matter (M) and Ash Free Dry Matter (AFDM) respectively. POM and periphyton were expressed as AFDM.

Figure 1. Map of Slovakia showing study sites.
The factors of stream metabolism – Retention (RR), rate of downstream movements (RT – km d⁻¹), Recycling rate (K – yr⁻¹) Turnover length (S – km), Turnover time (Y – yr) were estimated according to WEBSTER (1983) and KRNO et al. (1996). The breakdown of POM is dependent upon temperature, quality and size of POM and rate of consumption of POM by detritvores (microbial breakdown and consumption of detritvores – macroinvertebrates).

Macrophytes were taken from the benthometer, dried and ashed. Biomass of macrophytes was expressed as AFDM.

3. Results and Discussion

3.1. POM, TOM and Periphyton

Table 1 includes the localities which were the focus of our attention, but other biotopes, including montane torrents were also studied (Table 2). The sampling stations were at altitudes of 300–1500 m a. s. l. Most attention was focused on natural streams, but our investigations also included streams affected by human influences such as acidification or river basin erosion.

Our long-term hydrobiological investigations in various biotopes have confirmed the validity of the river continuum concept under natural conditions in the West Carpathians (KRNO et al., 1995, 1996, 1998). The biomass of POM (CPOM, FPOM) decreases steeply with increasing discharge (Table 1). The seasonal changes are shown using the example of our most recent results obtained in the Hučava stream basin. This stream rises in and flows through the caldera of the highest extinct volcano in Central Europe, in the Pol’ana mountain range.

Table 1. Ecological energy flow in selected habitats.

<table>
<thead>
<tr>
<th>Locality</th>
<th>Javorník</th>
<th>Hincov potok</th>
<th>Hučava</th>
<th>Turiec-Sklené</th>
<th>Turiec-Košťany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat</td>
<td>headwater</td>
<td>High mountain</td>
<td>submontane</td>
<td>submontane</td>
<td>submontane</td>
</tr>
<tr>
<td>Altitude m a.s.l.</td>
<td>530</td>
<td>1480</td>
<td>650</td>
<td>585</td>
<td>407</td>
</tr>
<tr>
<td>Average discharge m³ s⁻¹</td>
<td>0.0004</td>
<td>0.44</td>
<td>0.76</td>
<td>0.81</td>
<td>7.87</td>
</tr>
<tr>
<td>Temperature days °C</td>
<td>2850</td>
<td>1350</td>
<td>2482</td>
<td>3031</td>
<td>3260</td>
</tr>
<tr>
<td>Input CPOM g m⁻² AFDM</td>
<td>1530</td>
<td>182</td>
<td>254</td>
<td>183</td>
<td>123</td>
</tr>
<tr>
<td>Input CPOM g m⁻² AFDM</td>
<td>3044</td>
<td>541</td>
<td>1082</td>
<td>1373</td>
<td>1102</td>
</tr>
<tr>
<td>Periphyton g m⁻² AFDM*</td>
<td>5.3</td>
<td>2.0</td>
<td>3.0</td>
<td>2.3</td>
<td>11.5</td>
</tr>
<tr>
<td>Macrophytes g m⁻² AFDM*</td>
<td>0.0</td>
<td>47.7</td>
<td>0.0</td>
<td>0.0</td>
<td>220.0</td>
</tr>
<tr>
<td>Macrozoobenthos – production g m⁻² AFDM</td>
<td>12.1</td>
<td>2.3</td>
<td>9.7</td>
<td>6.5</td>
<td>26.1</td>
</tr>
<tr>
<td>P/B annual</td>
<td>6.5</td>
<td>4.9</td>
<td>5.9</td>
<td>4.2</td>
<td>7.8</td>
</tr>
<tr>
<td>Shredders g m⁻² yr⁻¹ AFDM**</td>
<td>5.8</td>
<td>0.4</td>
<td>1.3</td>
<td>1.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Gathers g m⁻² yr⁻¹ AFDM**</td>
<td>1.7</td>
<td>0.1</td>
<td>2.7</td>
<td>0.7</td>
<td>3.3</td>
</tr>
<tr>
<td>Filterers g m⁻² yr⁻¹ AFDM**</td>
<td>1.2</td>
<td>0.2</td>
<td>1.1</td>
<td>1.5</td>
<td>10.8</td>
</tr>
<tr>
<td>Scrappers g m⁻² yr⁻¹ AFDM**</td>
<td>0.3</td>
<td>0.9</td>
<td>3.4</td>
<td>1.5</td>
<td>8.0</td>
</tr>
<tr>
<td>Predators g m⁻² yr⁻¹ AFDM**</td>
<td>3.1</td>
<td>0.8</td>
<td>1.2</td>
<td>1.2</td>
<td>3.0</td>
</tr>
<tr>
<td>Retention (RR)</td>
<td>2938</td>
<td>496</td>
<td>105</td>
<td>111</td>
<td>49</td>
</tr>
<tr>
<td>Turnover length (S – km)</td>
<td>0.0009</td>
<td>0.05</td>
<td>0.80</td>
<td>0.86</td>
<td>2.10</td>
</tr>
<tr>
<td>Turnover time (Y – yr)</td>
<td>1.85</td>
<td>3.09</td>
<td>0.67</td>
<td>0.56</td>
<td>0.25</td>
</tr>
</tbody>
</table>

* annual mean of biomass
** secondary production
The highest values of CPOM (Fig. 2) were recorded at the end of autumn and the second highest values at the beginning of spring, while the minimum values were found in summer. In the Hučava basin there was an atypical detritus drift after a storm in July 1996. Maxima of FPOM and UFPOM, in contrast to CPOM, are strongly shifted towards the spring period of high discharges. The highest peak was recorded in mid-summer. The quantity of wood exhibits similar changes as CPOM. Similar results were obtained in the earlier studies of mountain streams by Krno et al. (1996, 1997).

The retention capacity of streams depends on the extent of afforestation in the basin (Krno et al., 1996). TOM in the Hučava stream reaches (Fig. 3) a sharp peak in autumn. During the flooding periods, we found that the amount of material transported increases up to 10–15 times in those basins affected by clear-cutting and subsequent erosion (Krno et al., 1996).

The growth of biomass ceases, as in other streams, by the end of winter (Krno et al., 1995, 1996). The seasonal dynamics of the periphyton is demonstrated in Fig. 4. From our investigations it seems that growth of biomass depends on the locality, reflecting the phosphate and calcium levels in the water, and their acidification (Krno et al., 1996, 1997). Minshall et al. (1992) also found that transported organic matter generally increased downstream (mainly the coarse fraction) and that stored benthic organic matter was highest in the headwaters. Primary production showed a general downstream increase, autotrophy prevailed in the 5 to 6th order streams.
3.2. Macrozoobenthos

In headwaters, macrozoobenthos peaks from autumn to the beginning of winter (Krno et al., 1997) and strongly depends on the supply of allochthonous organic material. In contrast, in the streams of the Carpathian valleys, which have high discharges, macrozoobenthos (filtrators, predators and collectors) peaks in summer – the peak period of FPOM, UFPM and macrophytes. A second peak (scrapers) occurs as winter turns to spring (Krno et al., 1996). As did Minshall et al. (1992), we observed that the TOM, and CPOM predominate in the upper streams, as do shredders and collectors and filtrators; primary production is dominant in the middle reaches. Annual production of macrozoobenthos according to Grubaugh et al., 1997 was correlated to standing crops of particulate organic material (POM) in low-order stream reaches but not in higher-order reaches. Scrapers increase toward the middle and lower streams (Table 1). The annual production figures estimated by Grubaugh et al. (1997) for sixth-order reaches of the continuum were amongst the highest reported thus far for lotic systems. In our study organization of the benthic community along the continuum, based on production estimates for individual functional feeding-groups, generally supported the predictions of the River Continuum Concept (RCC): shredder contributions were greatest in low-order reaches and declined downstream; scraper percentages were greatest in the middle of the continuum; collector-filterer contributions increased with increasing stream size. Longitudinal trends for collector-gatherers and predators did not support RCC predictions; these groups appeared to be influenced by localised changes in habitat availability and the occurrence of vertebrate predators along the continuum. Benke (1993) found polynomial regressions between secondary production of all functional groups of macroinvertebrates and discharge (except predators) and Morin (1997) extended this regression also to shredders.

The abundance of macrozoobenthos is positively influenced by the insolation reaching the stream and increasing discharge, and negatively by a higher proportion of boulders and rocks on the stream bottom (Krno et al., 1996). Macrozoobenthos production depends on altitude (Fig. 5), the same relationships were observed with stream slope. At higher altitudes, production decreases strongly due to low temperatures and hydraulic stress (steep slopes). In contrast, production increases with increasing calcium content (Fig. 6); Krueger and Waters (1983) and Griffith and Perry (1994) found a positive correlation between alkalinity and macroinvertebrate secondary production and Minshall and Robinson (1998) also observed that macroinvertebrate standing crop is greater in streams with higher alkalinity and conductance (mainly scrapers and gatherers), assuming it to be associated with food resource levels.

The proportion of predators in the headwater streams exceeds 20% of total abundance (Krno, 1990) and biomass (Krno et al., 1998). The proportion of scrapers increases with increasing discharge. In the streams of the Little Carpathians, which are often short of water, we recorded (Krno and Hullová, 1988) a strong discordance of the macrozoobenthos food.
guild structure with that predicted by the river continuum concept (Vannote et al., 1980). The 4th order streams are characterised, except for springs, by a high supply of CPOM and a high abundance and biomass of shredders, which corresponds to the 2nd order streams of Vannote et al. (1980). A similar shift, but in the reverse direction, was observed by Minshall et al. (1985) in the streams flowing through deserts (which have a deficiency of CPOM and high insolation).

We have found that abundance, biomass and production of scrapers, shredders and predators, as well as collectors, in the downstream reaches of the Turiec river were related to their food supply in the form of periphyton, CPOM, macrozoobenthos, and FPOM (Krno et al., 1996). Production of scrapers and shredders increases with their food resource, (Table 1) CPOM.

Macrozoobenthos production in relation to stream size (channel width) has a polynomial shape in these natural streams below the timberline (Fig. 7) with medium values in heterotrophic headwater-springs. At the transition to an autotrophic system (depending first of all on the primary producers) a strong decrease in production occurs, which is followed by a steep production increase in the autotrophic streams of the Carpathian valleys and at the valley mouths. Finally, we attempted a statistical evaluation of the influence of basic abiotic parameters on the production of macrozoobenthos (Fig. 8). As the stream width, habitat diversity and

Figure 5. The influence of altitude on the production of macrozoobenthos in the West Carpathians.

Figure 6. The influence of Calcium on the production of macrozoobenthos in the West Carpathians.
stream stability increase, the streams are less disposed to drying and water level fluctuations. There is strong positive evidence that secondary production of macrozoobenthos increases with discharge, coupled with stream width without a canopy effect, together with high

Figure 7. Production of macrozoobenthos in streams below the timberline and the influence of channel width in the West Carpathians.

Figure 8. Observed influence of basic abiotic parameters on the production of zoobenthos in the West Carpathians compared with those predicted by the overall regression model:

\[ P = 15.73 - 0.11A + 0.14Ca + 0.47W \] (\( p < 0.01 \); A – altitude m, Ca – calcium mg l\(^{-1}\), W – width of channel m).
concentrations of calcium. On the other hand, decreasing temperature and increasing channel slope have a negative influence on production. According to MORIN (1997) annual secondary production of lotic invertebrates is a function of their annual average temperature, total phosphorus concentration in the water and mean particle size of the substrate.

Above the timberline, streams of the alpine and subalpine zone do not correspond with the river continuum concept. This is shown in Figure 9. In alpine streams without an overhanging canopy and with low total production, the stream is functioning as an autotrophic system, which can be considered a contradiction of the river continuum concept (VANNOTE et al., 1980).

3.3. Metabolism

As can be seen in Table 2, the discharge regime considerably influences the supply of allochtonous organic material, primary production and the stream metabolism. This is reflected in the proportion of individual feeding guilds in the secondary production of macrozoobenthos. A higher proportion of predators in springs results from the absence of tertiary consumers. In this connection, the lower quantity of TOM in the downstream reaches of the Turiec river is interesting, in spite of the fact that production of bioseston filtrators is strong here. On the basis of the proportions of the different food guilds (ROSENFELD and MACKAY, 1987; KRNO et al., 1996), the spring area, Vel’ký Javorník, can be characterised as a typical heterotrophic ecosystem, the upper reaches of the Turiec (Turiec Sklené) and Hučava rivers as zones of transition from heterotrophic to autotrophic ecosystems, and the Turiec river downstream as an autotrophic ecosystem with a strong shift of metabolic processes from the stream bottom to the water column.

A stronger discordance with the river continuum concept was recorded in the alpine ecosystems (water basins) above the timberline (Table 2), which, in spite of their ultra-oligotrophy, behave as autotrophic systems. The grazing food chain based on the growth of mosses on the bottom of the stream (Table 1) plays a decisive role in such streams. MINSHALL et al., 1992 also found that, spiralling and retention revealed a general downstream increase in the rate of movement of organic matter, and turnover of POM increased progressively downstream.
4. Acknowledgements

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5. References


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Table 2. Production of macrozoobenthos and basic abiotic parameters in selected streams of West Carpathians (Danube basin).

<table>
<thead>
<tr>
<th>Name of stream</th>
<th>Altitude (m a.s.l.)</th>
<th>Slope (%)</th>
<th>Width of channel (m)</th>
<th>Annual of temperature days (°C)</th>
<th>Average production of macrozoobenthos (g m⁻² yr⁻² AFDM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hincov p.</td>
<td>1480</td>
<td>118</td>
<td>5.0</td>
<td>1132</td>
<td>2.6</td>
</tr>
<tr>
<td>Oružný p.</td>
<td>1100</td>
<td>125</td>
<td>3.0</td>
<td>1533</td>
<td>7.6</td>
</tr>
<tr>
<td>L’upčianka</td>
<td>780</td>
<td>27</td>
<td>13.0</td>
<td>2263</td>
<td>13.1</td>
</tr>
<tr>
<td>Hučava</td>
<td>650</td>
<td>22</td>
<td>4.5</td>
<td>2482</td>
<td>10.8</td>
</tr>
<tr>
<td>L’upčianka</td>
<td>530</td>
<td>13</td>
<td>12.0</td>
<td>2810</td>
<td>19.9</td>
</tr>
<tr>
<td>Turiec</td>
<td>407</td>
<td>2</td>
<td>20.0</td>
<td>3260</td>
<td>27.8</td>
</tr>
<tr>
<td>Vydrica</td>
<td>300</td>
<td>17</td>
<td>3.0</td>
<td>3320</td>
<td>7.3</td>
</tr>
<tr>
<td>Turiec</td>
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<td>14</td>
<td>5.5</td>
<td>3132</td>
<td>7.2</td>
</tr>
<tr>
<td>V. Javorník</td>
<td>530</td>
<td>14</td>
<td>0.4</td>
<td>3066</td>
<td>13.7</td>
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</tbody>
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