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# NATURAL AND ANTHROPOGENIC FACTORS THAT PARTICIPATE IN THE FORMING OF THE SPRING AND BENTHIC INVERTEBRATES IN THE KARST AREA OF CRACOW–CZĘSTOCHOWA UPLAND (POLAND)

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**Abstract.** The authors have carried out their investigations at the karst carbonate massif of the Cracow–Częstochowa Upland (CCU) since the 1990s of the XX century. The Upper Jurassic aquifer, which is a Major Ground Water Basin (MGWB No 326), was delimited in this area. It is closely connected with surface waters including living biocenoses and other dependent from the state of water. At the area of the CCU exist several hundred springs. At the drainage areas of springs authors conducted interdisciplinary investigations, including hydrogeological, geochemical, geological studies performed in spring drainage areas. The communities of benthic invertebrates were determined as the biomarkers of the environmental state. In natural springs remarkable groups of species such as oligostenothermic, crenophilic or crenobiontic prevailed whereas in springs under anthropopression mainly eurybiontic species could be stated. Stygobiontic species were also found in a few springs. The study, done together with the recognition of regional land management and pollution sources, allow to estimate the influence of natural and anthropogenic factors on water environment and its biotic elements within the karstic area of the CCU.

**Key words:** crenobionts, karst, springs, Cracow–Częstochowa Upland.

## INTRODUCTION

The necessity of groundwater protection is considered in the European Union in the context of its influence on the state of surface water and connected directly with terrestrial and water ecosystems, as well as in the context of its significance for the drinking water supply of the population. An estimation of ground and surface water quality includes among others the recognition of its biological elements of quality: plankton, macrophytes, phytobenthos and benthic invertebrates (Directive No. 2000/60/EC, 2000). The presented investigations refers to hydrogeoecological studies. They include interdisciplinary studies of ecosystems of damp areas under the influence of ground and surface water as well marshes. Investigations have dealt with the water environment regime and also with the presence of subterranean microorganisms and invertebrates in it (Humphreys, 2009). These habitats connected directly with groundwater outflow are treated in the so-called Habitat Directive of the European Union as very valuable and they have the rank of European cultural heritage.

Permanent springs establish specific habitat for aquatic fauna and flora due to the stability of water temperature, what results in the presence of oligostenothermic species. Due to small dimensions of many spring niches the influence of surrounding terrestrial habitats on the availability of food (various kinds of organic matter) as well as on the composition of fauna may be distinct. As a consequence even in small springs invertebrate species having different ecological requirements could be found.

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## HYDROGEOLOGICAL CHARACTERISTIC OF THE CCU SPRINGS AND STUDY OBJECTS

All presented investigations were carried out at the carbonate massif of the Cracow–Częstochowa Upland (CCU). This is the area of an upland karst not fully developed and diversified in its inner structure. The Upper Jurrasic aquifer, which is the Major Ground Water Basin (MGWB No. 326), was delimited in this area (Fig. 1). In its southern part, aquifer has typical unconfined character, closely connected with surface water. The Upper Jurassic aquifer has closely relations to the surface water including also living biocenoses and other dependent on the state of water. Due to protection of the natural environment and groundwater resources, most of the CCU area is protected by law (Ojców National Park, Landscape Parks, Nature 2000 area). Therefore, this region with its unique karstic features, extensive management and protected by law, is an excellent area for hydrogeological studies (Różkowski, 2006, 2009). At the area of the CCU exist several hundred springs. Not only are they the local groundwater drainage points but also form hydrologic biotic ecosysytems (Springer, Stevens, 2009). The durability and stability of habitat conditions in springs results in the occurrence of a specific fauna (crenobionts) and some relic species, e.g. in the area of the CCU – *Crenobia alpina* and *Bythinella austriaca*. The composition of fauna living in springs is influenced by hydrogeological conditions, their surroundings, zonal differences eucrenal–hypocrenal and also by disturbances, especially in the form of anthropopression (Dumnicka *et al.*, 2007).

Springs of the highest yield (40–190 l/s) occur in Częstochowa area along rocky limestone horizon. Artesian springs with large sun-heated niches are located along karstic tectonic dislocation zones. In Cracow area there are very numerous small springs of yield <1–5 l/s (70% of population) with small, very often shaded niches. Annual smallest spring discharge variability alters from 1:4 to 1:6, bigger ones from 1:1.13 to 1:2.4, while long-term changeability reaches from 1:5 to 1:15. Because of elevated localization of the recharge area localization and a character of outflow, descending springs are dominant, while ascending ones are in a minority. Taking into account morphology, hillside and near-channel springs predominate, while terrace and channel are subordinate. Springs are mainly of ruble and wastle-mantle character. Study of springs in the southern part of the CCU revealed conformity of the fissure and karstic channel directions with tectonic fracturing of massif. Dominant directions of springs exposure are NE and SW, while subordinate are NW and SE. Springs occur irregularly, mainly at the areas of tectonic engagement (Różkowski, 2006, 2009).

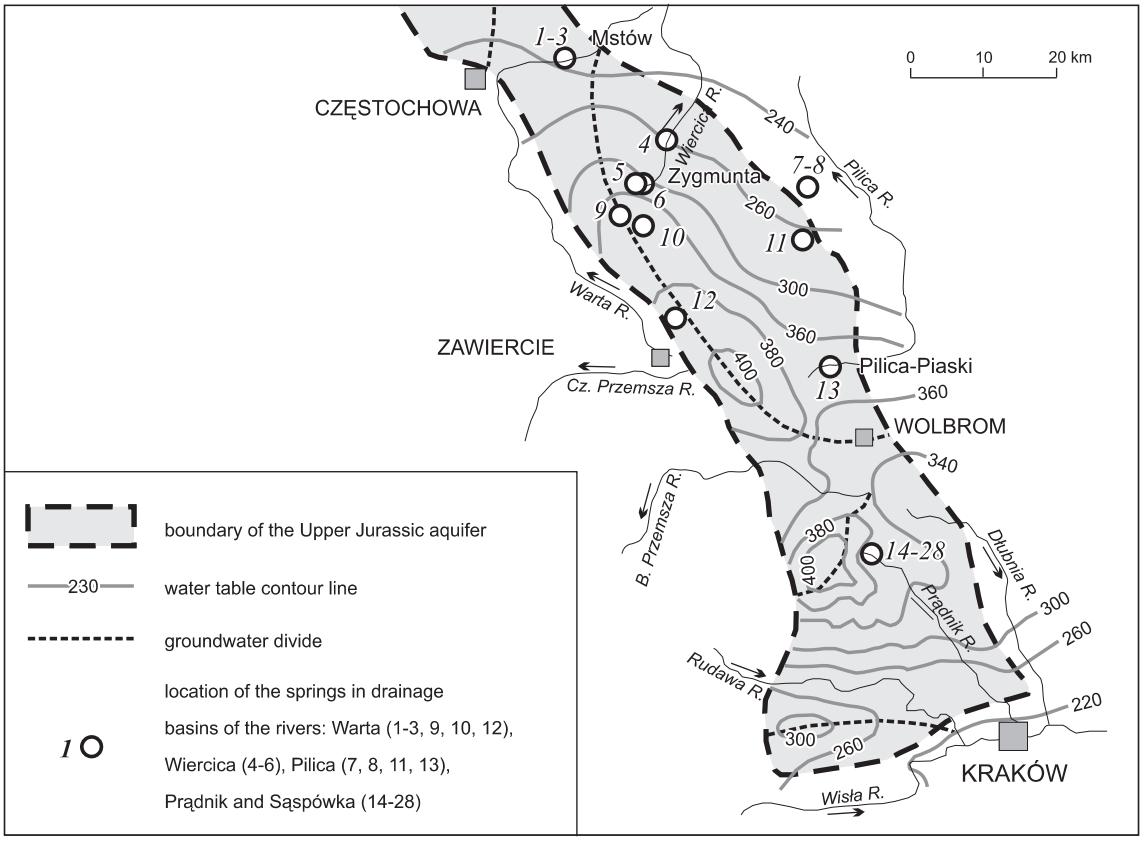


**Fig. 1. Hydrogeological map of the Cracow–Częstochowa Upland**

The Upper Jurrasic aquifer contains "memory element" represented by a system of scattered discharge. Hydrologic system reacts to preceding atmospheric precipitation mostly with a great delay. Time of initial and maximal pressure reaction of springs to thawing recharge, studied at the Prądnik river catchment area (in the southern part of the CCU), amounts: $t_1$ = 5–60 days and $t_2$ = 17–79 days. Average time of water storage in groundwater circulation system, calculated with curves of spring drying, ranges from 30 to70 days in case of springs of yield <1 l/s and 240–260 days in case of springs of yield 10–20 l/s. Usage of tritium method (considering retardation index) revealed longer period of water circulation 3–5 years in a recharge area of karstic springs of Rudawa river catchment area.

Chemical composition of groundwater of the Upper Jurassic aquifer forms in the system of the shallow circulation in the carbonate rock environment. Domination of acratopegae results form geological and climatic factors. Typical water characterizes with mineralization 185–430 mg/l, weak alkalinity (pH 7–8.13), medium and high hardness (total hardness 165–340 mg $CaCO_3$/l). Mineralization of waters altered by anthropogenic factors reaches up to 1200 mg/l. According to Szczukariew-Prikłoński classification they are as a rule two-ion waters of $HCO_3$–Ca type. Mean concentrations of major and minor components average: Ca – 104, Mg – 7.5, Na – 6.6, K – 2.2, $NH_4$ – 0.09, $HCO_3$ – 273, $SO_4$ – 34.9, Cl – 20.7, $NO_3$ – 22.0, $PO_4$ – 0.14, $SiO_2$ – 13.4 (mg/l). Waters altered by anthropogenic factors (occuring locally) belong to multi-ion types: $HCO_3$–$SO_4$–Ca and $HCO_3$–Cl–Ca–Mg. Concentrations of microelements in waters are low. Elements of natural origin predominate: Sr 49–98 µg/l, Ba 12–40 µg/l, Fe 1–16 µg/l, Al 0.3–46 µg/l. Usually waters are of good quality (80% of population). Seasonal lowering of water quality results from higher concentration of nitrates mainly.

In the land use of the CCU area predominate farming. In particular catchment areas arable lands have 55–79% share, forests 5–22%, orchards 2–4%, meadows and pastures 2–8%. Urban-industrial agglomerations are situated on margins of the CCU. A great part of the CCU area is under law protection (Ojców National Park, Jurassic Landscape Parks and nature reserves). Local pollution is connected with farming, areal sources, like air pollution and use of fertilizers and pesticides. Springs are located mainly in the areas under law protection and covered with forests. About 50% of springs preserved their natural character. The most important threat for springs have stream engineering and direct intervention in zone of spring niches (among others spring tapping-seizing, municipal waste dumping, tourism, road traffic).

## SCOPE AND METHODS OF RESEARCHES

Scope of researches included analysis of hydrogeological conditions and spring regime, mineralogical study of spring niche sediments, recognition of geomorphology, analysis of land use, sampling and determination of benthic invertebrates in spring niches and headwater sectors of the streams as biomarkers of water environment.

Since the year 2004 till 2007 hydrogeological and sozological mapping was accomplished as well as water sampling of 60 springs for chemical analysis including minor elements. Determinations were done at laboratories of the Geographical Departments of the Silesian University and in the Department of Hydrogeology and Engineering Geology of the University of Science and Technology in Cracow (with use of emission spectrometer ICP-AES PLASMA-40 and mass spectrometer ICP-MS ELAN 6100 among others). Since 2008 till 2009 there were sampled mineral sediments from a dozen or so spring niches within the CCU area. Mineralogical investigations were done at the Department of Mineralogy of the Silesian University with use of roentgen diffractometer of PANanalytical PW 3040/60 type and computer program H'PERT HighScore.

In 28 springs benthic fauna was sampled quantitatively: from coarse sediments by hand scraper and from fine sediments by the corer (Fig. 1). Invertebrates were sorted out under a stereoscopic microscope, fixed in 4% formaldehyde and after a few days preserved in 45% alcohol. Such taxonomic groups as: Turbellaria, Oligochaeta, Amphipoda, Gastropoda, Plecoptera, Ephemeroptera and Trichoptera were determined to the species level, the remaining groups of insects (Diptera and Coleoptera) – to family level. Moreover published data concerning Ostracoda (Matolicz *et al.*, 2006), Hydracarina (Biesiadka *et al.*, 1990; Biesiadka, Kowalik, 1999), Trichoptera (Czachorowski, 1990) and Coleoptera (Pawłowski *et al.*, 1994) from springs situated on CCU area were used. Relative abundance (expressed as percentage share of a particular taxon in total fauna abundance) was calculated. The average number of individuals per $m^2$ (density) was also designed.

## RESULTS OF INVESTIGATIONS AND CONCLUSIONS

Hydrogeological characteristics of springs and characteristics of area management in zone of spring niches are presented in detail publications of Różkowski (2006, 2009) and Różkowski, Żurek (2007). In the sediments of spring zones are present more mineral phases than exclusively of carbonate rocks. In a part of the spring zones predominate quartz originating from erosion and gravitational transport of the Quaternary overburden formation. Calcite and quartz are accompanied by clayey minerals, feldspar, dolomite, iron compounds and locally metallurgical wastes. Therefore spring niches can't be treated as an ecosystem connected exclusively with carbonate rock environment.

In the area of the CCU the species living exclusively in the springs (named crenobionts) are represented by a few species of water mites (Hydracarina) (Biesiadka, Kowalik, 1999) and small crustaceans (Ostracoda) (Matolicz *et al.*, 2006). Strictly crenobiontic species are not found in other invertebrates groups, but crenophilic taxons are common in various groups. Sometimes even taxonomic name of genus shows their connections with the springs e.g. *Krenopelopia, Krenosmittia* or *Crunoecia*. Typical mountain species living in cold waters with small temperature fluctuations (named oligostenothermic species) are the most important group of spring fauna in the area of CCU. Among them there are some relict species, e.g. flatworm *Crenobia alpina* and snail *Bythinella austriaca*. The populations of these species living in the CCU area are isolated from mountain populations probably since the end of the last glacial epoch, but genetic studies are necessary for the confirmation of their actual separation. Numerous specimens of *Bythinella austriaca* are present in almost all the studied springs (Dumnicka *et al.*, 2007) but *Crenobia alpina* is known from a few localities only. This species inhabits springs located along the middle course of Sąspówka stream, moreover it was found recently in one spring situated in Pilica-Piaski village (Tyc, 2004). It seems that other population, known from Źródło Zygmunta spring disappeared in 1980s totally (Skalska, Skalski, 1992). Larvae of a few insect species such as *Diura bicaudata* (stonefly, Plecoptera) and *Drusus trifidus*, *D. annulatus* and *Plectrocnemia conspersa* (caddis-fly Trichoptera) were also found exclusively in the springs and a short sector of headwater streams (hypocrenal) characterizing by low temperature. Several beetles (Coleoptera) live permanently (as larvae, pupae and imago forms) in such waters. In the CCU area they are represented by species from the genus *Agabus*, *Hydraena* and *Elmis* (Pawłowski *et al.*, 1994).

The highest densities of these stenothermic, crenophilic species were stated in the spring niches and they decreased along the stream very quickly, what was shown on the example of caddis-fly species named *Drusus trifidus* (Fig. 2A ).

Only in Sąspówka stream the above mentioned species and others which prefer low temperature but can survive its fluctuations, inhabited long stream sectors due to the presence of numerous near-channel or channel springs. It seems that the populations of oligostenothermic insects living in remote springs are not so strictly isolated as populations of flatworms or snails because adult forms of insects can actively migrate.

The most common species in karst running waters in the CCU area is *Gammarus fossarum* (Crustacea), which was found in all the studied springs. In some of them this detritivorous species forms about one half of the benthic community (Dumnicka *et al.*, 2007).

Interesting group of species, which may possibly be found in the springs, are stygobionts (the name originated from the underground Styx river known from Greek mythology). In the area of CCU the presence of a few such species was confirmed (Dumnicka, 2005, 2009). Crustacean *Niphargus tatrensis* vastly distributed in underground waters of Poland, in karst and non-karst areas (Skalski, 1981), was found in

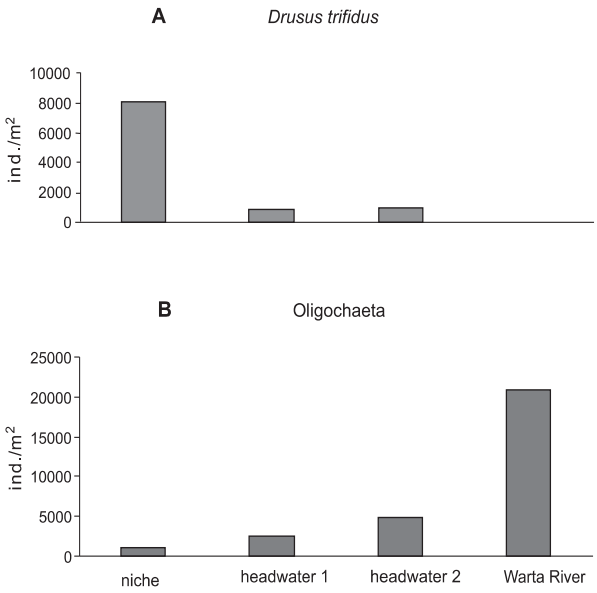


**Fig. 2. Density changes of representatives of various ecological groups of benthic fauna in the gradient: spring niche – headwater stream – river (with spring in Mstów as an example)**

**A** – for crenophilic species, **B** – for eurybiontic group

a small number of springs situated along Prądnik and Sąspówka streams and in Źródło Zygmunta spring (Dumnicka, 2005). Moreover two species of stygobiontic oligochaetes were present in the studied water bodies: *Trichodrilus cernosvitovi* in the southern part of CCU (Dumnicka, 2005) and *Gianius aquedulcis* in the northern part, exclusively in springs situated along Warta river in Mstów village (Dumnicka, 2009). This last mentioned species was for the first time found in Poland in these springs. Stygophilous species were more common and they had representatives in more invertebrate groups such as ostracods, hydracarins and oligochaetes. In Poland among insects larvae, widespread in surface aquatic environments, stygobiontic as well as stygophilous forms are absent.

Many semi-aquatic species were also present in studied springs, what is typical for small water bodies. Among them the most numerous were oligochaetes (Dumnicka, 2006) and larvae of flies (Diptera) (Dumnicka *et al.*, 2007).

Beside remarkable groups of fauna shortly presented above, there are many eurybiontic species living in the springs. They belong to various taxonomic groups and their percentage share in whole benthic fauna usually increased in encased or polluted springs, where typical inhabitants of such water bodies disappeared or at least diminished their abundance (Table 1). The density of eurybionts increased from the spring outlet to the Warta river (Fig. 2B). Even the localisation on protected areas does not assure the preservation of natural biocenoses in such springs, what could be observed in Źródło Zygmunta spring where the invertebrate fauna almost disappeared (Table 1) due to strong penetration by tourists (Dumnicka *et al.*, 2007).

The majority of springs situated on the CCU area, above all in its southern part, are small, that is why the diversity of

**Table 1**

**Characteristics of invertebrate benthic fauna in selected springs in the Cracow–Częstochowa Upland**

| Spring name | Character of human impact | Density of fauna | Eurybiontic taxons [%] | Interesting species |
|---|---|---|---|---|
| Źródło Zygmunta | tourist penetration | 2415 | 26.9 | *Niphargus tatrensis* |
| Spring in Mstów | elevated nitrate concentrations | 4800 | 23.6 | *Gianius aquedulcis* |
| Pod Maczugą | no impact | 4700 | 28.8 | *Niphargus tatrensis* crenobiontic ostracods |
| Spod Skały | no impact | 10520 | 17.1 | – |
| Źródło Harcerza | no impact | 18250 | 11.6 | *Crenobia alpina* |
| Pod Skałą Wernyhory | encased | 25420 | 59.2 | – |
| Spring in Jaworznik | encased | 32080 | 25.2 | high density of *Bythinella austriaca* |

benthic fauna in particular spring is not high. Existing faunistic and ecological studies on the springs located in the CCU indicate that they are highly diverse what resulted in high number of species found in this area. Up to now the information about diversity of fauna and the composition of spring-living communities is fragmentary because such studies were made in small number of objects. Moreover, there are no complex studies on fauna which take into account the presence and conditions of populations of crenobiontic and oligostenothermic species in individual springs.

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