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Dynamics in cyanobacterial communities from a relatively stable environment in an urbanised area (ambient springs in Central Poland)

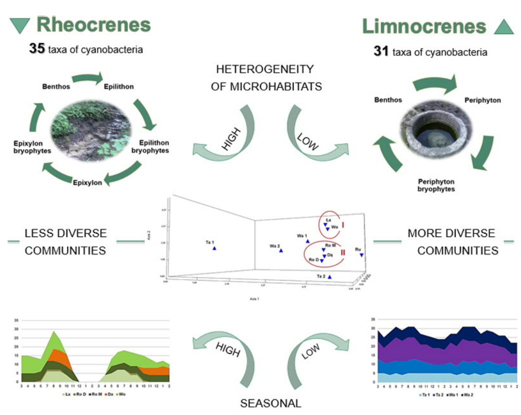
Paulina Nowicka-Krawczyk *, Joanna Żelazna-Wieczorek

Laboratory of Algology and Mycology, Faculty of Biology and Environmental Protection, University of Łódź, 12/16 Banacha Street, 90-237 Łódź, Poland

HIGHLIGHTS

- We recognised a high diversity of cyanobacteria in ambient springs.
- We recorded spatial heterogeneity and seasonal dynamics in communities.
- We compared the diversity of cyanobacteria in different microhabitats.
- We prepared a classification of springs according to the degree of human disturbance.
- Communities were modified by hydrochemical factors of an anthropogenic origin.

GRAPHICAL ABSTRACT



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ABSTRACT

Ambient springs are often cited as an example of an ecosystem with stable environmental conditions. A static biotope fosters the development of constant communities with a stable qualitative and relatively stable quantitative structure. Two years of studying cyanobacteria in different microhabitats of the rheocrenic and limnocrenic ambient springs located in urban areas showed that there is a high degree of cyanobacterial diversity and spatial and seasonal dynamics in communities. Spatial heterogeneity in relation to the type of spring and the type of microhabitat is reflected not only by a change in the quantitative structure (the number of species and their biomass), but also by a change in the composition of species. Seasonal changes depended on the type of spring and the type of microhabitat, where weather conditions influenced the communities by different degrees. Cyanobacterial communities of limnocrenes were more diverse in terms of composition and biomass, but they revealed a low seasonal dynamic in contrast to the communities of rheocrenes. The classification of springs based on their environmental conditions revealed that some springs were similar. The resemblance stemmed from the origin of human impact, which was reflected to a high degree in changes in the natural hydrochemical conditions of the springs.

For the purpose of understanding which environmental factors had the greatest influence on cyanobacterial communities, a BIO-ENV procedure was performed. The procedure revealed that of most importance was a group of ions not related to the nature of the spring environment – NH_4^+, NO_2^-, NO_3^-, and PO_4^{3-}. The presence of these ions in groundwater was a result of direct and indirect human activity in the area of aquifers. The dynamics in communities in the studied springs were accelerated by human impact and weather conditions.

* Corresponding author.
E-mail addresses: paulina_nowicka84@interia.pl (P. Nowicka-Krawczyk), zelazna@biol.uni.lodz.pl (J. Żelazna-Wieczorek).

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1. Introduction

Cyanobacteria or 'blue-green algae' are a phototrophic Gram-negative bacteria (Stanier and Cohen-Bazire, 1977). Due to the fact that they occur in the majority of aquatic environments, they are the subject of phycological investigations. Most often, cyanobacterial diversity studies analyse phytoplankton in standing water ecosystems. Massive and rapid development of phytoplankton occurs as a result of an excess of biogenic compounds. In eutrophic conditions, many species of cyanobacteria produce toxic strains and harmful cyanobacterial blooms (Backer, 2002; Vasconcelos, 2006). As a consequence, blue-green algae are often considered to be an adverse biological component of aquatic ecosystems, and their presence is regarded as a sign of an ecosystem's bad ecological status (Haande et al., 2011; Rajeshwari and Rajashekhar, 2012). However, many species of cyanobacteria are unable to grow in eutrophic waters. Such species are sensitive to biogenic pollution, and they have a narrow tolerance to an increase in nutrient content. Moreover, they play an important role in oligotrophic environments, being one, or sometimes the only primary producer in the trophic chains of ecosystems (Cantonati et al., 2015; Hagström et al., 1988).

Ambient springs are specific ecosystems, which in times of expanding urbanisation and industrialisation still have an oligotrophic character. The groundwater that supplies springs is characterised by stable physical and chemical parameters that depend on hydrogeochemical processes and the type of rock substratum (Glazier, 2009). Special features that characterise ambient springs are a low temperature of spring water, which is equal to the average annual air temperature in the spring's area, and a low thermal amplitude of water, amounting annually to 1–2 °C (Glazier, 2009; Macioszczyk and Dobrzyński, 2002; Pazdro, 1983). The environmental conditions of ambient springs create a very specific, unique and relatively stable habitat for biocoenosis (Moniewski, 2004; Żelazna-Wieczorek, 2011). However, the relative stability of the environmental conditions does not mean that ambient springs are mutually similar. Springs are multiple ecotones that link the terrestrial and aquatic environment, and they differ in terms of habitat complexity, hydrological regime, hydrochemical parameters and biotic relations (Cantonati et al., 2012a). Such heterogeneity results in a high degree of biodiversity in springs, which is determined by both time and space (Spitale et al., 2012a, 2012b). Furthermore, this diversity is determined not only by the presence of rare, endemic species, and species typical for springs – 'crenobionts', but also by species with broad ecological preferences, occurring worldwide (Cantonati, 1998; Cantonati et al., 1996; Sabater and Roca, 1992; Whitford and Schumacher, 1963; Żelazna-Wieczorek, 2011).

Changes in communities, which are reflected in qualitative and quantitative changes in the structure of organisms, stem from a low tolerance of species to changes in their optimal level of environmental conditions. As a result, the number of individuals in a population may be reduced, or less tolerant species may be replaced by cosmopolitan ones, with a wide spectrum of ecological preferences. Studies on the dynamics of cyanobacterial communities in aquatic ecosystems indicate that changes in communities are caused most often by a fluctuation in nitrogen, phosphorus and iron concentrations (Haande et al., 2011; McDonald and Lehman, 2013; Zębek, 2016), and by changes in water temperature, and pH (Dao et al., 2016).

In the case of ambient springs, the question is whether changes in cyanobacterial communities can be observed, since in general these ecosystems are characterised by relatively stable environmental conditions. Furthermore, if dynamics occur, which environmental factors are responsible for changes in the structure of communities? So far in Europe, a long-term study investigating the biodiversity and environmental integrity of springs was carried out in the Italian Alps – CRENODAT Project (Cantonati et al., 2010). Within the project, the diversity and autecology of cyanobacteria were described in great detail (Cantonati, 1998, 2008; Cantonati et al., 1996, 2012b). Furthermore, a comprehensive ecological and paleoecological study of crenological sites in the Western Carpathians was also made (Poulíčková et al., 2005a). Hašler and Poulíčkova (2005), and Poulíčková et al. (2005b) characterised the diversity of cyanobacteria in ambient springs, including bryophytes as a microhabitat.

Papers dealing with cyanobacteria and their distribution patterns in ambient springs are still very rare worldwide (Cantonati et al., 2015). They are dedicated mostly to some specific types of microhabitat including stones – 'epilithon' (Gesierich and Kofler, 2010; Gesierich and Rott, 2004; Uher et al., 2001), and brophytes – 'epibryon' (Dell'Uomo, 1975). Most phycological studies were focused on ambient springs located in areas protected by conservation agreements, where human pressure is low. In such cases, anthropogenic disturbance has only a slightly effect on the nature of the springs, and mainly in an indirect way through changes in the environment in the springs` surroundings. However, some ambient springs occur in urbanised areas where the natural conditions of springs are highly modified by indirect and direct human impact. Springs in urban areas are often treated as wastelands, and people do not protect their ecological status. The location of roads or agricultural land close to springs results in changes in hydrochemistry, which has a great impact on microalgal communities (Żelazna-Wieczorek, 2011; Żelazna-Wieczorek and Ziułkiewicz, 2007). Under human impact, the natural level of chemical parameters resulting from the type of sediment in aquifers is exceeded. The disturbance of groundwater of anthropogenic origin can be recognised by the presence of some co-occurring symptoms, including: increase in water conductivity and an increase in the concentration of: ammonium, nitrites, nitrates, phosphates, sulphates, chlorides, sodium and potassium ions (Macioszczyk and Dobrzyński, 2002; Żelazna-Wieczorek, 2011). What does cyanobacterial microflora look like in springs affected by human impact? Are there any species typical for spring environment? Is it possible to observe any patterns of spatial or seasonal changes in communities?

The aim of this research was to investigate the dynamics of cyanobacterial communities in ambient springs located in an urbanised area. The communities were studied in terms of spatial differentiation among springs and seasonal changes in communities during two years of regular study. The scope of the research included phycological analysis – qualitative and quantitative analyses of cyanobacteria collected from different microhabitats of springs; and an analysis of springs` heterogeneity in relation to hydrochemical parameters, environmental conditions, and to '*the degree of anthropogenic disturbance*' – evaluated and proposed as a tool for assessing human pressure on crenic habitats.

2. Material and methods

2.1. Study area

The study was carried out in 10 ambient springs located at 9 spring niches in the catchments of: the Bzura river, the Dzierżązna river, the Morżyca river, and the Wolbórka river (Łódź Province, Central Poland) (Fig. 1). The groundwater drains Quaternary sediments and flows out in springs formed from silicate sediments of the interglacial period, such as muds, river sands mixed with gravel and lake silts (Moniewski, 2004; Turkowska, 2001). The springs are located a short distance from city of Łódź, and close to main roads, including traffic-dense highways: the A1 and A2. Some of the springs are also located on agricultural land in the Łódź Province (Fig. A.1 in Appendix A).

The springs belong to two hydrobiological types – rheocrenes and limnocrenes (Fig. 2). Rheocrenic springs are jets of water that spurts out from the ground and flows along the land gradient forming a stream, while limnocrenic springs are basin-like depressions in the ground filled with water from the bottom. The studied limnocrenes were constructed by humans as concrete wells for the purpose of water retention (Fig. 2b). The physical and chemical analyses of spring water were carried out simultaneously with the collection of samples

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