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Drought and deluge: Influence of environmental factors on water quality of kettle holes in two subsequent years with different precipitation

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ABSTRACT

Thirty kettle hole ponds located in agricultural landscape of western Poland were studied with respect to physico-chemical (temperature and pH) and chemical (SC, dissolved oxygen, concentration of nutrients) variables of surface water quality during two subsequent years. Most of the ponds selected for the study host populations of endangered large branchiopod crustaceans, thus the aim of the study was to find out the rules governing these ecosystems and infer the best ways to protect them. Precipitation during the first year of the study was close to the average for the region, whereas severe drought was recorded during the second year. The influence of water regime, morphological parameters, catchment characteristics and vegetation on the parameters of water (pH, conductivity, contents of O_2, N-NH_4, N-NO_2, N-NO_3, SRP and TP) separately for both years was tested using redundancy analyses (RDA). The results showed that the factors significantly explaining the variance in water chemistry differed between years of the study. In the year of average precipitation, the most important factors were related to the morphology of the pond and its catchment. In contrast, under drought conditions the factors connected with pond vegetation and water depth were significant. However, in general, hydroperiod length of the pond was the most important factor, significant in all the models created.

1. Introduction

Small, mostly temporary water bodies of glacial origin, so-called kettle holes, are typical elements of the young moraine landscape (Kalettka, 1999). In intensively used farmland they often constitute the last strongholds of biodiversity (Gołdyn, 2009; Santi et al., 2010; Boix et al., 2012). They are islands of diverse, often endangered vegetation, as well as refuges and breeding places for animals important for farmland ecosystem function (Knutson et al., 2004; Biggs, 2006). For some species – like representatives of globally endangered large branchiopod crustaceans or several threatened amphibians – this type of wetland is often the sole available habitat in the transformed landscape of Europe (e.g. Bonk and Pabijan, 2010; Gołdyn et al., 2012). Kettle holes are significant also from the hydrological point of view. They are depressional wetlands collecting water from their closed drainage catchment and are often the main reservoirs of water during drought, and thus they regulate the subsoil water level (Surmacki, 1998).

Moreover, kettle holes in farmland areas are seriously threatened by human activity. First of all, due to changes in the water-table position, they tend to dewater and change into temporary marshes and reed-beds, finally to become meadows or even arable fields. Furthermore, the most kettle holes in arable land are subject to eutrophication and heavy metal pollution due to intensive artificial fertilisation in their catchment areas, especially with phosphorus fertilizers (Kalettka et al., 2001a,b).

Despite the conservation value of kettle holes, we still do not have full knowledge about the factors controlling water quality in this type of water bodies. Many of the publications on this problem come from the North American prairie pothole region (e.g. Elliott et al., 2001; Detenbeck et al., 2002; Whigham and Jordan, 2003; Kaushal et al., 2014; Pennock et al., 2014), but much less

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is on this subject from European countries (e.g. Frielinghaus and Vahrson, 1998; Kalettka and Rudat, 2000; Gałczyńska et al., 2011; Lischeid and Kaletka, 2012; Pätzig et al., 2012). Physicochemical water parameters are the major factors influencing the function of water ecosystems – mainly shaping the phytoplankton communities and thus the base of the food chain (particularly in the case of biogens concentrations) but also directly influencing functioning of populations of other organisms and circulation of matter in the ecosystem (e.g. Battle and Golladay, 2001; Williams, 2006; Pätzig et al., 2012). Therefore, it is crucial to know which of the environmental factors describing morphometry of waterbody and its catchment significantly control these parameters. Moreover, since global warming adversely affects the quality of freshwaters (Schindler, 2001), the influence of drought on water chemistry of especially sensitive small water bodies deserves special attention (Kaushal et al., 2014).

The water quality of temporary ponds is strongly dependent on their morphological parameters, hydrology and catchment area characteristics (e.g. Johnes, 1996; Williams, 2006). According to Gerke et al. (2010), soil structure and geomorphology of an area surrounding a kettle hole controls large fractions of ground water recharge and can be crucial for the runoff of chemicals in agricultural postglacial landscapes. Similarly, Florencio et al. (2014) compared a group of ponds differing in their catchment geomorphology and soil characteristics and found strong influence of these factors on plant and macroinvertebrate and amphibian communities. Sahuquillo et al. (2012) discussed nutrients and organic matter concentrations in water and in sediments among different types of Mediterranean ponds based on the source of water, hydroperiod and land use and found significant relations between these environmental variables and water quality. Influence of hydroperiod was also underlined by Espinar and Serrano (2009) who found it the major factor controlling most of the water quality parameters studied. Pätzig et al. (2012) demonstrated that water quality is strongly related to hydrogeomorphic kettle hole types and this way it significantly influences vegetation type and species richness. On the other hand, according to Joniak et al. (2007), structure and composition of aquatic macrophytes also significantly influences the physical–chemical features of small water bodies.

Good water quality and thus proper functioning of small, temporary water bodies is crucial for conservation of biodiversity – especially in areas greatly influenced by human activities, e.g. agricultural landscapes of European countries. Ponds in such areas are considered major hotspots of biodiversity, hosting populations of endangered plants and animals (e.g. Boix et al., 2012). One of such globally threatened invertebrate groups are the large branchiopod crustaceans (Anostraca, Notostraca, Leavicaudata and Spinicaudata) occurring almost exclusively in small, temporary ponds (e.g. Brendonck et al., 2008).

Our research was conducted in agricultural area of western Poland, on the group of 30 kettle holes described as the most valuable large branchiopod site of the country (Gołdyn et al., 2007, 2012). The aim of our study was to find out how the observable characteristics of kettle holes influence their water quality and how those relations change due to differences in precipitation. These issues are of major importance, since conservation of large branchiopod populations is possible only through proper protection and management of their sites. We hypothesise that the morphology of catchment and kettle hole determine water quality enabling predictions of unfavourable conditions for large branchiopods. The observed patterns might be useful to prioritise conservation activities. Furthermore, we aimed at testing if the relations between water quality and environmental variables tested are common across years differing in precipitation.

2. Materials and methods

2.1. Study site

The study was carried out in May of 2002 and 2003, approximately 20 km west of Poznań, Wielkopolska Province, western Poland (52°27′N, 16°57′E). The whole region was subject to intensive water table lowering mostly caused by land improvement for agricultural purposes, progressively changing the character of dominating ecosystems (e.g. Banaszak, 2003). The study area covers ca. 30 km^2 of intensively used farmland. Average annual precipitation in the study plot is about 550 mm, but in the years of this study its value were 551 and 317 mm, respectively (monthly precipitation for May: 70.2 and 6.2 mm). The geomorphology of this region was shaped during the last glaciation (about 12,000 years ago), and dominated by the forms typical for the young moraine landscape (Koralewska-Batura et al., 2010).

Thirty kettle holes located in the postglacial depressions were included in the present study (supplementary material 1). They are distributed randomly, and the maximum distance between the most outlying kettle hole is about 8 km (Gołdyn et al., 2007). Catchments of all the kettle holes studied (area = 0.75–14 ha) included exclusively arable lands (large monocultures of cereals and oilseed rape) and meadows. Land use in the catchments of the water bodies studied was similar, with most kettle holes located on the same fields and all the arable fields in the study area owned or leased by merely five farmers. Maximum elevation of the catchment area above the kettle hole bottom level varied from 3 to 11 m. The kettle holes varied in period of inundation (hydroperiod) from ephemeral (drying for 7–8 months a year) to permanent in the years of average precipitation. The area of the kettle holes varied from 135 to 2500 m^2 and their maximum depth from 0.5 to 1.6 m (Table 1).

Most of the kettle holes studied are fed by the water from surface runoff and most probably only six water bodies located in the deepest land depressions or surrounded by meadows have additional ground water inputs (based on own observations, groundwater comes from the area surrounding the kettle holes, corresponding to their catchments). Seven kettle holes are connected with temporary ditches providing additional source of water after thawing and snow melting or heavy rains.

Vegetation of the kettle holes consisted mainly of emergent species (e.g. *Agrostis stolonifera*, *Rorippa amphibia*, *Phragmites australis*, *Schoenoplectus lacustris*, *Carex acutiformis*, *Sparganium erectum*). Submerged species (usually *Ceratophyllum demersum* and *Ceratophyllum submersum*) occurred also in the more permanent kettle holes.

2.2. Collection of data

Samplings were conducted in May 2002 and 2003 in the similar weather conditions, approximately one week after the last rainfall occurred. Water samples for chemical analyses were taken in triplicates, by using 1.5 l plastic containers, just below the surface of water. Each time, in situ, some physicochemical parameters of water quality were measured (pH, temperature, conductivity, and dissolved oxygen content), by using a portable multiparameter meter (Hach sensION156). The water samples were transported directly to the laboratory, and concentrations of mineral forms of nitrogen (N-NH_4, N-NO_2, N-NO_3), soluble reactive phosphorus (SRP), and total phosphorus (TP) were measured. Ammonium was analysed spectrophotometrically with the Nessler reagent, nitrite with sulphanilic acid and 1-naphtylamine, nitrate by the salicylate method and phosphorus by the molybdate method, with ascorbic acid as a reducer. Before TP analysis samples were mineralised using the method with sulfuric acid and potassium peroxodisulphate (Elbanowska et al., 1999).