The influence of relief morphometric characteristics upon the occurrence of the species *Cordulegaster bidentata* in the particular conditions of the Western Carpathians

K. Petrovičová*, V. Langraf**, S. David**, L. Maták*, Z. Krumpálová*, J. Schlarmannová*

*Slovak University of Agriculture in Nitra, Nitra, Slovakia

**Constantine the Philosopher University in Nitra, Nitra, Slovakia

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Slovak University
of Agriculture in Nitra,
Tr. A. Hlinku 2,
949 76 Nitra,
Slovak Republic.
Tel.: +421-37-6 414 424.
E-mail: kornelia.petrovicova
@gmail.com

Constantine the Philosopher
University in Nitra,
Tr. A. Hlinku 1, 949 01 Nitra,
Slovak Republic.
Tel.: +421-37- 6408 -593.
E-mail: sdavid@ukf.sk

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The study concerns a monitoring survey of *Cordulegaster bidentata* Selys, 1843 (Odonata, Cordulegastriidae), which is considered near threatened in the European Red List of Dragonflies, in order to show its habitat preferences and clarify the influence of slope and orientation of slopes on the occurrence of the species. Investigations of water habitats were carried out during the period from 2019 to 2020 in the Kysuce Region in northwest Slovakia. The protocol consists of looking for larvae and characterizing larval micro-habitat of *C. bidentata* so as to show their habitat preferences and clarify the influence of slope and orientation of slopes on the occurrence of the species. We sampled 32 watercourses (epicrenal, hypocrenal, rheocren, heleocren, epihithral, metarhithral) at altitudes 420–950 m above sea level. A total of 79 larvae and 10 imagines (7♂ 3♀) of *C. bidentata* were found at 12 streams. In the present study, *C. bidentata* clearly preferred first-order stream sections, the slopes were steep and the proportion of small sediment grain sizes was high. The results show that the number of *C. bidentata* larvae grew with the increasing percentage of forests around streams. We also confirmed the trend for the number of *C. bidentata* larvae to increase with increasing values of slope and altitude of watercourses. Most of the individuals were recorded at the south and southwest oriented streams; we did not record larvae on the north and northwest oriented slopes. We assume that more suitable conditions for development of population exist in the streams on the south and southwest oriented slopes. The preference for watercourses oriented south and southwest ensures optimal conditions for the development of the population of this dragonfly species. The finding of larvae at the stages of instars shows the permanent occurrence of the species in the Kysuce Region.

Keywords: Slovakia; Kysuce Region; watercourses; forest dragonflies; larval habitat; orientation of slopes.

Introduction

The slope of the georelief in the direction of the fall line is a key morphometric parameter determining the instantaneous intensity of gravitationally conditioned geomorphological processes in the landscape. There is a strong relationship between the slope georelief towards the fall line and its orientation towards cardinal directions on one hand and exposure of the slopes to direct sunlight and prevailing winds on the other hand (Faly & Brygadyrenko, 2014, 2018). The importance of orientation usually increases with the increasing slope of the georelief, which affects the water regime in the country. “Forest species of dragonflies” are directly dependent on the morphometric characteristics of georelief influencing the properties of watercourses (thus the number and pattern of breeding habitats) in forest complexes. In the study, we were the first to have focused mainly on determining the influence of the orientation and slope of the georelief on the occurrence of larvae of the *Cordulegaster bidentata* Selys, 1843 in the territory of the Kysuce Region.

The *Cordulegaster* Leach, 1815 genus includes 30 species with Holarctic distribution (www.pugetsound.edu/academics/academic-resources/slater-museum/biodiversity-resources/dragonflies/world-odonata-list2). Widespread species in the Western Palearctic region are taxonomically divided into the *boltoni* group (including *Cordulegaster boltoni*, *C. trinaricia*, *C. princeps*, *C. heros* and *C. picta* species) and *bidentata* group (including *Cordulegaster bidentata*, *C. helladica*, *C. insignis*, *C. zymtae* species) (Boudot, 2001). Out of six European *Cordulegaster* species (Askew, 1988), two are reported for Slovakia: *Cordulegaster heros* Theischinger, 1979 (*C. h.* subsp. *heros* in the nominal subspecies) and *Cordulegaster bidentata* Selys, 1843 (*C. b.* subsp. *bidentata* in the nominal subspecies). The *C. bidentata* taxon is widespread in Slovakia mainly in

the mountainous areas of the Carpathian Mountains from the Biele Karpaty Mts. to Poloniny Mts. The most numerous populations are in the Poloniny Mts. (the Bukovské vrchy Mts). The data from the Nízke Beskydy Mts. and the Magurská Region are missing (David & Petrovičová, 2018). The species is distributed throughout Slovakia (David, 2005; Holuša, 2007; Matáková & David 2006; Šácha, 2011), including the westernmost part of the territory in the Malé Karpaty Mts. (Holuša, 2013). Until 2018, we recorded 139 occurrences in 103 localities (n = 373 individuals) for species *C. bidentata* (David & Petrovičová, 2018). The Kysuce Region is not “one of the known regions” for the occurrence of *C. bidentata*. As a part of the inventory research of the Kysuce odonatofauna in 2003, 8 individuals were recorded for the first time in the Kysuce Region (1♂, 1♀, 6 larvae) (Matáková, 2006).

The stenotopic species *C. bidentata* inhabits the flowing waters of forest streams and springs. Typical habitats are small, narrow forest streams (mostly up to 1 m wide), including their springs. The depth of these streams is usually only a few cm. The springs are often formed only by a wet substrate. The material of the bottom of the streams consists of organic mud with fine sand, sometimes with admixture of coarse sand and gravel (in the Carpathian region they are mostly weathering forms of sandstones and claystones) (Holuša, 2013). The springs often have no vegetation. Microhabitats of *C. bidentata* larvae are a fragile environment. Knowledge of larval habitats makes it possible to take better account of the problems associated with this species.

According to the Decree of the Ministry of the Environment of the Slovak Republic No 158/2014 Coll., *C. bidentata* is a species of national importance; according to the European Red List of Dragonflies (Kalkman et al., 2010), it is included in the Near Threatened (NT) category; according to the Draft red list of dragonflies (Odonata) of the Carpathians

(Šácha et al., 2014) the species is rated in the category of Least Concern (LC) and according to the Annotated Checklist of dragonflies (Odonata) of the Slovak Republic (David & Šácha, 2019), *C. bidentata* has a confirmed occurrence in Slovakia.

The objectives of the present study were (1) specifying the characteristics of the *C. bidentata* larval habitat and supplementing the information on the occurrence of the species in the Kysuce Region and (2) to clarify the influence of slope and orientation of slopes with the examined watercourses on the occurrence of the species.

Materials and methods

The study was conducted in the Kysuce Region, one of the hilly regions of North-Western Slovakia (Fig. 1–4, Table 1).

Fig. 1. Location of the study area in Slovakia

Table 1
Study sites of *Cordulegaster bidentata* findings

No.	Hydrological division of a watercourse	The total length of the stream, m	Altitude, m a.s.l.	♂	♀	L
1	metarhithral	711.8	611	1	–	1
2	metarhithral	901.3	612	–	–	1
3	metarhithral	901.3	629	–	–	2
4	metarhithral	901.3	592	–	–	1
5	metarhithral	901.3	593	2	2	4
6	metarhithral	267.4	704	–	–	1
7	epicrenal, heleocren	140.5	714	–	–	8
8	epirhithral	732.5	744	–	–	1
9	epirhithral	919.1	760	–	–	1
10	metarhithral	475.7	671	–	–	1
11	metarhithral	363.0	759	–	–	1
12	metarhithral	642.9	431	–	–	1
13	metarhithral	1129.1	613	–	–	1
14	epicrenal, heleocren	336.8	794	4	1	50
15	metarhithral	402.0	514	–	–	1
16	metarhithral	2126.0	643	–	–	1
17	metarhithral	2126.0	653	–	–	2
18	metarhithral	2126.0	648	–	–	1
Total:				7	3	79

Notes: No. – the number of locality; L – larvae.

The Kysuce Region lies between 18°19'21"E to 19°09'37"E and 49°14'51"N and 49°49'11"N, covering the area of 935 km² (654 km² out of this area is declared as a Protected Landscape Area Kysuce). The area also extends into the Beskydy Euroregion. The altitude varies from 325 m near the southern side (the Kysucká brána at the village of Rudínke) to 1,236 m (Veľká Rača peak) on the northern side with mountain peaks and ridges. The highest mountain peak of the Kysuce Region, Veľká Rača (1,236 m) is located in this district.

The valley areas around the watercourses and the adjacent hills and highlands of approximately up to 500–600 m high represent an area of moderately warm but very humid, highland pattern, with a mild summer, an average temperature of 16–17 °C, and an average annual rainfall accounting for 700–900 mm. The yearly snow cover is 80–100 days. The moderately cold, humid region comprises the highlands and marginal mountains (above 600 m) of the Kysuce Region, with short summer and average annual temperature oscillations of 12–16 °C. Average annual

rainfall amounts up to 1,000 mm, and over 1,200 m in the highest positions (Veľká Rača). The yearly snow cover days amount to 100–160 (Lapin et al., 2002). Highest average temperatures occur in July and lowest in January.

The Kysuce region has mainly developed of Tertiary flysch formations, which are characterized by monotonic rhythmic sedimentation of sandstones, claystones, and even clayey shales. The south and southeast of the area are bordered by a narrow strip of Klippen Belt formed by Mesozoic rocks, mostly of different types of limestone (Gerát, 1987).

Due to the shape of the relief, the Kysuce Region is characterized by high flysch mountains with main ridges, side ridges or groups, valleys with smaller river forms. According to the height, the middle-upland type of relief dominates (800–1,500 m above sea level) with a predominance of highlands (Gerát, 1995). The extent of forest cover of the area (mostly coniferous forests) is high, reaching up to 50%.

Fig. 2. Study area (the number 1) with sampling streams and their orientation towards the cardinals

The Kysuce Region belongs to the Váh river basin and is drained by the Kysuca River (the catchment area is 1,037.68 km²). The source of water of the currents is exclusively rain and snow, the surface runoff from the Kysuce basin comes in large amounts and is very unbalanced. The specific runoff from 1 km² varies 8.1 to 23.4 litres. In addition to the Kysuca River, the Bystrica and Čerňanka rivers may be considered the most important streams in the Kysuce Region. Over the recent decades, due to the global warming, the extremes of precipitation have also increased in the Kysuce Region. The most significant increase in air temperature is observed from January to March, in May and from June to August. It manifests in extreme heat in the summer and a more significant decrease of height and duration of snow cover in the winter. The highest amount of precipitation falls in the period between June and August, and least occurs from December to February. The highest daily overall amount of precipitation also occurs in the summer period (June to August) as torrential rains, storms and heavy rains. Extreme precipitation is an initial factor in

the occurrence of increased water flow. Extremely heavy torrential rains often exceed 200% of the overall monthly norms. Due to torrential rains, together with the interaction of the relief configuration, the nature of the soils and the geological subsoil (the Carpathian flysch zone), the risk of floods increases. Torrential rains have a negative impact on *C. bidentata* larvae, washing them to lower parts of watercourses.

Intense studies of water habitats were carried out during the period from 2019 to 2020 in the Kysuce Region in Slovakia in selected areas (regions are listed from west to east) – the Javorníky Mts., the Turzovská vrchovina Highlands and the Kysucké Beskydy Mts.

We sampled a large number of watercourses, including their source areas ($n = 32$, epicrenal, hypocrenal, rheocren, heleocren, epihithral, metarhithral) along the total length of 18,838 m at altitudes from 420.5 m to 950.8 m above sea level; with an inclination from 5.9° to 32.4° and an orientation towards the cardinal directions measuring 15.3° to 351.2° (Fig. 2–4).

Fig. 3. Study area (the number 2) with sampled streams and their orientation towards the cardinals

Fig. 4. Study area (the number 3) with sampling streams and their orientation towards the cardinals

The habitats of expected occurrence of *C. bidentata* were classified into the following five types:

1. Springs (epicrenal) and their immediate outflow (hypocrenal), water flowing down the slope (rheocren) and springs creating wetland (heleocren), depth 2–5 cm, frequent muddy sediments (Fig. 5, 6).

2. Narrow, shallow streams in forest at higher elevations; 2–10 cm deep, 10–50 cm wide, stream bed with a gentle slope without large boulders, frequent sand and muddy sediments, without large pools, and shaded by trees (Fig. 7, 8).

3. Stepped boulder-bed streams at middle and higher elevations; 10–30 cm deep, 30–100 cm wide, stream bed with boulders, frequent 40 cm

deep pools in the bed, sediments only in pools, with sand and gravel, and shaded by trees (Fig. 9, 10).

4. Stream bed without large boulders, with sand and gravel, stream dries up but eventually pools that are fed by water flow in the rubble and shaded by tree vegetation remain (Fig. 11, 12).

5. Broader sunlit streams at lower altitudes; 10–40 cm deep, 1–3 m wide, stream bed with a lower slope and bottom sediments of sand and silt, lacking both in large boulders and large pools. Sediments occur only locally near the banks.

Fig. 5. Locality on Rača Mountain – heleocren

Fig. 6. Locality on Rača Mountain – rheocren

Fig. 7. Stream in Hlavice (Klokočov willage)

Fig. 8. Stream on Rača Mountain

We evaluated all the examined watercourses ($n = 32$). For the analysis of the morphometric properties of the area, we used a digital relief model (DMR3.5, a raster model with the resolution of 10×10 m), which was created mainly by vectorization of altitudes according to topographic map. In the used version of DMR, the course of watercourses and areas was harmonized using DMR so that the watercourses in DMR represent

the thalwegs. The inclination and orientation of cardinal directions was calculated using ArcGIS 10.2. Subsequently, for the purposes of evaluating the dependence of the occurrence of dragonfly larvae on the orientation towards cardinal directions, the predominant orientations of slopes / thalwegs with the occurrence of watercourses were recalculated using raster analysis in map algebra.

Fig. 9. Stream on Rača Mountain (Klubina willage)

Fig. 10. Stream on Rača Mountain

Fig. 11. Pool with occurrence of larvae (Rača Mountain)

Fig. 12. Pool with occurrence of larvae (Rača Mountain)

Larvae (Fig. 13, 14) were the major focus of the study in the period from July to October, they were searched for in all the locations that had suitable material of stream sediment in all the types of watercourses. Larvae were captured by sluicing of sediments. In this study, we did not include imagines of *C. bidentata* in the analysis for the reason that males of this species regularly move away from the reproduction sites, flying not only over the forest streams, but also over the forest roads, along the edges

of the forest stands and over the adjacent pastures. Taxon *C. bidentata* was found at 18 localities (Table 1) in 13 streams (out of 32 examined). The localities of occurrence were at the altitudes from 431 to 794 m a.s.l., the average altitude being 649 m a.s.l.

We recorded 89 individuals of *C. bidentata* (7 ♂, 3 ♀, 79 larvae). In the present study, we did not include imagines in the analyses due to their vagility.

Fig. 13. Microhabitat of *Cordulegaster bidentata* with larvae

Fig. 14. More instars of larvae of *C. bidentata*

The analysis in the statistical program Statistica Cz. (www.statsoft.cz) was focused on the Shapiro–Wilk W-test, which determines the normality of data distribution. Based on the changes in the normal of the normality data distribution ($P = 0.001$), we used the nonparametric Kruskal–Wallis test (ANOVA) to test the differences in the number of individuals between the orientations. We expressed the relationship between the number of individuals and forestry, inclination and altitude using the polynomial regression.

Results

Presence of *C. bidentata* was confirmed in habitats which are characterized as natural streams, streamlets and springs (metarhithral, epirhithral,

epicrenal, heleocren) with clean water, basin width from 10 to 50 cm and depth between 2 and 15 cm. The habitats of the discovered localities correspond to the species demands. A numerous population of larvae and more instar larvae were found in only one sampling plot locality – spring (epicrenal, heleocren). Only individual occurrences of larvae in low densities were found in small residual pools in the stream bed. Due to the accuracy of the results (due to the vagility of the imagines), we included only larvae in the analyses (autochthony for the given localities).

The number of individuals was processed using the polynomial regression. Using the regression model, we expressed the relationship (correlation) between the number of individuals and forestry, inclination and altitude. The correlation coefficient value was moderately observed in the number of individuals as well as forestry ($r = 0.619$), inclination ($r = 0.719$) and altitude ($r = 0.732$). The reliability coefficient for forestry $r^2 = 0.761$ indicates the capture of 76.1% variability, for inclination $r^2 = 0.889$ (88.9% variability), for altitude $r^2 = 0.804$ (80.4% variability). The overall suitability of the regression model is statistically significant in forestry ($P = 0.034$), inclination ($P = 0.009$), altitude ($P = 0.047$).

The results show that the number of *C. bidentata* larvae (Fig. 15) also grew with the increasing percentage of forests around streams, whereby the forest cover surroundings of the studied watercourses ranged 0–100%; localities with larval findings were found in places with and without the occurrence of the immediate occurrence of forest stand.

Fig. 15. Effect of forestry to the number of individuals

We also confirmed the increasing trend of the number of *C. bidentata* larvae with increasing values of slope (Fig. 16) and altitude (Fig. 17) of watercourses. The species was found in very narrow steep streamlets in the forest complex. The average altitude of the localities was 649 m a.s.l.

Fig. 16. Effect of inclination on the number of individuals

We confirm the statistically significant difference ($P = 0.028$) in the average number of individuals between slope orientations. The highest

average value of the number of individuals was recorded on the south and southwest oriented streams; we did not record larvae on the north and northwest oriented slopes (Fig. 18). We assume that more suitable conditions for development of the population are in the streams on the south and southwest oriented slopes.

Fig. 17. Effect of altitude on the number of individuals

Fig. 18. Analysis of the average value of the number of individuals according to the the orientations of slopes

Discussion

The *C. bidentata* Selys, 1843 prefers spring areas and forest streams (Heidemann & Seidenbusch, 2002; Ott, 2013; Morvan & Doucet, 2018), the species is referred to in the literature (and also found in field research) as a “forest species”. In the present study, we confirmed the increase in the number of larval findings with increasing afforestation around watercourses, which indicates the importance of forest stands near the breeding habitats of the species. The predominant tree species was the Norway spruce *Picea abies*, in some localities with the admixture of *Abies alba*, *Fagus sylvatica*, *Sorbus aucuparia* and *Acer pseudoplatanus*, which provided suitable conditions for the animals *C. bidentata* larvae feed on. Despite suitable habitat conditions, we did not confirm the occurrence of larvae in dense stands of spruce *Picea abies*. According to our own experience, the imagines (males) of *C. bidentata* regularly flew not only over the forest roads, but also along the edges of forest stands and over the adjacent stands. In the present study, we recorded that pastures and meadow ecosystems around springs and forest streams are very important for the maturation and hunting of imagines, which is also mentioned by other researchers, e.g. Ott (2013), Tamm (2012a, 2013). For the occurrence of *C. bidentata* larvae in forest streams, Ott (2013); Stenberg et al. (2000a) indicate five different suitable types of habitat such as marginal parts of streams with low flow and high proportion of fine detritus; marginal areas with low flow and coarse sand; “pools” in the middle of streams, created

by the accumulation of leaves and wood; quiet areas of the watercourse in front of or behind obstacles in the stream; areas in the middle of streams with faster flow and mixed deposits of sand, coarser gravel and small proportion (<10%) of organic material. In addition to the epirhithral (mountain spring streams) and springs, *C. bidentata* may sometimes live in bog hollows (David & Petrovičová, 2018). According to our findings, the larvae in the Kysuce Region were located in the marginal parts of the streams with low flow and high proportion of fine detritus; in the “pools” in the middle of the streams created by the accumulation of leaves and wood; they did not occur in places where the water depth, streams width, sediment thickness and flow rates were too great.

Despite the fact that the details of life cycle, biology and ecology of *C. bidentata* are available (e.g. Prodon, 1976; Blanke, 1984; Buchwald, 1988; Donath, 1988; Dombrowski, 1989; Salowsky, 1989; Bocker, 1995; Bissinger, 1996; Corbet, 1999), there is very little data on the effect of slope and altitude on the occurrence of *C. bidentata* or more precisely there is no information on the impact of orientation of relief towards the cardinal points. The gradient of the slope is largely related to the flow of water in the watercourse. According to Leipelt (2005), larvae are resistant to strong currents, but even so, water flow is the main limiting factor in watercourses. The number of larvae grew with the increasing angle of streams. Larvae were also recorded in the areas with relatively steep slope of the relief and at greater distance from the spring. Our results correspond to the works of Tamm (2012b) and Henheik (2011). The number of *C. bidentata* larvae grew with increasing altitude. Statistical significance for the correlation of sites of *C. bidentata* occurrence with altitude was confirmed by David & Petrovičová (2018), while the average altitude of occurrence sites for *C. bidentata* in Slovakia was 563 m (min. altitude = 182 m, max. altitude = 1530 m). In addition to altitude, the orientation of the flow towards the cardinal points is an important parameter for optimal population development. This aspect was observed during our research. We were the first to try to determine the influence of the orientation of watercourses towards the cardinal points on the occurrence of the species. The southern and southwest slopes in the conditions of northwest Slovakia provide the most suitable conditions for the occurrence of *C. bidentata* larvae. They are optimal for reproduction and the existence of the population.

According to Morvan & Doucet (2018), Rempel et al. (2000) the choice of a suitable reproductive microhabitat within a watercourse to a large extent depends on the physical, chemical and morphological parameters of the watercourse, as confirmed by several authors (Leipelt & Suhling, 2001; Leipelt, 2005; Kalivoda et al., 2010). Our research has confirmed the specific requirements of the species in terms of larval habitat not only for shallow water depth, but also for the presence of fine-grained sediments. *C. bidentata* preferred fine-grained sediments (mud, organic sediments) and avoided sandy sediments. The larvae preferred places where organic material accumulated. This may be due to lower flow and lower water velocity, as well as an increased incidence of prey in these areas. Ott (2013) recorded similar results and confirmed that larvae living buried in the sediments of the stream like to stay mainly in areas with calm currents, in places with a small, difficult-to-detect surface flow, where fine sediments were deposited. Other authors agree that *C. bidentata* larvae clearly prefer small sediment grain sizes or detrital deposits (Bocker, 1995; Kotarac, 1997; Lolive & Guerbaa, 2007; Morvan & Doucet, 2018). Lang et al. (2001) also found that *C. bidentata* larvae were associated with particulate organic matter and throughout the research, water depth at larval positions ranged 1 cm up to 16 cm for *C. bidentata*. According to Morvan & Doucet (2018), *C. bidentata* does not occur in localities with a water depth of more than 5 cm, a sediment thickness of more than 15 cm and a flow width of more than 60 cm; Ott (2013) states that most larvae locate in areas less than 20 cm deep. Buchwald (1988) observed water depths from 2 to 20 cm in the streams where *C. bidentata* larvae were abundant. Preferred water depths at larval locations in the present study ranged 5–10 cm; the preferred stream bed width was up to 20 cm. The studied watercourses in the Kysuce Region are not inhabited continuously, or the number of larvae was so small that even with the help of intensive search – as in this study – a positive finding of larvae was not always recorded in places where we expected the species to occur. Ott (2013) and Stenberg et al. (2000b) indicate unsuitable substrate (no fine sediment), lack of food, an environment that is too acidic, drying of the

spring for a long time, branches close to spring or watercourse, intensive forestry, dense coniferous monocultures, large populations of wild game destroying microhabitats and feeding on larvae among the factors that definitely lead to the lack of species individuals or their absence at the sampling sites. If springs and forest streams are surrounded by coniferous monocultures, according to Ott (2013), Buchwald (1988), Heitz (2006), there occur acidification of aquatic habitats and absence of typical food sediment (e.g. alder) for *Gammarus fossarum*, which is an important food source for dragonfly larvae. According to our observations, the relatively small number of larvae in streams results from lack of reproductive microhabitats with fine sediments, uneven hydrological regime (drying of streams) and very frequent torrential rains that drive the larvae from the upper to lower parts of the stream. We determined lack of food was not the cause of the absence of larvae, as we recorded a large amount of food in all places of potential and recorded occurrence of larvae.

Conclusion

The most important life stage of species with life cycle of several years – which also includes the species *C. bidentata* – is the larval stage. Therefore, studies of the larval stage make it possible to improve knowledge of microhabitats of this species. In the study, we evaluated the habitat characteristics and preferences of *C. bidentata*. We focused mainly on assessing the impact of forestry, altitude and slope. An essential and new contribution to knowledge is the impact of the morphometric (not yet examined) relief characteristic – the orientation of the watercourse towards the cardinal points on the occurrence of *C. bidentata* species. This ecological characteristic has not yet received increased attention in research on other species of the genus *Cordulegaster* (Lang et al., 2001; Leipelt, 2005; Manenti et al., 2013; Holuša & Holušová, 2014; Boda et al., 2015; Jabiol et al., 2015; Pernecker et al., 2020). According to preliminary results, altitude, orientation of the watercourse towards the cardinal points, forest cover of streams, small soil fraction, covering with organic material and the stream basin slope appear to be important factors for the occurrence of the species. These results are based on the analysis of several localities in the Kysuce Region. More exact results would be obtained from an analysis of more localities. The specific requirements of *C. bidentata* and its habitat preferences depend not only on springs and forest streams, but also forest management. In the Kysuce Region, there is frequent degradation of streams after logging and destruction of breeding habitats, and predation of larvae by game is also probable. Over a long term, climate change can have a negative impact, especially long hot and dry periods in summer, despite good drought tolerance of the larvae.

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