

The environmental requirements of *Crunoecia irrorata* (Curtis, 1834) (Trichoptera: Lepidostomatidae) and the potential of the species for use as an indicator: an example from the Vistulian glaciation area

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ABSTRACT

The caddisfly *Crunoecia irrorata* is a wide-spread species in Europe and inhabits permanent spring areas with pristine or moderately disturbed habitat conditions. However, the pattern of its distribution on the national scale as well as detailed preferences toward water properties are still insufficiently known. To complete this knowledge we analysed at first the distribution of this species in Poland which showed that its extent involves the whole territory, however, with sparse occurrence in most regions and with large areas where the species has not been observed yet. The data compilation also showed that the species' frequency of occurrence is highest in the central-western region of Poland. Furthermore, its frequency of occurrence decreased towards the east and the northeast. Because the highest frequency of occurrence of this species was found in central-western Poland, the spring sites in this region were used as a model area for the analysis of the hydrochemical conditions associated with the species (25 parameters). The results of the study showed that *C. irrorata* strongly prefers habitats with low nitrate (NO_3) and chloride (Cl) concentrations. In detail, a regression model showed that the probability of occurrence of *C. irrorata* was only 5% at concentrations of $32 \text{ mg L}^{-1} \text{ NO}_3$ and $35 \text{ mg L}^{-1} \text{ Cl}$. In contrast, high concentrations of heavy metals (zinc, lead, copper, chromium, and cadmium) as well as of total iron and manganese did not significantly influence the presence of this species. In conclusion, environmental assessments relating to human health and landscape health can use *C. irrorata* as an indicator species for biogenic and salt pollution, but the species is not a potential indicator of heavy metals in spring water. Therefore, information on the presence of *C. irrorata* can serve to preserve crenic ecosystems and their assemblages and can be used to prevent anthropogenic contamination of these ecosystems.

Key words: Caddisflies, springs, species distribution, pollution, nitrate, chloride.

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INTRODUCTION

Crunoecia irrorata (Curtis, 1834) (Trichoptera: Lepidostomatidae) is classified as a rare species at the European scale (Graf *et al.*, 2006, 2008; Graf and Schmidt-Kloiber, 2011) and is the only caddisfly species legally protected in Poland (Ministerstwo Środowiska, 2014). The species is stenotopic and occurs primarily in lowland and upland springs across Europe (Graf *et al.*, 2008; Graf and Schmidt-Kloiber, 2011). Its marked habitat restriction and a characteristic tetrahedral case allow simple identification, thus making it an excellent candidate for an umbrella species (cover species) to protect crenic ecosystems and their assemblages (Czachorowski *et al.*, 2000a). It has been shown that *C. irrorata* is strongly associated with natural and near-natural springs (Schindler, 2004; Martin and Brunke, 2012), thus serving as an indicator of nearly undisturbed habitat conditions. Additionally, a higher species richness, as well as a higher number of red-listed species, have been reported from springs occupied by *C. irrorata* compared with springs

without this species (Buczyńska, 2008; Ilmonen, 2008). This information also suggests the great potential of this species in terms of the conservation of the co-occurring rare crenic specialists. However, knowledge of the distribution of *C. irrorata* in Poland is still scattered and incomplete. Since the species has been protected in Poland, no comprehensive work summarising the current distribution and habitat preferences of *C. irrorata* has appeared. The only summary of the distribution of caddisfly species in Poland was furnished almost 50 years ago by Tomaszewski (1965). Although there are many records for *C. irrorata* in the recent literature, primarily as a result of faunistic studies, it is extremely difficult to note either hot spots or areas lacking information about this species. Consequently, it is difficult to evaluate conservation strategies for *C. irrorata* and to effectively preserve the habitats in which this species resides.

Undisturbed springs are considered to represent sources of high-quality water (Galas, 2005). For this reason, they have an important function for humans as a

source of drinking water (Chelmicki *et al.*, 2011). Simultaneously, they are also characterised by a low level of temporal variability of hydrological and hydrochemical conditions compared with other freshwater sources. Thus, the species inhabiting spring ecosystems are often strictly associated with these ecosystems (Glazier, 1991; Hahn, 2000; Schindler, 2004; Gerecke *et al.*, 2009; Cantonati *et al.*, 2012). Many previous investigations have documented more or less strong relationships between various environmental components and the composition and/or diversity of crenic assemblages (Schindler, 2004; Barquín and Death, 2009; Ilmonen *et al.*, 2012). However, considerably less information on the tolerance of individual species to particular water characteristics is currently available (Bonada *et al.*, 2004; Qu *et al.*, 2010), although the available information allows the determination of indicator species for specific pollutants in aquatic habitats and, additionally, for the assessment of water quality (Bonada *et al.*, 2004). However, knowledge of the ecological requirements of individual species is an important tool in management and in strategies of biodiversity conservation, especially for predicting optimal conditions for rare species.

The main goal of the present study was to analyse the state of knowledge of the distribution of *C. irrorata* in Poland, based on a compilation of all available data with records of this species. Next, the environmental requirements of *C. irrorata* were identified based on an analysis of hydrochemical conditions in representative springs, *i.e.*, springs with low (local) human impact, with and without this species. A large spring area with ca. 700 individual springs and seeps in the central-western region of Poland was selected for the present study (Szczucińska, 2009, 2014). Because *C. irrorata* is a conservative habitat specialist throughout its entire distribution, our research can provide model studies for crenic habitats at the European scale. We aimed to identify the role of *C. irrorata* as a potential indicator of water quality in springs, particularly in terms of biogenic and heavy metal pollution.

METHODS

Our compilation of records, made to document the distribution of *C. irrorata* in Poland, relies on i) peer-reviewed publications (scientific notes, articles, and books); ii) unpublished bachelor's, master's and doctoral theses; and iii) new results from the authors' investigations. The material includes all sources available from the beginning of the 20th century until the present that include information on the occurrence of *C. irrorata*. The geographical locations specified in the records were critically verified, and the data were transformed into the UTM coordinate system (UTM grid) with 10×10 km squares as basic units, using GNOMON 3.2 software for the graphical presentation of the data on the distribution of *C. irrorata*. Addi-

tionally, the stage of *C. irrorata* (imago/larva), habitat type, and a brief area description were furnished in a summary table.

To determine the environmental preferences of *C. irrorata*, we analysed a broad spectrum of 25 physico-chemical water variables from 21 springs located in the Lubuska Upland (central-western Poland) (Fig. 1, Tab. 1). The larvae of *C. irrorata* were found in 13 springs (Tab. 1). The characteristics of the water in the selected springs have already been studied (Szczucińska, 2014), and the results of that study indicated a gradient of nutrient and trace metal components, demonstrating the relevance of the selected springs to the purpose of this study.

The water sampling procedures used to obtain this information have been explicitly described elsewhere (Szczucińska, 2014). In brief, water samples from each spring were taken five times (September 2012, December 2012, April 2013, July 2013, and October 2013) directly from groundwater outflows. The water temperature (digital thermometer ETI 2001, Electronic Temperature Instruments Ltd., Worthing, United Kingdom), electrical conductivity (EC) (conductivity meter CC-401, Elmetron Sp.j., Zabrze, Poland) and pH (pH meter 315i, Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany) were measured immediately in the field. The analyses of other parameters were conducted in the laboratory following Polish and international norms. The analyses included primary components (bicarbonate, sulphate, chloride, silicate, magnesium, calcium, sodium), secondary components (total iron, potassium, nitrate, fluoride), minor components (phosphate, manganese, cadmium, chromium, copper, lead, zinc), and other parameters [ammonium, nitrite, total organic carbon (TOC), total water hardness (TWH)].

Differences in physico-chemical water parameters between springs with and without *C. irrorata* were tested with a non-parametric Mann-Whitney test. Further, water parameters with significant results on the Mann-Whitney test were used individually as independent variables in binary logistic regression models to predict the probability of occurrence of *C. irrorata*. All statistical analyses were performed using SPSS software (IBM Inc., Chicago, IL, USA).

RESULTS

Distribution of *C. irrorata* in Poland

Prior to this publication, 88 localities for *C. irrorata* had been documented in Poland (Tab. 2): 64 records were known up to 1999, and 24 records have been published since 2000. Furthermore, 18 new records have been added by the authors, giving 106 localities in total (Tab. 2). Overall, *C. irrorata* was found in the larval stage at 68 localities. These findings confirmed the exact habitat location and habitat type. Of these localities, 74% were springs, whereas

26% constituted streams, upper zones of rivers, and tributaries. In 38 cases of imago records, the nearest habitat types were given: 53% streams, 18% springs, and 29% records for which an exact habitat classification was not possible because of the presence of both spring and stream habitats or the lack of a precise description.

The current distribution of *C. irrorata* extends over the entire territory of Poland, but the species occurs sparsely in most regions and has not yet been observed in large areas (Fig. 2). There are only 3 regions in Poland with substantial concentrations of sites: between the Odra

and Warta River valleys in the central-west, 15 records (UTM: WU10; -11;-20; WT07; -09; -18; -28,-39); in the Central Polish Lowlands, 6 records (CC85; -95; DC04; -13; -23); and in Roztocze, in the southeast, 6 records (FA49; -58;-67;-68; FB31) (Tab. 2). Further, *C. irrorata* is well distributed throughout the mountain regions of Poland, with records in Sudety in the southwest, in the Western and Central Carpathians in the south, in the Eastern Beskidy Mountains in the southeast, and in the Świętokrzyskie Mountains in the central part of Poland. However, the number of mountain localities is rather low,

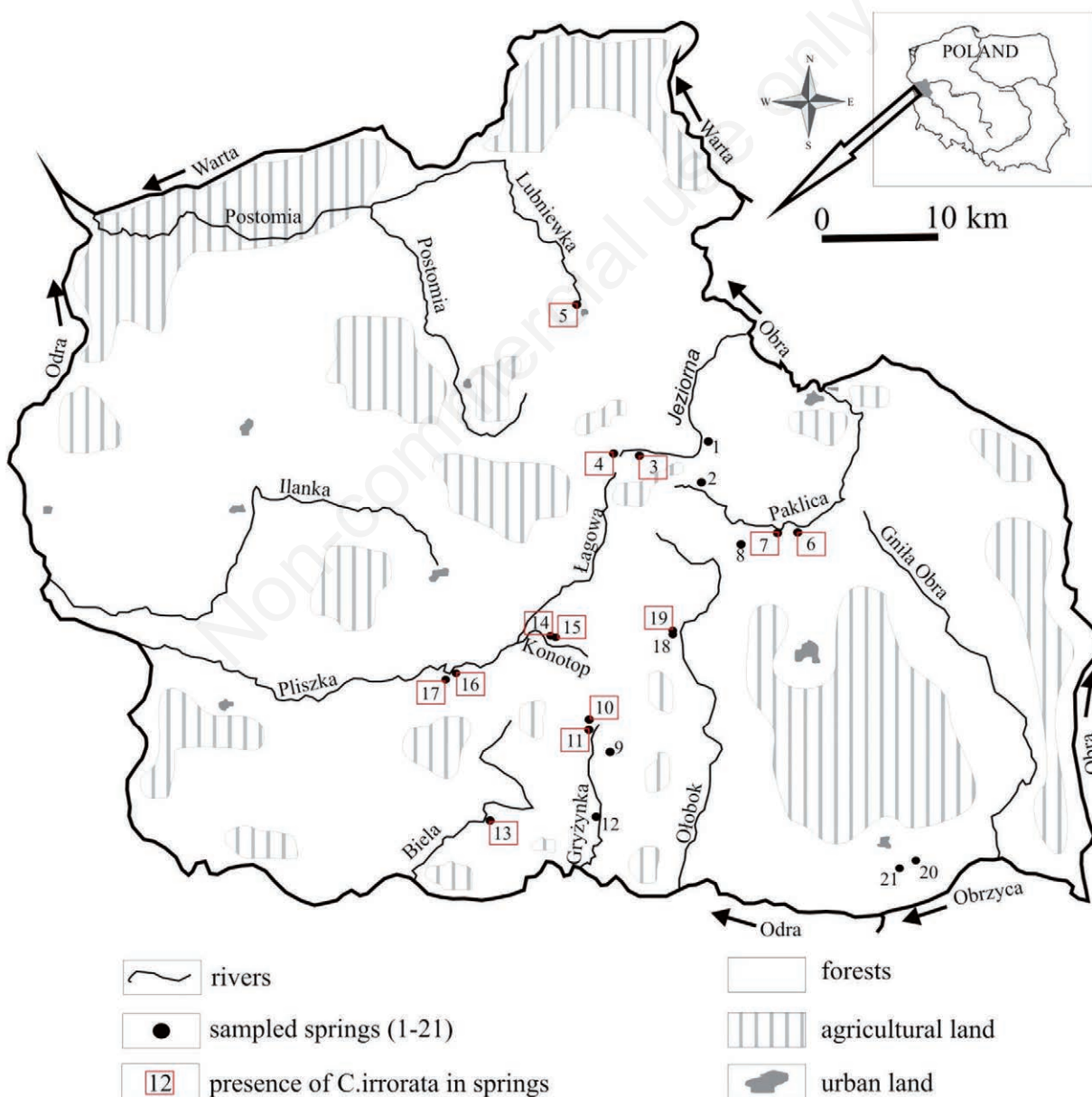


Fig. 1. Location of the 21 springs analysed for their water properties, with area characteristics.

with a few small areas with greater concentrations of records identified in the Świętokrzyskie Mountains (UTM: DB93), Stołowe Mountains (UTM: WR98), Babia Góra (UTM: CV99), and Gorce Mountains (UTM: DV29). In other Polish regions, only single and widely scattered localities are known from the South Baltic Coastal Regions and Lake Districts in the north as well as from the Małopolska- and Silesian-Cracovian Upland in central Poland.

Water characteristics of *C. irrorata* habitats

To determine the environmental preferences of *C. irrorata*, with particular emphasis on its potential as an indicator, we analysed the characteristics of the water from 21 representative springs from the central-western area, including 13 springs in which the presence of this species has been confirmed and 8 springs from which the species is known to be absent (Tab. 1). Our analyses showed that *C. irrorata* occurred over wide ranges of almost all measured water parameters (Fig. 3). However, the most remarkable discrepancies in presence/absence were observed with respect to nitrate. In detail, *C. irrorata* was almost exclusively observed in springs with low concentrations of nitrate of approximately 1.0 mg L⁻¹ and not exceeding 20 mg L⁻¹ (Fig. 3, Tab. 3). Statistically, the

probability of occurrence of *C. irrorata* decreased significantly as NO₃ concentrations increased (Fig. 4, Tab. 4). According to the corresponding binary logistic regression model, the probability of recording the species was less than 5% at a concentration of 32 mg L⁻¹ NO₃ (Tab. 4). Furthermore, significantly lower values of EC, TWH, Cl, Mg, Na, SiO₂, K, and F, as well as significantly higher values of pH, were indicated for springs harbouring *C. irrorata* (Tab. 3). For three components (Cl, F, and K) as well as for pH the results of logistic regression were also significant. Based on these regression results, the probability of recording the species was less than 5% at concentrations of 35 mg L⁻¹ Cl, 0.55 mg L⁻¹ F, and 5.2 mg L⁻¹ K (Tab. 4).

High concentrations of heavy metals (Zn, Pb, Cu, Cr, and Cd), as well as the total levels of iron and of manganese, did not influence the presence of *C. irrorata* (Fig. 3, Tab. 3). In general, the median values of these parameters were equal in spring groups with and without *C. irrorata* or even slightly higher in habitats with *C. irrorata*. Moreover, the species was observed in certain springs with the highest seasonal (extreme) values of these metals, maximally reaching 0.23 mg L⁻¹ Zn, 0.13 mg L⁻¹ Pb, 0.043 mg L⁻¹ Cu, 0.012 mg L⁻¹ Cr, 0.005 mg L⁻¹ Cd, 19.0 mg L⁻¹ Fe, and 3.3 mg L⁻¹ Mn. These ex-

Tab. 1. Location and characteristics of 21 springs selected for physico-chemical analyses of water properties, with additional information on presence (+)/absence (-) of *C. irrorata*.

Spring number	Geographical coordinates		River catchment	Outflow type	Outflow position	<i>C. irrorata</i>
	Longitude	Latitude				
1	15.46389	52.41027	Jeziorna	D	U. hillside	-
2	15.40443	52.36595	Paklica	D-A	U. hillside	-
3	15.32523	52.40692	Jeziorna	D	U. hillside	+
4	15.30436	52.40742	Jeziorna	D	U. hillside	+
5	15.17056	52.45591	Lubniewka	D	U. hillside	+
6	15.50941	52.32510	Paklica	D-A	U. hillside	+
7	15.51022	52.32503	Paklica	D	U. hillside	+
8	15.45114	52.29362	Paklica	D	U. hillside	-
9	15.28052	52.16915	Gryżynka	D-A	U. hillside	-
10	15.27521	52.18211	Gryżynka	D	U. hillside	+
11	15.27114	52.17522	Gryżynka	D-A	U. hillside	+
12	15.27382	52.12755	Gryżynka	D	U. hillside	-
13	15.13733	52.11305	Biela	D	U. hillside	+
14	15.20443	52.25462	Konotop	D	Hillside	+
15	15.20488	52.25375	Konotop	D	Hillside	+
16	15.16449	52.24569	Pliszka	D	Hillside	+
17	15.16357	52.24489	Pliszka	D	U. hillside	+
18	15.37834	52.24591	Ołobok	D	U. hillside	-
19	15.37840	52.24621	Ołobok	D	U. hillside	+
20	15.72020	52.06730	Obra	D	Hillside	-
21	15.71110	52.06521	Obra	D	U. hillside	-

D, descending (gravity spring); D-A, descending-ascending (water discharged under pressure); U. hillside, under hillside.

treme concentrations were 2 to 7 times greater in springs with *C. irrorata* than in springs without *C. irrorata*. Similarly, slightly higher concentrations of nutrients other than nitrate (TOC, NH_4 , NO_2 , and PO_4) did not influence the distribution of the species in any way (Fig. 3, Tab. 3). *C. irrorata* was recorded at maximal values of $0.33 \text{ mg L}^{-1} \text{ NH}_4$, $0.18 \text{ mg L}^{-1} \text{ NO}_2$, and $0.86 \text{ mg L}^{-1} \text{ PO}_4$.

DISCUSSION

Patterns in the distribution of *C. irrorata* in Poland

A compilation of available information on the occurrence of *C. irrorata* in Poland was urgently needed due to the species' legal protection since 2004. The law providing protection to this and other species is one of the strongest tools implemented for nature and diversity conservation at the national scale. Based on a summary of the distribution of Trichoptera in Poland (Tomaszewski, 1965), *C. irrorata* was almost exclusively reported from

mountain regions (Sudety Mountains, Beskid Zachodni and Tatry Mountains) in southern Poland, with a single observation from the Masurian Lake District in the north, thus making it a very rare species on the national scale. Further investigations showed, however, that this species can also be found in spring-rich lowland and hill regions across the whole country. Nevertheless, the localities in which the species is currently found are also strongly scattered, suggesting that it is rather uncommon in Poland. Furthermore, a strong tendency to occupy only small spring areas or certain locations in ostensibly homogenous spring-reach areas is evident. This pattern is well documented from the Tanew (Buczyńska, 2010) and Młynówka (Majecki, 2006) River valleys as well as from mountains: Stołowe (Michejda, 1954), Gorce (Szczęsny, 1975, 1986), and Świętokrzyskie (Szczęsny, 1990), where *C. irrorata* was found more frequently only in a few groundwater outflow zones. This general pattern corresponds well to the knowledge about the patchy distribu-

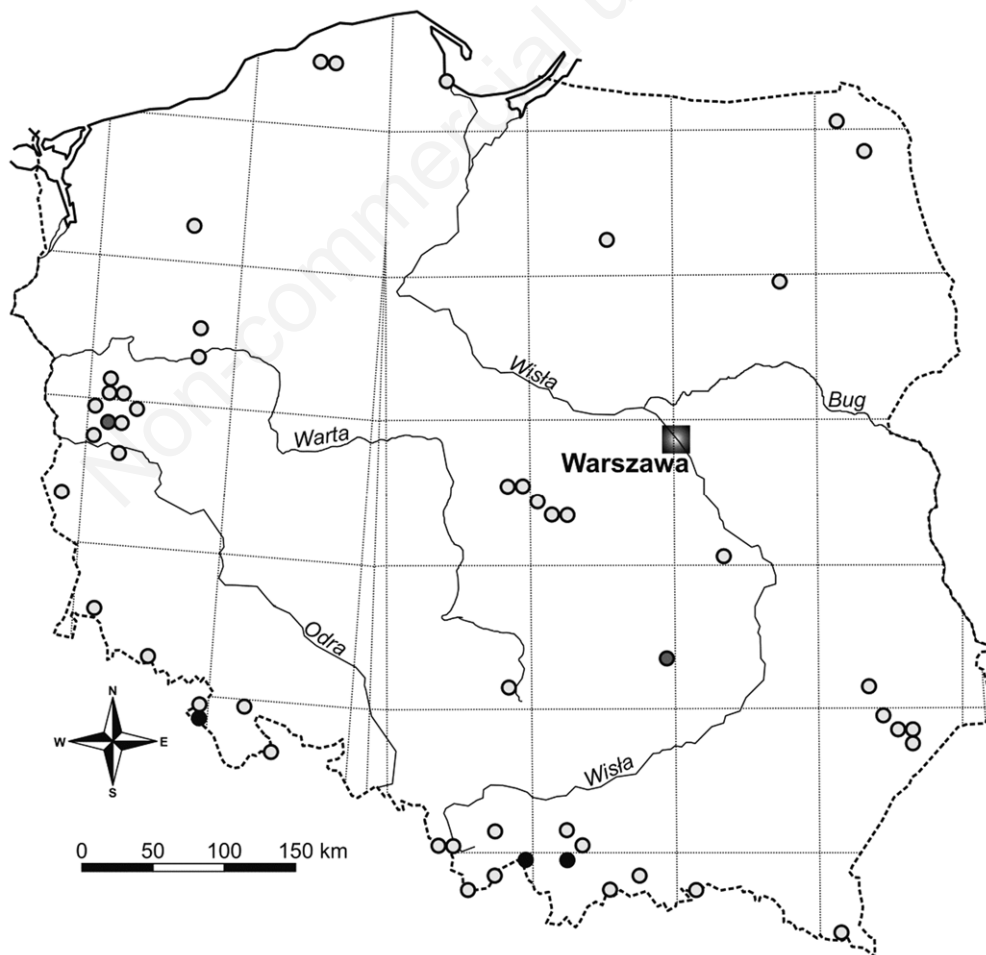


Fig. 2. Distribution of *C. irrorata* in Poland. The colours of symbols refer to number of sites in a single grid: light grey, 1-4 sites; dark grey, 5-8 sites; black, ≥ 9 sites.

Tab. 2. Summary of sites for *C. irrorata* in Poland, with information on location (UTM square), number of records, stage, habitat type and brief description of the area, with references.

UTM	Records	Stage	Notes to habitat and location with references
CA40	1	Im	Stream Leśnica (Szczęsny, 1986)
CA50	2	Im	Spring and stream Leśnica (Szczęsny, 1986)
CA71	1	La	Stream Potok Wielka Puszcza and its tributaries (Zaćwilichowska, 1964)
CB81	2	Im	Zygmunt's and river Wiercica's springs (Riedel, 1972)
		La	Spring of river Wiercica (Czachorowski, 1990)
CC85	1	La	Springs of river Linda (Majecki, 2006)
CC95	1	La	Spring of river Ciosenka (Majecki, 2006)
CF43	1	La	Springs of stream Kamienny Potok (Ciechanowski, 2004)
CV57	1	Im	Stream Racza (Szczęsny, 1986)
CV78	2	Im	Spring and stream Żabnica (Szczęsny, 1986)
CV99	10	Im	Mount Babia Góra: Markowa in Zawoja (Dziędzielewicz, 1911); Zawoja (Dziędzielewicz, 1920); ? (Racięcka, 1933); stream at Krowiarki, karst spring and stream at Gruba Jodła, River Skawica in Zawoja (Botosaneanu, 1965); streams: Potok Suchy, Dejaków Potok, tributary of Markowy Potok (Sowa and Szczęsny, 1970); stream Przywarówka (Szczęsny, 1986)
DA22	1	?	Myślenice (Racięcka, 1933)
DA30	2	Im	Spring and stream Stradomka (Szczęsny, 1986)
DB93	7	La	Spring and stream Dębno, tributary of stream Podlūsica, spring of stream Łyszczka, stream Czarny Potok (Szczęsny, 1990)
DC04	2	La	Helocrenes at river Młynówka (Majecki, 2006)
DC13	1	La	Helocrene at river Mroga (Majecki, 2006)
DC23	1	La	Spring stretch of river Rewica (Majecki, 2006)
DE62	3	La	Helocrenes at river Łyna (Szczepański, 2003)
DV29	11	Im	Spring, stream and tributary of stream Poniczanka (Szczęsny, 1986); stream Olszowy (Szczęsny, 1975)
DV57	2	Im	Stream Pieniński Potok and spring on Toporzyska (Riedel, 1978)
DV78	1	Im	Stream Mała Roztoka Ryterska (Riedel, 1972)
EC30	1	La	Springs at river Zagożdżanka in Królewskie Źródło reserve (Pachocka, 2003)
ED79	1	La	Stream in Kalinowo reserve (Czachorowski <i>et al.</i> , 2000b)
EV17	1	Im	Stream Ropka (Szczęsny, 1986)
FA49	2	La	Springs of stream Krupiec (Buczyńska, 2010)
FA58	1	La	River Tanew (Buczyńska, 2010)
FA67	1	La	Springs of river Tanew (Buczyńska, 2010)
FA68	1	La	River Tanew (Buczyńska, 2010)
FB31	1	La	River Wieprz (Buczyńska, 2010)
FE38	1	La	Springs at Lake Wigry (Demel, 1922)
FF10	1	La	Helocren at river Czarna Hańcza (Buczyńska and Buczyński, 2014)
FV14	1	Im	Mountainside of Połonina Caryńska (Riedel, 1966)
VT83	1	La	Spring at stream Pstrąg (Rychła and Buczyńska, 2013)
WR98	4	La	Springs and streams in Góry Stołowe mountains (Michejda, 1954)
WR99	10	La	Springs and streams in Góry Stołowe mountains (Michejda, 1954)
WS15	1	Im	Stream Czarny Strumień (Tomaszewski, 1932)
WS52	1	La	Spring of river Łomnica (Tomaszewski, 1932)
WT07	1	La	Rheocrene at river Biela (present work)
WT09	1	La	Spring at river Ilanka (present work)
WT18	7	La	Rheocrenes at rivers Gryżynka, Konotop, and Pliszka (present work)
WT26	2	La	Helocrenes at river Łączka (present work)
WT28	1	La	Rheocrene at river Ołobok (present work)
WT39	2	La	Rheocrenes at river Paklica (present work)
WU10	1	La	Rheocrene at river Jeziorna (present work)
WU11	1	La	Rheocrene at river Lubniewka (present work)
WU20	1	La	Rheocrene at river Jeziorna (present work)
WU73	1	La	Spring at Lake Kubek (Adamek, 2006)
WU75	1	La	Spring at fish pond (Adamek, 2004)
WV62	1	La	Stream and tributary of Lake Lubie (Pietrzak, 2000)
XA44	1	La	Spring at river Łupawa (Veith, 2006)
WA54	1	La	River Łupawa (Veith, 2006)
XR29	1	La	Springs at town Bardo (Tomaszewski, 1932)
XR36	1	Im	Springs of stream Kleśnica (Tomaszewski, 1932)

Im, imago; *La*, larvae.

tion of this species in other European countries and, consequently, to its classification as a rare species on a continental scale (Hoffsten and Malmqvist, 2000; Graf *et al.*, 2006, 2008; Graf and Schmidt-Kloiber, 2011). The patchy large-scale occurrence of *C. irrorata* surely results from its strictly stenotopic preferences for small and highly isolated habitats such as springs. Given the poor flying ability of imagines, which has also been demonstrated in spring habitats by Hoffsten (2004), the regional rarity of the species may, furthermore, arise from the high degree of isolation of pristine and near-pristine crenic ecosystems offering the optimal conditions required by this species.

At present, the occupancy of *C. irrorata* is highest in three Polish regions: between the Odra and Warta River valleys in the central-west, in the Central Polish Lowlands, and in Roztocze in the southeast. Most of the sites for *C. irrorata* in the central-western region have only recently been discovered and are, thus, first reported in this publication. It is noteworthy that this area has the highest frequency of occurrence of *C. irrorata* in Poland reported to date: the species was found in 13 of 21 investigated springs (62%). Moreover, the western region of the country is potentially important for obtaining further records of *C. irrorata* and is consequently of high importance for the conservation of crenic fauna because approximately

700 individual springs and seeps have been reported as a result of detailed groundwater outflow mapping conducted during the past decade (Szczucińska, 2009, 2014). For comparison, the frequency of occurrence of the species in the 2 other mentioned regions of central and eastern Poland is much lower, 36% (Majecki, 2006) and 27% (Buczyńska, 2010), respectively. Further, a study of 66 lowland springs in north-eastern Poland (Masurian Lake District) showed that only 4.5% are inhabited by *C. irrorata* (Szczepański, 2003). The current frequency data show a continuous decrease towards the east and north, suggesting a climate-related effect. A brief comparison with the average long-term (1981-2010) air temperatures in the principal cities of these regions (western: 8.9°C, central and south-eastern: 8.4°C, northeastern: 7.6°C) (<http://www.pogodynka.pl/polska/daneklimatyczne/>) generally supports this hypothesis at the national scale. However, the frequency values of 42% from the region of Finland (Ilmonen, 2008), with average annual air temperatures of approximately 4°C (Pirinen *et al.*, 2012), contradict the hypothesis. Therefore, our interpretation should be treated with caution because it requires detailed faunistic knowledge of the species to provide a firm basis for testing the hypothesis of a climate-related effect. The picture obtained of the distribution of *C. irrorata* may in-

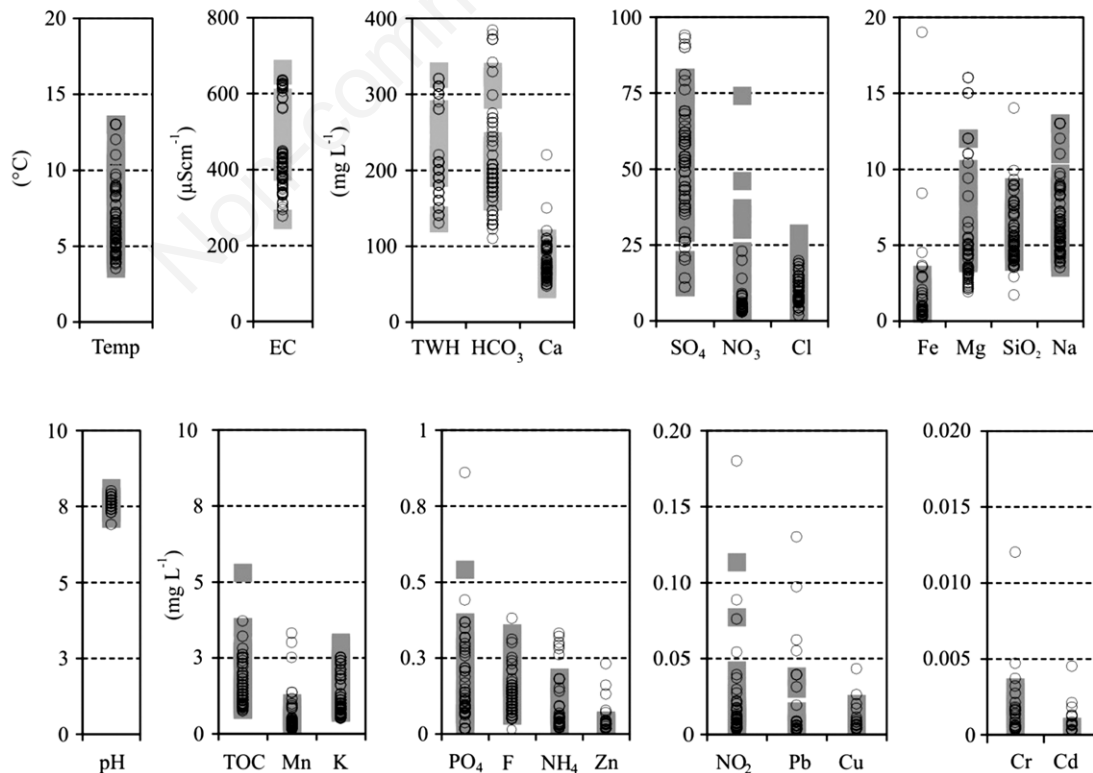


Fig. 3. Presence (black circles) and absence (grey squares) of *C. irrorata* in relationship to physico-chemical parameters.

clude a margin of error due to the variation in the recognition of Trichoptera from region to region in Poland and due to the use of data from different periods. However, such a margin of error is unavoidable and is characteristic of analyses of many species in different countries. This difficulty has also been highlighted as one of the important obstacles by Hering *et al.* (2009) in terms of potential analyses of the impact of climate on Trichoptera at the European scale.

Environmental preferences and potential of *C. irrorata* as an indicator species

Knowledge of the influence of the physical and chemical properties of water on *C. irrorata* and, thus, of its potential as an indicator of water quality is still very poor. Therefore, the most noteworthy information presented by our study is an evidence of the sensitivity of the species to nitrate and chloride. For nitrate, our regression model predicted with a correctness of 72% that a concentration

greater than 32 mg L⁻¹ might be the limiting value for *C. irrorata* in springs. Such a level of nitrate exceeds its natural content in groundwater and thus is, in itself, evidence

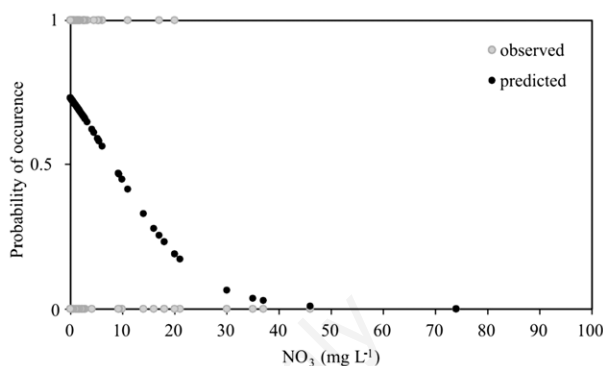


Fig. 4. Observed (grey dots) and predicted (black dots) occurrence of *C. irrorata* across nitrate gradient (details of the model equation are given in Tab. 4).

Tab. 3. Comparison of physico-chemical parameters of water (median, minimum and maximum values) for 21 springs with and without *C. irrorata*, with results of Mann-Whitney-tests.

Variable	Unit	Presence of <i>C. irrorata</i> (n=65)		Absence of <i>C. irrorata</i> (n=40)		Z value with P
		Median	Min-max	Median	Min-max	
Physical components						
Temp.	°C	9.4	7.0-13.2	9.6	6.2-13.0	-1.009
pH	-	7.7	6.9-8.0	7.6	7.1-8.1	-2.306*
EC	μS cm ⁻¹	414	277-635	474	267-665	-2.534*
Primary components						
HCO ₃	mg L ⁻¹	177	110-384	204	159-329	-1.360
SO ₄		53	11-94	50	11-80	-0.579
Cl		9.0	0-18.0	12.0	1.4-27.0	-2.821**
Si		5.0	1.7-14.0	5.8	3.9-8.8	-2.387*
Mg		3.5	1.9-16.0	5.9	3.8-12.0	-3.879***
Ca		72	47-220	78.5	43-110	-1.644
Na		5.9	3.5-13.0	7.5	3.3-10.0	-2.079*
Secondary components						
Tot. Fe	mg L ⁻¹	0.3	0.02-19.0	0.3	0.02-2.9	-0.185
K		0.9	0.5-2.5	1.3	0.69-3.0	-3.287**
NO ₃		1.0	0-20.0	2.1	0-74.0	-2.77**
F		0.10	0-0.38	0.16	0.05-0.33	-3.225**
Minor components						
PO ₄	mg L ⁻¹	0.066	0-0.86	0.050	0-0.54	-0.722
Mn		0.14	0-3.3	0.09	0.001-0.84	-1.399
Cd		0.00002	0-0.005	0.00002	0-0.001	-0.035
Cr		0.0002	0-0.012	0.0003	0-0.003	-0.357
Cu		0.001	0-0.043	0.001	0-0.020	-0.056
Pb		0.001	0-0.13	0.0006	0-0.038	-0.468
Zn		0.0025	0-0.23	0.0028	0-0.044	-0.324
Other components						
NH ₄	mg L ⁻¹	0.01	0-0.33	0.03	0-0.17	-1.63
NO ₂		0.007	0-0.18	0.009	0-0.13	-0.601
TOC		1.3	0.74-3.7	1.6	0.78-5.3	-1.857
TWH		200	130-320	225	130-330	-2.543*

EC, electrical conductivity; TOC, total organic carbon; TWH, total water hardness; *P≤0.05; **P≤0.01; ***P≤0.001.

of contamination (Chelmicki *et al.*, 2011) that might be associated with local agriculture or domestic/tourist activities in the studied area. Our predictions of the effect of nitrate on the occurrence of *C. irrorata*, although they are based on a relatively small sample size, appear to be highly consistent with findings from other European regions, *e.g.*, Rhineland-Palatinate (Germany), where more than 90% of the springs occupied by this species had a concentration of nitrate less than 30 mg L⁻¹ (Schindler, 2004). A very low tolerance of pollution by biogenic contaminants such as phosphate and ammonium has also been shown for the entire family Lepidostomatidae and particularly for another species belonging to this family (*Lasiocephala basalis*) in Mediterranean streams (Bonada *et al.*, 2004). These findings suggest that species in the family Lepidostomatidae generally have the potential to serve as indicators of biogenic pollution. For chloride, our regression model predicted an upper limit of 35 mg L⁻¹ Cl, again agreeing well with corresponding results from the German Rhineland-Palatinate spring region (Schindler, 2004). Additionally, a strong preference for low concentrations of Cl has also been documented at the family level in Lepidostomatidae (Bonada *et al.*, 2004). In contrast, however, there is evidence that the genus *Lepidostoma* (Lepidostomatidae) can survive for 48 h at chloride pollution levels of up to 6000 mg L⁻¹ (Williams *et al.*, 2000). This value exceeds the limit predicted by our regression model by almost 200-fold, but note also that 50% of the tested individuals died after 96 h of exposure to this extremely high chloride concentration (Williams *et al.*, 2000). These results indicate that a low level of chloride concentration might be required for long-term occupancy of a site by representatives of the Lepidostomatidae, including *C. irrorata*.

The effects of other water components are of low importance for the distribution of *C. irrorata*. Our results slightly support the observation that *C. irrorata* prefers

higher pH values (Ilmonen, 2008) and lower values of water hardness (Schindler, 2004). However, based on currently available results, the relatively weak differences, although statistically significant, of these and several other components (*e.g.*, EC, Si, Mg, Na, and K) between springs with and without *C. irrorata* in our study area do not permit these components to be used as predictive factors for the occurrence of this species. It appears that other morphological characteristics, such as the total area and minerogenic area associated with brooks (Ilmonen, 2008), as well as the occurrence of surrounding deciduous vegetation in association with specific and more diverse substrate types (Hahn, 2000; Schindler, 2004), are more important factors. In this context, Czachorowski (1999) specified helorheocrenes as the general habitat of *C. irrorata* in Poland. However, among the springs examined in the current study, more than 50% cannot be simply included in a particular category of spring types. The basic habitat-related approach to morphological typing of the springs (Thienemann, 1924) inhabited by this species still appears to be unsatisfactory as a method of classification and is too simplified to describe the more complex nature of spring morphology, especially on the national scale. This problem has also been discussed by von Fumetti and Nagel (2011) in the context of spring invertebrate assemblages.

Heavy metals also affect the water quality of springs for aquatic organisms and for humans because of potential toxicity and potential accumulation. However, the relationship between these pollutants and caddisfly representatives is rather complex. In general, the effects of heavy metals on the order Trichoptera (structure and abundance) in streams appear to be of minor importance, although slightly negative effects (Qu *et al.*, 2010) as well as slightly positive effects (Hirst *et al.*, 2002) of particular heavy metals have been observed. However, various levels of sensitivity have been documented for individual taxa within the order Trichoptera. For example, *Polycen-*

Tab. 4. Results of logistic regression for selected physico-chemical parameters of water for 21 springs.

Variable	Model correct (%)	R	B0	B1	Exp(B)	P	Conc. of 5% prob.
NO ₃	72.4	-0.22	0.993	-0.122	0.885	0.003	32
Cl	72.4	-0.25	1.934	-0.136	0.87	0.001	35
F	65.7	-0.21	1.651	-8.262	0.0003	0.004	0.55
K	63.8	-0.20	1.622	-0.874	0.42	0.006	5.2
pH	64.8	0.11	-17.10	2.318	10.15	0.050	6.2
SiO ₂	60.0	0.000	1.284	-0.138	0.87	0.236	-
Mg	59.0	-0.046	1.000	-0.085	0.92	0.129	-
EC	58.1	-0.08	1.959	-0.003	0.99	0.085	-
TWH	57.1	-0.06	1.774	-0.006	0.99	0.109	-
Na	57.1	0.000	1.286	-0.117	0.89	0.222	-

R, regression coefficient; B0 and B1, coefficients in regression equation; Exp(B), odds ratio, Conc. of 5% prob., estimated concentrations for 5% probability of occurrence of *C. irrorata*; EC, electrical conductivity; TWH, total water hardness.

tropus sp. and *Apsilochorema* sp. are known to show positive responses to metal contamination, whereas *Ryacophila* sp. and *Sericostriata* sp. are highly sensitive to such contamination (Qu *et al.*, 2010). For the family Lepidostomatidae, evidence of significantly negative effects of lead and nickel as well as slightly negative effects of cadmium and zinc have been found for *Lepidostoma* sp. in Chinese streams (Qu *et al.*, 2010), suggesting that *C. irrorata*, as a representative of the same family, might show a similar sensitivity to these heavy metals. Surprisingly, high concentrations of neither these nor the other metals considered influenced the presence of *C. irrorata* in our study area in any way. Given that the maximal values for cadmium, zinc, and lead in our study area were seasonally approximately 10, 3, and 2 times, respectively, higher than in the studied Chinese streams, our results indicate that *C. irrorata* adapts well to habitats that are at least moderately polluted by heavy metals. Consequently, no potential for this species as an indicator of metal contamination in spring water can be demonstrated to date. However, it should be stressed that the concentrations of heavy metals show strong seasonality (Szczucińska *et al.*, 2010). The highest concentrations are usually observed in early spring. One may speculate whether contamination during this season is of importance for i. a. the early stage of the life cycle.

CONCLUSIONS

The analysis in this study of the distribution of *C. irrorata* at the national scale showed that the species occurs in the entire territory of Poland. Nevertheless, the localities at which the species is currently found are also strongly scattered, suggesting that the species is relatively uncommon at the national scale. This general pattern corresponds well to that found for the species in other European countries. Consequently, this pattern is consistent with the classification of *C. irrorata* as a rare species at the continental scale (Hoffsten and Malmqvist, 2000; Graf *et al.*, 2006, 2008; Graf and Schmidt-Kloiber, 2011). Further, the data compilation showed that the species occurs most frequently in the central-western region of Poland and indicated a geographically biased distribution pattern with a continuous decrease towards the east and the north-east. However, the causes of this pattern could not be explicitly identified.

In terms of the environmental preferences of the species, a comparison of the characteristics of water in springs with and without *C. irrorata* showed that the species is most strongly associated with habitats characterised by low nitrate and chloride. Therefore, the species is potentially a strong candidate for use in the bioassessment of crenic ecosystems in terms of biogenic and salt pollution. In contrast, no effect of heavy metals or of iron and manganese was found. These results suggested that *C. irrorata* is relatively insensitive to these metals and is

not a potential indicator of metal pollution. In this context and in a broad sense, *C. irrorata* can be used as an indicator of water quality, with crucial implications for human health, because nitrate is a well-known toxic and harmful substance. In ecological terms, this caddisfly species can serve to determine environmental health because springs with *C. irrorata* can be considered free from negative processes such as eutrophication.

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