ECOLOGICAL AND DISTRIBUTION TRAITS OF THE LARGE WHITE-FACED DARTER *Leucorrhinia pectoralis* (Charpentier, 1825) IN SLOVAKIA

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Abstract

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The dragonfly *Leucorrhinia pectoralis* was recorded in Slovakia at 38 sites in 112 findings and there were 707 imagoes. Reproduction was confirmed in seven sites by finding of 35 larvae and exuviae. The highest number of sites with the occurrence of *L. pectoralis* is located in the Záhorská nížina lowland; most sites in Slovakia are located at an altitude of 213–351 m. *L. pectoralis* was recorded together with 49 species of dragonflies, and the average number of *L. pectoralis* was 9.56 individuals per site. It occurs in the communities as a dominant species (9.5%) together with eudominants *Coenagrion puella*, *C. hastulatum* and *Libellula quadrimaculata*. By non-metric multidimensional scaling (NMDS), we found a coenotic correlation to peat species *Libellula quadrimaculata*, *Leucorrhinia rubicunda*, *L. dubia* and *Sympetrum danae*. By redundancy linear analysis (RDA), we found a Monte Carlo permutation test to make a non-random contribution to the explained variability of seven factors ($p = 0.012–0.034$). *L. pectoralis* statistically significantly prefers habitats in the forest landscape ($r = 0.62$, $p = 0.0063$), the presence of vegetation ($r = 0.94$, $p = 0.0003$) and peatbogs ($r = 0.61$, $p = 0.0058$). We did not confirm a significant correlation to altitude. Based on easy determination, territoriality (especially males) and bioindicative sensitivity of larvae, *L. pectoralis* is accepted as an umbrella species. *L. pectoralis* has a high dispersion potential and is suitable for creating the meta-population character of local populations, which is important for the conservation management of the species.

Key words: dragonfly, dispersion potential, assemblages, wetland, umbrella species.

Introduction

The World Odonata List (Schoor, Paulson, 2020) lists 14 taxa of the genus *Leucorrhinia* (family *Libellulidae*). Euro-Siberian (Palearctic) distribution with occurrence in Europe has five species (Boudot, Kalkman, 2015): *Leucorrhinia albifrons* (Burmeister, 1839), *L. dubia* (Vander Linden, 1825), *L. caudalis* (Charpentier, 1840), *L. pectoralis* (Charpentier, 1825) and *L. rubicunda* (Linnaeus, 1758). These species also occur and reproduce in Slovakia (David, Šácha, 2019). Dragonfly *L. pectoralis* has an islet-like occurrence in Central Europe, linked to the localization of suitable peatland habitats. Numerous breeding populations of *L. pectoralis* are in Poland and the Baltic republics (Kalniņš, 2007). Dragonfly *L. pectoralis* inhabits nutrient-poor dystrophic to mesotrophic bog marshes, transitional peatbogs, uplands, forest lakes with littoral-type vegetation, ponds with *Phragmites australis* vegetation, grounded canals and dead peat-type river branches. The authors (Dijkstra, Lewington, 2006; Dolný et al., 2008; Sternberg, Buchwald, 2000) equally attach great importance to the presence of littoral vegetation and the growth of higher vegetation around the water body, which pro-

vides protection of imagoes from the wind, and imago males like to use it to rest. A specific case of the habitat is flooded mine areas after hard coal mining in the Karviná region in Silesia (Czech Republic). Harabiš et al. (2006) found here 45 species of dragonflies, several of which belong to sphagnophilic, endangered or protected species, for example, *Somatochlora flavomaculata*, *Sympetrum danae*, *Leucorrhinia pectoralis* and *L. rubicunda*. Larvae of *L. pectoralis* prefer peat habitats in the middle successive stage of overgrowth with vegetation with stands of *Utricularia* sp., *Ceratophyllum* sp. and water depths up to 50 cm (Sternberg, Buchwald, 2000; Rannap et al., 2011). Boudot and Kalkman (2015) specify that the optimal habitats of *Leucorrhinia pectoralis* are regionally specific, and in this species, the habitat ecological niche is relatively wide.

For the species *L. pectoralis*, the metapopulation character of local populations with a high dispersion of imagoes and the search for new habitats is important. Jaeschke et al. (2013) report a maximum observed dispersion distance of *L. pectoralis* of 27 km, depending on the two-year development of larvae. Imago flights between sites were also recorded throughout the season (Dolný, Harabiš, 2004; Harabiš, Dolný, 2012). In repro-

ductive habitats of *L. pectoralis*, the survival and abundance of populations are influenced by synergistic abiotic and biotic factors (Mauersberger, 2010; Boudot, Kalkman, 2015; Sternberg, Buchwald, 2000): grounding of aquatic habitats and vegetation overgrowth by ecological succession and direct habitat destruction. Fish predation may be locally important, especially European perch (*Perca fluviatilis*) (Mauersberger, 2010). The abundance of local populations can thus vary considerably over the years. During one season, there may be only a few individuals at the site, but under suitable conditions, the number may increase to several hundred individuals at the same site in another year (Dolný et al., 2008).

The concept of umbrella/surrogate species has proved to be a useful tool for biodiversity protection. By protecting the umbrella species, we also indirectly protect other species (Lambeck, 1997). According to Seddon and Leech (2008), the concept of umbrella species is not a simple tool; it requires knowledge of the ecology of a potential umbrella species as well as co-occurring species. Kietzka et al. (2019) present some properties of umbrella species, and several are identical with the properties of bioindicative species (easy determinability, territoriality and sensitivity to changes). However, criticism of the concept of surrogate species pointed to a lack of quantification of their selection. Therefore, an umbrella index was developed, which is the sum of three sub-indices [(i) co-occurrence with other species (PCS), (ii) number of sites where the species occurs (R) and (iii) susceptibility to anthropogenic species). This direction of umbrella species selection is being developed mainly in North America and East Asia (Kietzka et al., 2019). Based on bioindicative sensitivity, Czachorowski et al. (2000) identified umbrella species (*Trichoptera*, *Heteroptera*, *Lepidoptera*, *Odonata*, etc.) for different habitats of running and standing waters. From dragonflies (*Odonata*), it is also *L. pectoralis* for peatbogs.

The first published data on *L. pectoralis* from the territory of today's Slovakia come from Mocšary (1896), and it states a finding from the vicinity of Kremnica and Štrba. The first confirmed occurrence is from 1961 (Trpiš, 1969) from the oxbow lake of Latorica River – Dlhé Tice near the village of Rad (1961, 2 males, leg. M. Trpiš, rev. S. David). Most records of the occurrence of *L. pectoralis* come from western Slovakia, the geomorphological unit of Záhorie (e.g. Šácha, Šíbl, 2000; Šíbl, 2001; Blaškovič, 2007). This area is characterized by the occurrence of peatbogs, which are suitable habitats of the species (Šíbl, 2001; Moyzeová, 2019; Kalivodová et al., 2018). The latest incidence data are the result of monitoring *L. pectoralis* as a species of Community interest (Habitats Directive, Annex 4).

The synergistic effect of risk factors results in the evaluation of *L. pectoralis* as an endangered species. The Global Red List (iucnredlist.org) places the species in the least concern (LC) category with the population trend of the species as stable. The European Red List of Dragonflies (Kalkman et al., 2010) also evaluates the species in the LC category, but with a declining population trend. The conservation assessment of *L. pectoralis* for the Carpathian mountain range was prepared by Šácha et al. (2014). In the Slovak and Czech parts of the Carpathians, *L. pectoralis* is included in the vulnerable (VU) category, in Polish and Ukrainian in the data deficient (DD) category, in Hungarian in LC category and in Romanian in not evaluated (NE) category. Due to its reproduction on endangered habitat types, *L. pectoralis* is assessed as a species of Community interest and included in

the Berne Convention (Appendix II) and the Habitats Directive (Council Directive 92/43/EEC, Annexes II and IV). This implies the obligation to monitor the species and evaluate its 'favourable condition'. The results of the performed monitoring for the years 2013–2015 were processed by Šácha (2015a).

The aim of our study is to process the distribution, coenological characteristics, habitat preference and threatening factors of the population and habitats of *L. pectoralis* in the Slovak Republic on the basis of occurrence data.

Material and methods

We compiled a database of *L. pectoralis* findings from our own research, published and unpublished sources. After removing incomplete data, we obtained 112 records, which is the number of *L. pectoralis* individuals found in one day at the site. The data come from 38 sites ($n = 742$ individuals, 707 imagoes, 25 exuviae and 10 larvae) from Slovakia from 1961 to 2020. The data were obtained by semi-quantitative methods of faunistic research. The sites were visited with different frequency, and the number of larvae and exuviae is low. An exception is the data obtained by the methodology of biomonitoring of *L. pectoralis* as an annex species, originating from eight sites (Šácha, 2015b).

We analysed the finding data by descriptive statistics, and we tested the normality of the hypsometric distribution of sites by the Shapiro–Wilk test in the Statistika.cz program (StatSoft, 2004). For species, we calculated their dominance. Dominance and the categories are reported according to Losos et al. (1985). Other indices (Simpson's index N_2 , Shannon entropy H' , the maximum value of Shannon entropy H'_{max}) were exported from the Canoco5 program (ter Braak, Šmilauer, 2012). We analysed the structure of the group of dragonflies co-occurring with *L. pectoralis* in the Canoco5 program (ter Braak, Šmilauer, 2012). From the species matrix (50 species, 38 sites), we removed sites with the occurrence of only *L. pectoralis* and species with the occurrence of two or less individuals, thus eliminating their accidental occurrence. We choose the choice of ordination methods according to the highest length of the environmental gradient (it is in standard deviation (SD) units). We used robust non-metric multidimensional scaling (NMDS) using the Bray–Curtis dissimilarity index for species structure analysis. In the second step of NMDS, Canoco5 uses principal component analysis (PCA) to rotate the ordination axes in order to maximize the variance of the case score. We determined the loss of information according to the stress criterion value (SCV), and it takes a value from 0 to 1 (Šmilauer, Lepš, 2014). For species matrix sites, we derived 17 environmental variables that determine: (a) vegetation complexity (vegetation complexity – aquatic and swamp vegetation or tall riparian vegetation – littoral stands of *Phragmites australis*, *Typha* sp.), (b) habitat types (ponds, sand/gravel pits, regulated brooks, peatbogs, paleopotamals, interdunal ponds), (c) land use (forests, arable land, arable land/forests) and (d) hypsometric and ecological characteristics of the site (altitude; successional stages of hydrosere – initial, mediate, climax; metapopulation character of the site yes/no; water-level stability – permanent/temporal). Statistical significance ($p_a = 0.05$) of environmental factors was tested by Monte Carlo permutation test with 499 permutations. Null hypothesis (H_0): i – altitude values of *L. pectoralis* sites have a normal distribution and ii – species groupings

Fig. 1. Distribution of sites ($n = 38$) and numbers of *Leucorrhinia pectoralis* individuals in Slovakia in the network of the Slovak Fauna Database (DFS), the grid has a size of 11×12 km, and we made the map in the ArcMap 10.1 program (ESRI, 2011).

are independent of selected explanatory variables of their sites. We measured the success of the analysis by the value of the coefficient of determination (R^2) and its adjusted value R^2_{adj} . We verify the tightness of the mutual relationship (correlation) of environmental factors by non-parametric Spearman correlation coefficient, and the input is a correlation matrix from Canoco5 (log. file, $p_a = 0.05$). We evaluate the tightness of a linear bond expressed by the r coefficient according to Conelly (2012): strength of correlation $r < 0.2$ slight, $r = 0.2-0.4$ low, $r = 0.4-0.7$ moderate, $r = 0.7-0.9$ high and $r > 0.9$ very high. We specify the correlation between species and environmental characteristics by a generalized linear model (GLM) with a Poisson distribution. As response variables, we use the 'target species' *L. pectoralis*, and we test separately explanatory variables.

Results

Count of specimens and hypsometric analysis of *L. pectoralis*

For the processing of autecological analysis of *L. pectoralis*, we used a data set of 112 findings, 742 individuals from 38 sites (Fig. 1, Appendix). Autochthonous occurrence (reproduction) was confirmed only in seven sites: at western part of Slovakia in Šajdikové Humence (4Ex, loc. 11), Šaštín (2Ex) and Lakšárska Nová Ves (2L); at northern part in Zázrivá (8Ex), Klin (3L) and Osturňa (11Ex, 2L); and at middle Slovakia in Detvianska Huta (3L).

Using descriptive statistics (Table 1), we evaluated the number of individuals (NS) of *L. pectoralis* for the finding records ($n = 112$). The values of variability and symmetry indicate a violation of the normality of the distribution of values (numbers of individuals), which was confirmed by the Shapiro–Wilk test ($p = 0.0000$). Average number of individuals recorded in one day at a given site $\bar{x} = 6.63$, minimum value = 1 and maximum value = 47 (NS, Table 1). Different numbers of individuals indicate high values of the SD = 8.09. The symmetry (skewness) $\gamma_1 = 2.49$ is positive (low numbers of individuals predominate), and the spike (kurtosis) $\gamma_2 = 7.33$ is also positive (if it is a spiky distribution, the values are concentrated around the median). Hypsometric distribution of sites ($n = 38$) *L. pectoralis* has an average value of $\bar{x} = 282$ m above sea level (m a.s.l.), minimum value = 98 m a.s.l. and maximum value = 863 m a.s.l. (ALTI, Table 1). The confidence altitude interval around the diameter is from 213 to 351 m a.s.l. and SD = 209.69 m a.s.l. The variability values (minimum and maximum values and SD) indicate a violation of the normality of the distribution of altitude values, which was confirmed by the Shapiro–Wilk test ($p = 0.0000$).

Synecological characteristics of odonatocoenosis with *L. pectoralis*

In the data set of species from 38 sites, we found the occurrence of *L. pectoralis* together with another 49 species of dragonflies. From the data set for synecological analysis, we removed 11 sites

Table 1. Descriptive statistics of findings, hypsometric distribution and co-occurrence of *L. pectoralis* with other species.

	n	Average	–95%	+95%	Med	Mod	Min	Max	SD	Skew	Kurt
NS	112	6.63	5.11	8.14	3.50	1	1	47	8.09	2.48	7.33
ALTI	38	282	213.08	350.92	199	200	98	863	209.69	1.46	1.16
ASSE	27	9.59	7.92	11.27	9	4	4	18	4.24	0.39	–0.94

Notes: NS, number of specimens on each samples; n, number of records found; ALTI, altitude of sites; n, number of sites for the assessment of their altitude; ASSE, assemblage of *L. pectoralis*; n, number of sites for evaluation of cenotic structure; SD, standard deviation; Skew, skewness; Kurt, kurtosis.

Table 2. Descriptive statistics, species richness and diversity of 27 sites (samples) of the habitat preference *Leucorrhinia pectoralis*; at sites 5, 11, 14, 25, 28 and 31, the reproduction of *L. pectoralis* (grey lines) was found. For the site 27 (Detvianska Huta), indices were not calculated, and the occurrence of only *L. pectoralis* was confirmed.

Samples	Average	Count	RelCount	Total	N2	H'	LogCount	Evenness
1	4.35	12	0.30	174	4.45	1.82	2.48	0.73
2	0.38	9	0.23	15	7.26	2.08	2.20	0.95
5	0.33	4	0.10	13	2.68	1.16	1.39	0.83
7	0.35	7	0.18	14	4.90	1.75	1.95	0.90
8	13.63	13	0.33	545	3.78	1.75	2.56	0.68
11	13.05	18	0.45	522	5.73	2.06	2.89	0.71
13	6.83	10	0.25	273	1.77	1.01	2.30	0.44
14	1.53	11	0.28	61	6.78	2.11	2.40	0.88
15	0.30	7	0.18	12	4.80	1.75	1.95	0.90
16	0.13	4	0.10	5	3.57	1.33	1.39	0.96
17	6.60	14	0.35	264	6.98	2.26	2.64	0.86
18	1.63	6	0.15	65	3.71	1.50	1.79	0.84
19	0.48	5	0.13	19	4.46	1.55	1.61	0.96
20	3.88	11	0.28	155	3.62	1.51	2.40	0.63
21	0.73	6	0.15	29	2.57	1.28	1.79	0.71
22	0.25	4	0.10	10	2.94	1.22	1.39	0.88
23	6.10	17	0.43	244	9.00	2.39	2.83	0.84
25	42.03	15	0.38	1681	3.07	1.51	2.71	0.56
26	2.88	8	0.20	115	5.13	1.77	2.08	0.85
28	1.68	8	0.20	67	3.10	1.35	2.08	0.65
29	0.88	5	0.13	35	1.76	0.92	1.61	0.57
30	14.85	16	0.40	594	3.22	1.66	2.77	0.60
31	16.35	14	0.35	654	3.18	1.59	2.64	0.60
34	16.90	12	0.30	676	2.61	1.39	2.48	0.56
35	4.38	10	0.25	175	5.26	1.82	2.30	0.79
36	1.20	5	0.13	48	3.85	1.44	1.61	0.90
38	3.50	8	0.20	140	1.94	1.05	2.08	0.50

Notes: Total count of species = 40; Average (sample average = total/total count of species); Count (count of species within samples); RelCount (relative count of species within samples = count/total count of species); Total (count of specimens within samples); N2 (Simpson index); H' (Shannon entropy); LogCount (Hmax); Evenness.

with the occurrence of only *L. pectoralis* (27 sites remained) and 10 species of dragonflies, which occurred in the site in only one finding in the number of one and two specimens (40 species remained). The average number of species at the sites (including *L. pectoralis*) was $\bar{x} = 9.59$, the minimum number of species at the site was 4, and the maximum number was 18 (ASSE, Table 1). The slope is positive $\gamma_1 = 0.39$, low values slightly prevail over larger ones, the slope is negative $\gamma_2 = -0.94$, and the values of the

number of species are not concentrated around the mean value (Shapiro–Wilk test $p = 0.14485$).

Coenagrion puella (D = 37%, eurytopic species), *C. hastulatum* (D = 13%, sphagnophilous species) and *Libellula quadrimaculata* (D = 10%, sphagnophilic species) were eudominantly represented in the community of dragonflies with *Leucorrhinia pectoralis*. The dominant species was only *L. pectoralis* (D = 9.5%). Subdominant were the species of standing, vegetated

Fig. 2. Fit (26 species of dragonflies are shown) ordination graph principal component analysis of the species matrix *Leucorrhinia pectoralis* forms with the species *Cordulia aenea* and *Coenagrion ornatum* creates an isolated ordination cluster. The full names of the dragonflies are shown in Fig. 3.

waters *Cordulia aenea*, *Ischnura elegans*, *Aeshna isoteles*, *Lestes dryas*, *Sympetrum sanguineum* and *Pyrrhosoma nymphula* ($D = 2.93\text{--}2.08\%$). The other 30 dragonfly species were recedent and subrecedent species.

Using the Canoco5 program, we calculated descriptive statistics, species richness and species diversity of dragonfly communities with the occurrence of *L. pectoralis* for 27 sites (Table 2).

For ordination analysis, the species matrix had 27 localities and 40 species. With indirect detrended correspondence analysis (DCA), we found the length of the gradient on the 1st ordination axis = 2.77 SD units. Since this is a short gradient, we performed an indirect (unrestricted) PCA. We used fitting with a species significance of 0.5%, and 26 species are shown in the ordination graph (Fig. 2). The first ordination axes explain 36.49% of the variability of species data, the cumulative value of variability on axis 2 = 51.47% and on axis 4 = 69.34%. In the fitted (0.5%) PCA ordination chart of the species matrix, *Leucorrhinia pectoralis* correlates with *Cordulia aenea* and *Coenagrion puella*. Species *Somatochlora flavomaculata*, *Anax imperator*, *Libellula quadrimaculata*, etc. form a transition to a species-rich grouping of eutrophic aquatic habitat species. Contrary to expectations, *Leucorrhinia pectoralis* is not part of a grouping of sphagnophilic (peat) species of *Coenagrion hastulatum*, *Aeshna juncea*, *Leucorrhinia rubicunda* and the like.

As ordination analysis did not show the expected coenotic link to peatland species (and habitats) of dragonflies, we also performed a non-metric analysis of the species matrix by multi-dimensional scaling (NMDS). We used species scores (response variables) on four ordination axes from PCA. The resulting ordination graph (Fig. 3) confirmed the uniform distribution of species with the position of *Leucorrhinia pectoralis* near the intersection of the ordination axes. Although there is no significant coenotic preference, we identify a positive correlation to peat species such as *Libellula quadrimaculata*, *Leucorrhinia rubicunda*, *L. dubia* and *Sympetrum danae*. The stress score for the two selected dimensions = 0.16 is the value of a good ordination model, and the good model is also confirmed by the values of species scores MNDS1 and NMDS2, which after PCA rotation almost coincides with the original NMDS scores (Fig. 3). Explained variability on the 1st ordination axis = 59.1%, and its fitted value = 57.2%. The significance test confirmed the significance of NMDS1 and NMDS2 on the first two ordination axes (pseudo-F for axis 1 = 1.1, axis 2 = 1.4, $p = 0.002$).

The names of the dragonflies in the ordination graph are the same as in Fig. 2: *AeshAffn*, *Aeshna affinis*; *AeshCyan*, *A. cyanea*; *AeshIsoc*, *A. isoteles*; *AeshJunc*, *A. juncea*; *AnaxImpr*, *Anax imperator*; *BracPrat*, *Brachytriton pratense*; *CalpSpln*, *Calopteryx splendens*; *CoenHast*, *Coenagrion hastulatum*; *CoenPuel*, *C. puella*; *CoenPulc*, *C. pulchellum*; *CordAene*, *Cordulia aenea*; *CrocEryt*, *Crocothemis erythraea*; *EnalCyat*, *Enallagma cyathigerum*; *EpitBimc*, *Epitheca bimaculata*; *ErytNajs*, *Erythromma najas*; *ErytVird*, *E. viridulum*; *ChalVird*, *Chalcolestes viridis*; *IschEleg*, *Ischnura elegans*; *IschPumil*, *I. pumilio*; *Lest Barb*, *Lestes barbarus*; *LestDrya*, *L. dryas*; *LestSpon*, *L. sponsa*; *LestVirn*, *L. virens*; *LeucCaud*, *Leucorrhinia caudalis*; *LeucDubi*, *L. dubia*; *LeuctPect*, *L. pectoralis*; *LeucRubc*, *L. rubicunda*; *LiblDepr*, *Libellula depressa*; *LiblFulv*, *L. fulva*; *LiblQuad*, *L. quadrimaculata*; *OrthAlbs*, *Orthetrum albistylum*; *OrthCanc*, *O. cancellatum*; *PlatPenn*, *Platycnemis pennipes*; *PyrrNymp*, *Pyrrhosoma nymphula*; *SomtFlav*, *Somatochlora flavomaculata*; *SympFusc*, *Sympecma fusca*; *SympDana*, *Sympetrum danae*; *SympFlav*, *S. flaveolum*; *SympSang*, *S. sanguineum*; *SympVulg*, *S. vulgatum*.

Habitat preference of *L. pectoralis*

For the analysis of the binding of *L. pectoralis* to habitat types, we used the second table as in the synecological survey (27 sites and 40 species remained). We supplemented the evaluation of sites with the Simpson Diversity Index, the Shannon Entropy Index and other values obtained with the export statistics tool in the Canoco5 program (Table 2). For 27 sites, we derived 17 habitat characteristics (environmental variables), which are listed as significant due to the impact on dragonflies. We used constrained redundancy analysis (RDA) according to the gradient length value ($SD = 2.77$). The analysis returned (log file) information on collinearity variables: interdunal ponds, arable land/forest, meta-population – no, tall riparian vegetation and temporary type of water surface. The values of inflation factors were $IF < 6.2$, only the factors complexity vegetation = 13.39 and permanent water surface = 12.61. Initial information on the statistical significance of the selected factors was obtained by a Monte Carlo permutation test (499 permutations) using the summarize effects of explanatory variables method. A non-random contribution to the explained variability was made by seven factors that were statis-

Fig. 3. Position of *Leucorrhinia pectoralis* in the NMDS ordination graph among dystrophic and eutrophic water habitats overgrown with vegetation with projected NMDS axes.

tically significant (pseudo- $F = 3.2$ – 2.3 , $p = 0.012$ – 0.034). After Bonferroni correction (a/number of independent environmental characteristics), these factors were not statistically significant ($p > 0.204$). We selected factors with minimal mutual correlation using the forward selection of explanatory variables method, and only the factors forest (pseudo- $F = 3.2$, $p = 0.01$) and altitude (a.s.l.) (pseudo- $F = 2.4$, $p = 0.03$) were statistically significant. After adjustment, we left six environmental variables in the analysis; their mutual correlation, correlation to ordination axes and species are shown in Fig. 4. The number of species 30 in the ordination chart is the result of their fitting with a significance of 1%.

To evaluate the success of our model, we present the values of variability explained by the given ordination axis – eigenvalues (1st axis = 0.15; 2nd axis = 0.10, 4th axis = 0.02). Cumulative variations in species data are as follows: 1st axis = 14.54%; 2nd axis = 24.33% and 4th axis = 29.75%. The values of the fitted cumulative variance (variability of species data explained by our chosen environment variables) are as follows: 1st axis = 45.27%; 2nd axis = 75.71% and 4th axis = 92.59%. The value of sum of all canonical eigenvalues = 0.32 (= 32%) is the variability of the file, which is explained by our selected environment variables. Canoco5 directly calculates the value of R^2 , and our selection of environmental factors captured 32.13% of the variability in the species data. However, the more accurate adjusted value of $R^2_{adj} = 11.77\%$ is significantly lower. The group of environmental factors, com-

plexity, forest and peatbog are correlated together according to the direction and angle between the vectors (Fig. 4). Statistically significant ($p < 0.05$) Spearman correlations are as follows: forest $\times$ complexity ($r = 0.83$), forest $\times$ peatbog ($r = 0.089$), the highest (negative) value is the factor forest $\times$ permanent ($r = -0.94$).

Dragonfly *L. pectoralis* statistically significantly prefers habitats in the forest landscape (forest, $r = 0.62$, $p = 0.0063$), the presence of vegetation (complexity, $r = 0.94$, $p = 0.0003$) and peatbogs (peatbog, $r = 0.61$, $p = 0.0058$). The negative correlation is to the factor of permanent water surface (permanent, $r = -0.92$, $p = 0.00015$), the factor pond ($r = -0.35$, $p = 0.8472$) and altitude (a.s.l., $r = -0.00$, $p = 0.8472$). The last two factors are not statistically significant.

Discussion

Dragonfly *L. pectoralis* is a species with local and short-term mass occurrence in the site. In Slovakia, after 2000, the species was recorded at 35 sites, one to two flying individuals were recorded at eight sites. Only in seven sites was the reproduction of *L. pectoralis* confirmed by finding of larvae and exuviae. Different numbers of *L. pectoralis* sites are mentioned from Central Europe. For instance, Bernard et al. (2009) mentioned 283 sites from Poland occurring after 1990; Mancu and Popescu (2016) published from Romania only three recent breeding sites from the southern part

Fig. 4. Analysis of selected habitat factors of sites and species of odonatocoenosis with the onset of *Leucorrhinia pectoralis*.

of the Carpathians, from an altitude of 1000 m a.s.l. In Slovakia, the highest number of individuals was recorded at the Šaštíň site (NR Vanišovec). In 2001, T. Blaškovič (in litt.) recorded 34 imagoes here; in 2016, Z. Šiblová (Šiblová, Moyzeová, 2019) confirmed the occurrence of 47 imagoes. Dolný et al. (2008) state a significant fluctuation in the number of local populations in the Czech Republic, from which we derive their metapopulation character. We also suppose a metapopulation structure for local populations in the Borská nížina lowland. The condition of the metapopulation concept is a high ability to disperse *L. pectoralis* (Jaeschke et al., 2013).

In Baden-Württemberg, there is a vertical range of sites from 172 to 700 m a.s.l. (Sternberg, Buchwald, 2000); 30% of sites are located in the altitude range 500–600 m a.s.l., and 55% of sites are at an altitude of 630–700 m a.s.l. In Switzerland (Sternberg, Buchwald, 2000), 72% of the 47 sites are located between 400 and 600 m a.s.l. From the province of Trentino in the Dolomites of northern Italy (Macagno et al., 2012), the occurrence of a stable population of *L. pectoralis* is reported from a peatbog at an altitude of 930 m a.s.l. Most sites in Poland and Lithuania lie at an altitude of 160–180 m a.s.l. (Bernard et al., 2009; Kalniņš, 2007). Slovak sites ($n = 38$) of *L. pectoralis* have an average altitude of 282 m a.s.l.; the highest frequency of occurrence (mode) of sites is 200 m a.s.l., and hypsometric gradient also shows a significant values: minimum 98 m a.s.l. and maximum 863 m a.s.l. (Table 1). Occurrence in lowlands and mountain areas is the result of a preference for peatland habitats. It is necessary to monitor the dynamics of changes in the occurrence in the height (and latitude) gradient of species with high conservation value *L. pectoralis*.

In the recorded material from Slovakia, we found a solitary occurrence of *L. pectoralis* in 11 sites, and in the remaining 27 sites, it occurred (on the same day) together with other 49 species of dragonflies. The average number of species at the sites was $\bar{x} = 10.07$ (including *L. pectoralis*); the highest was 20 species (Table 1). The high number of co-occurring species is also a result of the flight activity of the species, but some of them (e.g. *Anax parthenope*, *Coenagrion ornatum*, *Ophiogomphus cecilia* and *Somatochlora metallica*) occurred in low abundance, sporadically – only a few individuals. According to our results, *Leucorrhinia pectoralis* correlates only slightly with the species *Cordulia aenea* and *Coenagrion ornatum* (Fig. 2). Dragonflies *Somatochlora flavomaculata*, *Anax imperator* and *Libellula quadrimaculata* form a transition to a species-rich cluster of eutrophic aquatic habitat species. According to our initial PCA, *L. pectoralis* is not part of a cluster of typical peatland species as reported by Sternberg and Buchwald (2000), for example, *Coenagrion hastulatum*, *Aeshna juncea*, *Libellula quadrimaculata*, *Leucorrhinia rubicunda*, *Leucorrhinia dubia* and *Sympetrum danae*. The analysis of the coenotic position of *L. pectoralis* (we used NMDS using the Bray–Curtis dissimilarity index) showed the position of *Leucorrhinia pectoralis* near the intersection of the ordination axes (Fig. 3) as a weak habitat preference for a certain odonatocoenosis. A positive correlation to sphagno-philic species *Libellula quadrimaculata*, *Leucorrhinia rubicunda*, *L. dubia*, *Sympetrum danae*, etc. is indicated. When using NMDS, there is a certain loss of information, see Material and methods. Its value is for our two selected dimensions (ordination axes) $SCV = 0.16$, which is according to Dexter et al.

(2018) the value of a good ordination model without the risk of misinterpretation.

For dragonfly *L. pectoralis* we recorded in several types of habitats, larvae and exuviae were found only in seven sites. We derived 17 habitat variables from the sites of *L. pectoralis*, especially categorical variables. We assumed that some factors would show collinearity, which was confirmed for the variables habitat type (interdunal ponds and temporary type of water surface), land use (combination of arable land/forest), population type (metapopulation – no), and vegetation (tall riparian vegetation). Obviously, when processing metadata, the choice of factors is problematic. This was also confirmed (by the Monte Carlo permutation test), so seven factors were statistically recorded. Using the forward selection of explanatory (environmental) variables method, we found the factors with the least mutual correlation (forest, $p = 0.006$ and altitude, $p = 0.016$). We used six site variables in the RDA ordination graph (Fig. 4), which explain $R^2 = 32.13\%$ of the variability in the species data ($R^2_{adj} = 11.77\%$). We verified the significance of our model by testing all ordination axes ($p = 0.052$), that is, just on the border of statistical significance of the influence of selected factors on species data. The occurrence of *L. pectoralis* is positively correlated with factors as forest landscape ($p = 0.0063$), because especially they preferred peatlands ($r = 0.61$, $p = 0.0058$). They have been destroyed or are fragmented in agricultural land. The complexity factor ($r = 0.94$, $p = 0.0003$) expresses the representation of life forms and height stratification of vegetation in habitats with the occurrence of *L. pectoralis*. According to Randlkofer et al. (2010), vegetation complexity significantly influenced by species diversity of plant communities. In Lithuania (Kalniņš, 2007), the highest frequency of *L. pectoralis* had habitats of oxbow lakes (~21 sites) and eutrophic lakes (~44 sites) with vegetation of the *Magnopotamion* and *Hydrocharition* type, having the character of peat. In our study, *Leucorrhinia pectoralis* does not show affinity for altitude ($r = -0.00$, $p = 0.8472$), which is determined by the altitude of suitable (peatland) habitats – conditions. As confirmed in a study by Jaeschke et al. (2013), will be the conservation of peatland habitats under conditions of climate change limiting the conservation of *L. pectoralis* populations. Using the models of boosted regression tree (BRT) model and GLM, the authors predict a 30% loss of the present distribution by 2035. The decline of the species will be evident especially in southern and central Europe with the shift of sites to foothills and mountains. According to the BRT model, the forecast for 2050 assumes a centre of expansion in the north Poland, southern Scandinavia, the Baltics and Karelia. The extreme situation is predicted by the GLM; the European occurrence of *L. pectoralis* will be concentrated in two centres East Pomerania and Baltic-Karelia. In this context, the study by Buczyńska and Buczyński (2019) examined habitat characteristics important for *L. pectoralis*, for example, area of water surface, perimeter of the pit, cover of peatbog *Sphagnum* sp. and cover of macrophytic vegetation of pits after peat extraction. The analysis confirmed the key properties of habitats, also artificially created, are suitable for the reproduction of *Leucorrhinia pectoralis*. They are the pH of water, the cover of peatlands *Sphagnum* sp. and the circumference (size) of the water surface. These results are important for the conservation management of *L. pectoralis* as an umbrella species.

Conclusion

Between 1961 and 2020, the occurrence of the species of Community interest *L. pectoralis* was found in Slovakia in 38 sites in 112 records in the number of 707 imagoes, which is a comparable number with other Central European countries. Reproduction was confirmed in only few sites by finding larvae and exuviae. Most sites with the occurrence of *L. pectoralis* are located in the Záhorská nížina lowland, 213–351 m a.s.l. The dragonfly *L. pectoralis* occurs in the community as a dominant species, and the average number of species of dragonflies in sites with the occurrence of *L. pectoralis* was 10 species. We found a coenotic affinity for peat species *Libellula quadrimaculata*, *Leucorrhinia rubicunda*, *L. dubia* and *Sympetrum danae*. We evaluated 17 environmental variables for sites with occurrence of *Leucorrhinia pectoralis*, and after adjustment, we left six of them. We confirmed (by using a GLM) a statistically significant preference for the localization of *L. pectoralis* habitats: (i) the forest landscape ($r = 0.62$, $p = 0.0063$), (ii) the presence of submerged, emergent and macrophytic vegetation ($r = 0.94$, $p = 0.0003$) and (iii) the preferences of peatbog habitats ($r = 0.61$, $p = 0.0058$). By evaluating the basic criteria for umbrella species, Czachorowski et al. (2000) proposed to classify *L. pectoralis* as an umbrella species. Our results confirmed several properties required of umbrella species. They are easy determination of males and females, territoriality of males, preferences of peatland-type habitats with present macrophytic vegetation, two-year development of larvae and creation of species-rich communities of dragonflies with *L. pectoralis* reported in the literature. Therefore, we recommend continuing to use *L. pectoralis* as an umbrella species in conservation management. For the management of the population of *L. pectoralis*, we propose to identify suitable breeding sites that meet the habitat requirements of the species (peatlands with stands of *Sphagnum* spp. and sufficient water area). *Leucorrhinia pectoralis* has a high dispersion potential, and local populations can form a metapopulation structure, which is important for the conservation management of the species. The area that meets the above conditions is the Záhorská nížina lowland. The suitable spatial distribution of sites can also be supplemented by artificially created aquatic habitats. The regional biodiversity of plant and aquatic insect species, who have lived in peatlands and are bog specialists, would be significantly enhanced.

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Appendix

Overview of research and basic data on sites with confirmed occurrence of *L. pectoralis* in Slovakia.

Year	LOC	I	E/L	SUM	CAD_AREA	WGS-84	ALT
1987–1988	1/4	7	0	7	Bohunice	48°21'26.09"N 18°46'11.04"E	480
2000	2/1	1	0	1	Sekule	48°35'51.7N 16°59'26.47E	151
2000	3/1	2	0	2	Plavecký Peter	48°33'5.07N 17°18'1.36E	195
2000–2002	4/2	14	0	14	Lakšárska Nová Ves	48°33'19.09N 17°9'15.18E	218
1998–2002	5/3	1	2	3	Lakšárska Nová Ves	48°33'40.42N 17°10'7.47E	224
2000–2002	6/2	10	0	10	Lakšárska Nová Ves	48°34'18.54N 17°34'10.44E	225
1998	7/1	2	0	2	Svätý Jur	48°15'24.67N 17°9'22.36E	465
2000–2018	8/9	69	0	69	Lakšárska Nová Ves	48°36'15.08N 17°10'12.41E	200
2000–2001	9/2	60	0	60	Láb	48°22'27.51N 16°57'22E	148
2000	10/1	2	0	2	Plavecký Štvrtok	48°23'49.68N 16°58'16.02E	155
2000–2019	11/10	114	4	118	Šajdíkove Humence	48°38'26.48N 17°16'3.97E	200
2000	12/1	7	0	7	Šajdíkove Humence	48°38'33.28N 17°16'39.87E	200
2000	13/3	4	0	4	Čuňovo	48°3'9.1N 17°10'23.94E	128
1999–2014	14/6	3	3	6	Klín	49°25'43.18N 19°29'55.27E	618
1961	15/1	2	0	2	Rad	48°27'3.73N 21°52'4.75E	104
2001	16/1	2	0	2	Muránska Lehota	48°43'46.41N 20°2'44.42E	383
2017–2019	17/3	8	0	8	Čičov	47°46'36.73N 17°43'53.31E	112
2013–2014	18/5	30	0	30	Strážne	48°22'52.68N 21°51'24.37E	98
2014–2019	19/3	4	0	4	Párnica	49°11'55.5N 19°12'55.89E	453
2008	20/1	2	0	2	Rusovce	48°3'1.48N 17°10'19.67E	130
2007	21/1	1	0	1	Budiš	48°52'29N 18°45'47.91E	480
2008	22/1	1	0	1	Komárno	47°48'22.22N 18°8'1.01E	107
2007	23/1	1	0	1	Mlynčeky	49°10'11.15N 20°23'43.62E	674
2018–2019	24/5	6	0	6	Vyšný Blh	48°28'19.95N 20°8'13.18E	415
2009–2019	25/11	85	13	98	Ostruňa	49°20'30.69N 20°13'19.83E	821
2011	26/1	7	0	7	Moravský Ján	48°34'34.31N 16°57'18.01E	150
2013	27/1	0	3	3	Detvianská Huta	48°34'25.21N 19°36'28.22E	863
2013–2017	28/6	7	8	15	Zázrivá	49°16'7.89N 19°8'40.88E	657
2015	29/2	26	0	26	Svätá Mária	48°26'10.55N 21°49'38.18E	100
2001–2019	30/7	44	0	44	Malacky	48°28'51.44N 17°3'49.87E	175
2001–2020	31/6	97	2	99	Šaštín	48°36'48.3N 17°8'53.76E	205
2020	32/1	1	0	1	Šránec	48°37'53.97N 17°22'1.87E	200
2002	33/1	2	0	2	Čunovo	48°2'24.32N 17°11'23.61E	129
2001–2020	34/3	36	0	36	Riadok	48°28'3.9N 17°3'38.36E	198
2001–2002	35/2	29	0	29	Čáry	48°40'31.19N 17°3'21.17E	164
2001	36/1	11	0	11	Čáry	48°40'56.11N 17°3'41.72E	164
2001	37/1	1	0	1	Čáry	48°40'49.26N 17°3'21.37E	164
2001	38/1	8	0	8	Brodské	48°40'52.15N 17°2'31.51E	163

Notes: Year, research period; LOC, serial number of the sites/number of finds; I, number of imagoes; E/L, number of exuviae/larvae; SUM, number of all individuals; CAD_AREA, cadastral area; WGS-84, sites coordinates; ALT, altitude.