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Ladybird (Coleoptera, Coccinellidae) communities on nonnative blue spruce in central Europe

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Abstract

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Blue spruce (*Picea pungens*) has been planted in urban greenery as an ornamental tree in central Europe for more than 150 years. We investigated whether this nonnative spruce is a convenient habitat for ladybirds (Coleoptera, Coccinellidae). In 2021 and 2022, adults and larvae were sampled in four towns in Slovakia at monthly intervals throughout the growing season, from April to October. We recorded adults of 27 species and larvae of 11 ladybird species. Conifer specialist ladybird species predominated both in adult and larval communities (adults – 9 species, 85.2% of all individuals; larvae – 7 species, 92.1% of all individuals). *Exochomus quadripustulatus* and *Aphidecta obliterata* were the most common in adult (31.8% and 33.5% of all individuals, respectively) and larval (57.5% and 25.1% of all individuals, respectively) communities. The most abundant generalist species was nonnative invasive *Harmonia axyridis* (adults – 5.6%, larvae – 6.8% of all individuals). Adults and larvae of ladybirds were more abundant on solitary trees than on trees growing in groups. Our results confirmed that blue spruce hosts rich ladybird communities and provides them shelter and food resources.

Keywords

aphidophagous insects, ornamental trees, *Picea pungens*, recruitment of insects, urban environment

Introduction

Trees in urban environments provide a wide range of benefits (see Garcia et al., 2022 for review), one of which is the provision of habitat for increasing the biodiversity of insect fauna in nonforest urbanised landscapes (Dreistadt et al., 1990; Chalker-Scott, 2015; Korányi et al., 2021; Stemmelen et al., 2022). These planted trees, often nonnative ornamental species, are an integral part of urban habitats such as town squares, parks, streets, yards or cemeteries. One such species is blue spruce (also called Colorado blue spruce or green spruce), *Picea pungens* Engelm. It is native to the central and southern Rocky Mountains (western USA) (Daubenmire, 1972; Fechner, 1990). Due to its ornamental appearance, it has become very popular in urban planting (Benčať, 1982; Kulfan et al., 2010; Kula

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et al., 2016), and early after its discovery in 1861, it was introduced to Europe (Pagan and Randuška, 1988; Fechner, 1990). Recently, it can be found in every part of Europe (Kulfan et al., 2010; Guillot Ortiz, 2014; Černý et al., 2016; Menkis et al., 2016; Yovkova et al., 2016). Due to its popularity in some European countries, it has also been planted in forests, for example, in reforestation programmes in air-polluted areas of the Czech Republic (Slodičák and Novák, 2008; Kršiak et al., 2009; Kula et al., 2016).

In its native region, blue spruce hosts a rich entomofauna, including Hemiptera (Aphidinae), Lepidoptera, Hymenoptera and Coleoptera (Furniss and Carolin, 1977; Dixon and Foltz, 1990; Fechner, 1990). Since its introduction into Europe, it has also become a nonnative host for various groups of European indigenous insects, such as beetles (Coleoptera) (Juutinen, 1953; Voolma, 1980; Yunap, 1980; Andrš, 2001; Kršiak et al., 2009; Kula et al., 2009, 2012, 2013a, 2013b; Pop et al., 2010), moths (Lepidoptera) (Schnee, 2000; Kollár, 2007; Kulfan et al., 2010), sawflies (Hymenoptera, Symphyta) (Kollár, 2007; Kula et al., 2016), aphids and coccids (Homoptera) (Harding et al., 1998; Kollár, 2007; Fryč, 2016; Wojciechowski et al., 2016) and Diptera (Kollár, 2007). Precise data about ladybirds (Coleoptera, Coccinellidae) occurring on this spruce in Europe are still missing. Native conifers in Europe, such as Scots pine (*Pinus sylvestris* L.), Norway spruce [*Picea abies* (L.) Karst.], silver fir (*Abies alba* Mill.) and European larch (*Larix decidua* Mill.) are known as valuable hosts for many ladybird species (e.g., Bielawski, 1961; Hodek, 1973; Bastian, 1982; Czechowska 1995a, 1995b; Zelinková et al., 2002; Gossner et al., 2005; Zöbl et al., 2006; Burmeister et al., 2007; Selyemová et al., 2007; Brown and Roy, 2018; Holecová et al., 2018; Kenis et al., 2020). Ladybird communities have already been studied on other nonnative conifers in Europe – *Pseudotsuga menziesii* (Mirb.) Franco, *Picea sitchensis* (Bong.) Carr., *Abies grandis* (Doug.) Lindl., etc. (Parry, 1992; Austarå et al., 1998; Timms, 2004; Gossner et al., 2005; Burmeister et al., 2007; Straw et al., 2023).

We investigated whether blue spruce planted in urban environments can support the diversity of ladybird species. We hypothesised that blue spruce could be inhabited by ladybirds – conifer specialists that are usually found on native conifers, especially on congeneric Norway spruce. Most coccinellid species are not associated with only one conifer species, but they occur on several tree species (Koch, 1989; Roy et al., 2011; Roy and Brown, 2018; Nedvěd, 2020) and therefore may also colonise blue spruce. It is likely that food of ladybirds – small arthropods (e.g., insect herbivores), associated with native Norway spruce, also occurs on nonnative congeneric blue spruce (cf. Roques et al., 2006; Branco et al., 2015; Kirichenko and Kenis, 2016). It is known that communities of arthropods on solitary trees and trees growing in stands (or patches) differ (Faeth and Simberloff, 1981; Ozanne et al., 2000; Gove et al., 2009; Maldonado-López, 2015; Sarvašová et al., 2021). We hypothesised that ladybird communities on solitary trees would differ from ladybird communities on trees growing in groups. Finally, as aphids are known to be essential prey of many ladybirds (Hodek, 1973; Hodek and Evans, 2012; Majerus, 2016; Nedvěd, 2020), we assume that the presence of aphids will have a positive effect on ladybird abundance.

Specifically, we sought answers to the following questions. (1) What is the species composition of the ladybird communities (presence and abundance of adults and larvae) living on blue spruce? (2) What social position of host trees (i.e., solitary trees versus tree groups) is preferred by the ladybirds? (3) Does the presence of aphids on host trees affect the spatial dispersion of ladybirds?

Material and methods

Sampling of ladybirds

Sampling of ladybirds was conducted in four towns in different regions of Slovakia (SK), central Europe (southern SK: Levice, 48°13’2.772’’N, 18°36’5.078’’E; central SK: Zvolen, 48°34’45.605’’N, 19°8’55.925’’E, and Sliač, 48°36’45.255’’N, 19°9’11.143’’E; and northern SK: Žilina, 49°11’52.736’’N, 18°44’17.889’’E). Ladybirds on blue spruce (*Picea pungens*) growing in urban habitats (parks, cemeteries, housing estates, alleys, yards, etc.) were sampled using circular beating trays with a diameter of 1 m and wooden sticks (Roy et al., 2011; Roy and Brown, 2018; Viglášová et al., 2017). Sampling was carried out on days without strong wind and rain (Roy and Brown, 2018). Coccinellids were sampled at monthly intervals throughout the two growing seasons from April to October in 2021 and 2022. At each sampling occasion (at each locality and date), ten blue spruce trees were sampled for the presence of ladybirds. One sample consisted of ladybirds at the stage of larvae and adults obtained from 10 branches of the lower canopy (ca. 1–3 m above the ground) of one tree. In total, we sampled ladybirds from 5,600 branches of 560 trees during 56 sampling sessions.

For each sample tree at the study sites, we recorded the following environmental variables: (1) the relative abundance of aphids on the sample tree per 100 cm^2 (aphids were counted in a frame 10 ×10 cm on randomly selected area of the beating tray following the method used by Viglášová et al. (2017), and (2) the position of the sample tree (a tree growing in a group of two or more conspecifics vs. a solitary tree).

Most of the ladybirds were released immediately after identification at the site. Small beetles belonging to subfamilies Scymninae and Coccidulinae, which are harder to identify, and larvae were taken and stored in 70% ethanol. These specimens were identified in the laboratory using a stereomicroscope and the keys of Savoiskaya and Klausnitzer (1973) and Nedvěd (2020).

Statistical analysis

Ladybirds were classified according to their habitat preferences (preferences of a host plant) into three groups: conifer specialists, nonconifer specialists (species associated with herbal vegetation or broadleaved trees) and generalists (ubiquists) according to Koch (1989), Holecová et al. (2018) and Nedvěd (2020).

Redundancy analysis was used to determine the

Table 1. List of ladybird species recorded on blue spruce (*Picea pungens*). The order in the list is given according to abundance. (Ladybirds were classified according to host plant preference following Koch (1989), Holecová et al. (2018) and Nedvěd (2020). C – conifer specialist, NC – nonconifer specialist, G – generalist).

Species	Abbreviation	Adults dominance (%)	Larvae dominance (%)	All dominance (%)	Host plant preference
Exochomus quadripustulatus (Linnaeus, 1758)	*Exo.qua*	31.83	57.47	36.77	C
Aphidecta obliterata (Linnaeus, 1758)	*Aph.obl*	33.54	25.14	31.92	C
Rhyzobius chrysomeloides (Herbst, 1792)	*Rhy.chr*	7.27	2.46	6.34	C
Harmonia axyridis (Pallas, 1773)	*Har.axy*	5.60	6.81	5.83	G
Harmonia quadripunctata (Pontoppidan, 1763)	*Har.qua*	4.79	4.54	4.74	C
Adalia conglomerata (Linnaeus, 1758)	*Ada.con*	3.84	1.51	3.39	C
Coccinella septempunctata Linnaeus, 1758	*Coc.sep*	4.02	0	3.24	G
Scymnus abietis Paykull, 1798	*Scy.abi*	3.52	0	2.84	C
Stethorus pusillus (Herbst, 1797)	*Ste.pus*	1.94	0	1.57	NC
Adalia decempunctata (Linnaeus, 1758)	*Ada.dec*	0.50	0.19	0.44	NC
Scymnus interruptus (Goeze, 1777)	*Scy.int*	0.50	0	0.40	NC
Chilocorus bipustulatus (Linnaeus, 1758)	*Chil.bip*	0.27	0.76	0.36	NC
Vibidia duodecimguttata (Poda, 1761)	*Vib.duo*	0.45	0	0.36	NC
Scymnus rubromaculatus (Goeze, 1777)	*Scy.rub*	0.36	0	0.29	NC
Anatis ocellata (Linnaeus, 1758)	*Ana.oce*	0.18	0.57	0.26	C
Propylea quatuordecimpunctata (Linnaeus, 1758)	*Pro.qua*	0.27	0	0.22	G
Oenopia conglobata (Linnaeus, 1758)	*Oen.con*	0.27	0	0.22	NC
Myzia oblongoguttata (Linnaeus, 1758)	*Myz.obl*	0.14	0.38	0.18	C
Scymnus frontalis (Fabricius, 1787)	*Scy.fro*	0.23	0	0.18	NC
Psyllobora vigintiduopunctata (Linnaeus, 1758)	*Psy.vig*	0.09	0.19	0.11	NC
Calvia quatuordecimguttata (Linnaeus, 1758)	*Cal.qua*	0.09	0	0.07	NC
Scymnus ferrugatus (Moll, 1785)	*Scy.fer*	0.09	0	0.07	NC
Myrrha octodecimguttata (Linnaeus, 1758)	*Myr.oct*	0.05	0	0.04	C
Hippodamia variegata (Goeze, 1777)	*Hip.var*	0.05	0	0.04	NC
Platynaspis luteorubra (Goeze, 1777)	*Pla.lut*	0.05	0	0.04	NC
Scymnus auritus Thunberg, 1795	*Scy.aur*	0.05	0	0.04	NC
Scymnus haemorrhoidalis Herbst, 1797	*Scy.hae*	0.05	0	0.04	NC
∑		n = 2,215	n = 529	n = 2,744	

spatial dispersion of ladybird species (larvae and adults separately) in relation to the environmental variables: the presence of aphids and the social position of the sample tree – a tree growing in the group. We determined the significance of the abovementioned environmental variables using the Monte Carlo permutation test (iteration 499) in Canoco 5 software (Ter Braak and Šmilauer, 2012).

We assessed the normality of the data distribution of the abundance of ladybirds by the Shapiro–Wilk (SW) test. Due to the violation of the normality for adults ($p = 0.00002$) and larvae ($p = 0.00008$), we used the nonparametric Mann–Whitney U test to evaluate the difference in the abundance of ladybirds (number of individuals) between different social positions of the sample trees (trees growing in groups and solitary trees). The statistical analyses were performed in the R program (version 4.1.3).

Results

During two growing seasons (April – October) in 2021 and 2022, we recorded a total of 2,744 ladybird individuals on blue spruce, of which 2,215 were adults (27 species) and 529 were larvae (11 species). *Exochomus quadripustulatus* and *Aphidecta obliterata* were eudominant (abundance of more than 10%) both in adult and larval communities (Table 1).

The proportions of the individual specialised ladybird groups according to association with the host plant strongly differed. Conifer specialists (C, see Table 1) considerably dominated adult communities (85.2% of all individuals), although only nine species belonged to this group. Despite the highest species richness (15 species), nonconifer ladybirds (NC, Table 1) reached minor representation in communities of adults (5.0%). Generalists (G, Table 1) were represented by three species (9.9%), and among them, the nonnative *Harmonia axyridis* was the most abundant.

For the larvae, seven species belonged to conifer specialists (92.1% of all individuals). The same species were generally the most common as those for the adult communities. Nonconifer species were recorded in very small numbers (3 species, 1.1% of all individuals), and generalists were represented by only one species – *H. axyridis* (6.8%), which was the third most abundant species in the larval communities (Table 1).

Using redundancy analysis (RDA) [standard deviation = 1.1 (Fig. 1) and 1.3 (Fig. 2) on the first axis, respectively], we determined the relationship of adults (Fig. 1) and larvae (Fig. 2) of ladybird species to two environ-

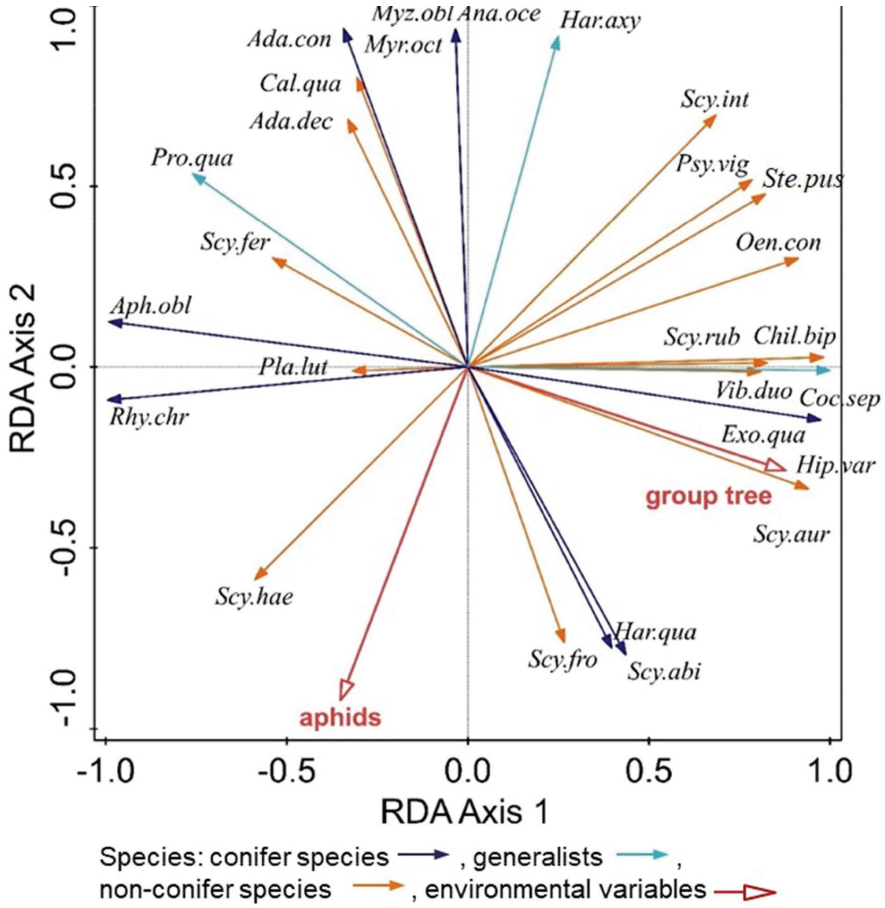

Fig. 1. The relationship of ladybird adults to environmental variables via RDA. Abbreviations of ladybird names are presented in Table 1; "aphids" = relative abundance of aphids on the sample tree, "group tree" = the sample tree was in a group of blue spruces.

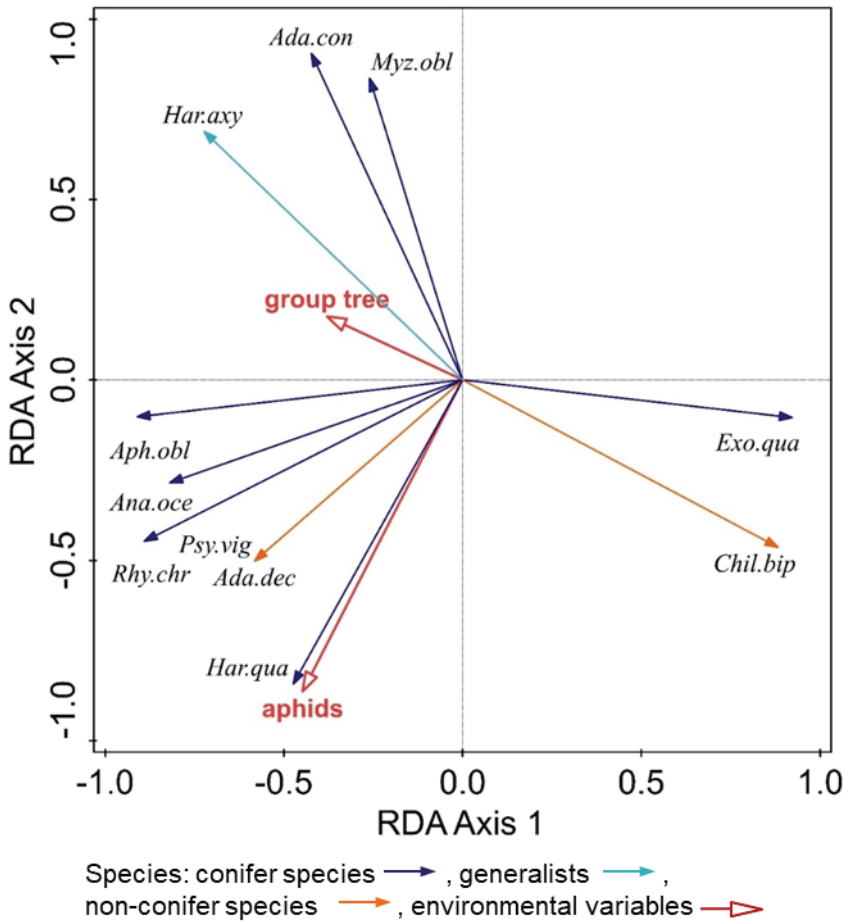

Fig. 2. The relationship of ladybird larvae to environmental variables via RDA. Abbreviations of ladybird names are presented in Table 1; "aphids" = relative abundance of aphids on the sample tree, "group tree" = the sample tree was in a group of blue spruces.

mental variables: (1) the relative abundance of aphids on a sample tree – "aphids" and (2) the specific social position of a sample tree, namely, the tree located in a group of blue spruces – "group tree". The species variability of ladybird adults and larvae expressed on the first axis was 50.6% (60.0%, respectively), and on the second cumulative axis, it was 80.8% (75.0%). After adding the influence of environmental variables, the variability on the first axis increased to 94.5% (81.9%, respectively) and on the second cumulative axis to 98.0% (92.0%). The variable "aphids" had a statistically significant effect on the spatial dispersion of adults and larvae ($p = 0.032$ and $p = 0.0364$, respectively). The variable "group tree" did not have any significant effect ($p = 0.13$) on the structure of the ladybird community for adults, but for larvae, it still had a significant effect ($p = 0.0216$).

According to the study of the relationship of adults to two environmental variables, we identified three different groups (see Fig. 1): (1) three abundant species (with more than 10 specimens), *Coccinella septempunctata*, *Exochomus quadripustulatus* and *Vibidia duodecimguttata*, were associated with the variable "group tree", (2) two abundant species (namely, *Harmonia quadripunctata* and *Scymnus abietis*) were related to both variables ("aphids" and "group tree"), and finally, (3) six other abundant species (namely, *Adalia conglomerata*, *A. decempunctata*, *Aphidecta obliterata*, *Harmonia axyridis*, *Scymnus interruptus* and *Stethorus pusillus*) did not show correlation to any of the environmental variables. The different status has been confirmed with larvae with only five species with more than 10 collected specimens (see Fig. 2). Here, we can also define three groups: (1) *Exochomus quadripustulatus* was not bound to any of the examined factors, (2) *Harmonia axyridis* was associated with the variable "group tree", and finally, (3) three species (namely, *A. obliterata, H. quadripunctata* and *Rhyzobius chrysomeloides*) showed a relation to the variable "aphids" (Fig. 2).

There were differences between the total abundance of ladybird adults recorded on solitary trees and on trees growing in groups of blue spruces; more ladybirds were on solitary trees (Mann–Whitney U test, $p = 0.000178$) (Fig. 3). The same result was found for larvae, which occurred in significantly higher abundances on solitary trees ($p = 0.006351$) (Fig. 4).

Discussion

During two consecutive growing seasons, we recorded 26 native and one invasive coccinellid species on blue spruce, which is almost one-third (30.7%) of all 88 ladybird species occurring in Slovakia (Haviar and Merkl, 2004; Nedvěd, 2020). That is more than Selyemová et al. (2007)

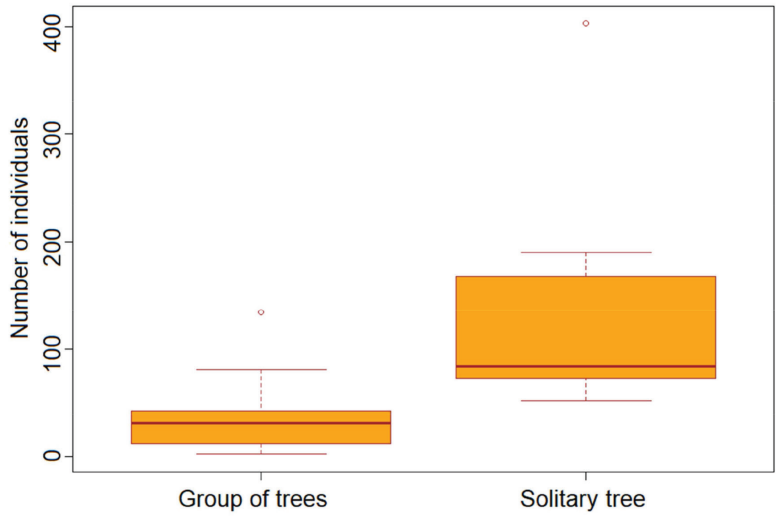

Fig. 3. Effect of blue spruces growing in groups and solitary trees on the collected individuals of ladybird adults. The boxplots illustrate (express) the median (bold line) and 25th and 75th percentiles (box) of the samples. Whiskers represent the data range excluding outliers (values extending more than 1.5× interquartile range from the upper and lower box limits).

Fig. 4. Effect of blue spruces growing in groups and solitary trees on the collected individuals of ladybird larvae. The boxplots illustrate (express) the median (bold line) and 25th and 75th percentiles (box) of the samples. Whiskers represent the data range excluding outliers (values extending more than 1.5× interquartile range from the upper and lower box limits).

found on Norway spruce in Slovakia (17 native species). However, our sampling of beetles was carried out in an urban environment, and Selyemová et al. (2007) studied coccinellids in submountain and mountain forests. We also found 11 observed species as larvae, which is evidence that these ladybirds can develop on this nonnative conifer.

Our hypothesis predicted that the conifer ladybirds would have predominated on nonnative blue spruce due to the presence of native conifers in the country, including the native congener Norway spruce. The prediction was confirmed because conifer specialists (in total 9 species) strongly dominated in both adult and larval communities (85.2% and 92.1%, respectively). The recorded conifer ladybirds represent almost two-thirds (64.0%) of all (14) conifer species in Slovakia (Nedvěd, 2020). Two species, *E. quadripustulatus* and *A. obliterata*, predominated markedly among the adult (65.4% together) and larval (82.6%) communities (Table 1). While the recorded number of adults of both species was almost the same, the larvae of *E. quadripustulatus* were twice as abundant as the larvae of *A. obliterata*. Thus, it seems that blue spruce occurring in the urban environment provides suitable conditions for reproduction and development, especially for *E. quadripustulatus*. Comparing the results of our study with those of Selyemová et al. (2007), *A. obliterata* was predominant as on Norway spruce in forest as on blue spruce in urban habitats, and *E. quadripustulatus* was common only on blue spruce in towns. As *E. quadripustulatus* is mostly distributed at low-

er altitudes (pers. observation of authors, Selyemová, pers. communication), this may be the reason for its higher abundance on blue spruce in towns compared to mountain Norway spruce forest (Selyemová et al., 2007). *Anatis ocellata, Myzia oblongoguttata* and *Adalia conglomerata*, common in Norway spruce forests (Klausnitzer and Bellmann, 1969; Selyemová et al., 2007), were markedly less abundant on blue spruce in towns. All conifer species of ladybirds that we found on blue spruce (with the exception of *Myrrha octodecimguttata*) also occur on Norway spruce (Bielawski, 1961; Klausnitzer and Bellmann, 1969; Reddersen and Jensen, 2002; Selyemová et al., 2007). *Myrrha octodecimguttata*, a typical inhabitant of mature crowns of Scots pine (Klausnitzer, 1968; Czechowska, 1995a, 1995b; Burmeister et al., 2007), occurred on blue spruce, probably as a tourist because there were often pines in the urban greenery of the studied towns.

For the generalists, only 3 species were recorded on blue spruce, including an invasive species, *H. axyridis*, which dominated markedly among them. Overall, *H. axyridis* was the fourth dominant species among all adults and the third dominant species among all larvae obtained. It tends to be abundant on broadleaved trees such as limes and maples, while on coniferous trees, it is rather less abundant (Eschen et al., 2007; Brown et al., 2011; Honěk et al., 2015; Roy et al., 2016; Viglášová et al., 2017; Brown and Roy, 2018; Holecová et al., 2018; Szawaryn et al., 2018; Kenis et al., 2020). Its dominance (5.3%; adults + larvae) (Brown and Roy, 2018) on pines in Great Britain was similar to the 5.8% recorded by us on blue spruce. In ladybird communities on pines in Switzerland, *H. axyridis* was the second most abundant species, while on spruce, it was almost absent (Kenis et al., 2020). Selyemová et al. (2007) did not record the species on Norway spruce because they investigated ladybird communities before its arrival in 2008 in Slovakia (Brown et al., 2011; Panigaj et al., 2014). Unlike *H. axyridis*, only adults of native generalists were observed on blue spruce in our research. *Coccinella septempunctata* was relatively common on blue spruce but less dominant than on Norway spruce in forests (Selyemová et al., 2007).

The last specialised group of ladybirds recorded on blue spruce – nonconifer species – was represented by 15 species (Table 1). Although these species comprised more than one half of all species recorded on blue spruce, their total abundance barely reached 5.0% in the communities of adults (similar findings as on Norway spruce, Selyemová et al., 2007). Among larvae, only 3 nonconifer species were recorded. Compared to communities on Norway spruce in mountain forests, apart from conifer specialised *S. abietis*, we recorded 8 other nonconifer species of subfamily Scymninae (genus *Scymnus*, *Platynaspis* and *Stethorus*) on blue spruce in towns. A possible reason for the occurrence of these species mostly inhabiting broadleaved trees may be a warmer climate in towns (Pickett et al., 2001; Honek et al., 2021), as many of them are thermophilous (Nedvěd, 2020).

Our data indicate differences in coccinellid abundances in relation to the social position of host trees. We recorded significantly higher abundances of adults and larvae on solitary trees than on trees growing in groups. In accordance with our results, a study of canopy communities on isolated trees of Scots pine and trees growing in patches revealed significant differences in the abundances of carnivorous beetles (higher abundance on solitary trees than in patches) (Ozanne et al., 2000). Unlike our results, Faeth and Simberloff (1981) assumed that predator densities should be lower on solitary trees (oaks) than on trees growing in patches. Whether the differences were caused by a studied tree species (broadleaved trees versus coniferous trees), microclimate conditions, food resources, ladybird preferences or a larger disperse of insect individuals in the tree groups, we can only speculate, and this question therefore requires further research.

The majority of central European ladybirds are considered to be aphidophagous (Hodek, 1973; Koch, 1989; Hodek and Evans, 2012; Nedvěd, 2020), so we expected that there would have been more ladybirds on trees with the aphids present. This was confirmed only in some abundant species. Among the adults, the abundant species *H. quadripunctata* and *S. abietis* showed their affinity to "aphids" and "group trees" together. Among larvae, three abundant species, *A. obliterata*, *H. quadripunctata* and *R. chrysomeloides*, showed affinity for "aphids". All these species are listed as aphidophages in the literature (Koch, 1989), so our findings confirmed their affinity for this kind of food. Other abundant ladybirds did not show their relation to the factor "aphids", although some of them (*A. conglomerata* and *C. septempunctata*) are aphidophages (Koch, 1989). There is plenty of other possible food for ladybirds on blue spruce, but this is a question of further research.

Colonisation of nonnative tree species by native insects is relatively rapid in areas where native trees relative to nonnative trees are present: from 100 to 300 years (Strong, 1974; Connor et al., 1980; Dajoz, 2000). Our results confirmed that blue spruce has been established strongly in European urbanised areas since its introduction approximately 160 years ago. Recently, it has been able to host rich ladybird communities as conifer specialists and generalists as well as nonconifers and provide them suitable shelter and food resources.

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