Izvirni znanstveni članek / Original scientific article

HOVERFLIES (DIPTERA: SYRPHIDAE) AS BIODIVERSITY INDICATORS FOR ASSESSING URBAN FOREST HABITATS

MUHE TREPETAVKE (DIPTERA: SYRPHIDAE) KOT KAZALNIKI BIOTSKE PESTROSTI ZA OCENJEVANJE HABITATOV MESTNIH GOZDOV

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ABSTRACT

Urban and peri-urban forests are important habitats for maintaining biodiversity in cities. In this paper, we report a method for using hoverflies as biodiversity indicators in urban forest habitats. As a case study, forest habitats in three peri-urban and urban forests were assessed and compared to rural forests in Slovenia. Rožnik (Ljubljana) was chosen as the urban forest site, Mestni log (Ljubljana) and Brdo (Kranj) were chosen as the peri-urban sites, and eight sites were chosen in rural forests in different ecoregions in Slovenia. Forest hoverfly species richness and the species composition of different biological traits were compared between the peri-urban forests, urban forest and rural forest sites. In addition, species richness was assessed for changes in response to weather conditions between years. The number of species with the investigated traits in the urban and peri-urban forests was within the range of the number of species observed in the rural forests. The number of saproxylic species was higher in the urban forest but lower in the peri-urban forests compared to the rural forests. The proportions of species with different feeding modes and different development times were similar between the peri-urban, urban and rural forests. The proportions of species with development times of less than 2 months or more than 1 year and of predatory species were similar in the urban and peri-urban forests but higher in the rural forests. The species composition of the other biological traits differed between the peri-urban, urban and rural forests. Species richness and abundance displayed large differences in phenological patterns between 2012 and 2013; these differences are related to differences in the minimum temperature for these years. The results are discussed in relation to forest management in urban forests, the usefulness of hoverflies as a biodiversity indicator and possible extrapolation to other species groups.

Key words: biological traits, ecosystem services, forest management, saproxylic species, hoverflies, Syrphidae, urban forest

IZVLEČEK

Mestni in primestni gozdovi sestavljajo pomembne habitate za ohranjanje biotske pestrosti v mestih. V tem članku predstavljamo metodo za uporabo muh trepetavk kot kazalnikov biotske pestrosti v urbanih gozdnih habitatih. To metodo smo uporabili za oceno gozdnih habitatov v treh primestnih in mestnih gozdovih ter jih primerjali s podeželskimi gozdovi v Sloveniji. Kot mestni gozd je bil izbran Rožnik (Ljubljana), kot primestni gozd sta bila izbrana Mestni log (Ljubljana) in Brdo (Kranj), kot podeželske gozdove v različnih ekoloških regijah v Sloveniji pa smo izbrali osem gozdnih območij. V teh gozdovih smo primerjali bogatost gozdnih vrst muh trepetavk in njihovo vrstno sestavo glede na biološke lastnosti v izbranih mestnih, primestnih in podeželskih gozdovih. Poleg tega smo spremljali tudi odziv vrstne pestrost muh trepetavk glede na različne vremenske razmere med posameznimi leti. Število vrst z raziskanimi biološkimi lastnostmi v mestnih in primestnih gozdovih je bilo v podobnem razponu kot v podeželskih gozdovih. Število saproksilnih vrst je bilo večje v mestnih in manjše v primestnih gozdovih kot v podeželskih gozdovih. Deleži vrst z različnimi načini prehranjevanja in različnim trajanjem razvoja so bili podobni med mestnimi, primestnimi in podeželskimi gozdovi. Deleži vrst, katerih razvoj traja manj kot dva meseca ali več kot eno leto, ter deleži plenilskih vrst so bili podobni v mestnih in primestnih gozdovih, ne pa tudi v podeželskih gozdovih. Vrstna sestava drugih bioloških lastnosti se je med primestnimi in mestnimi ter podeželskimi gozdovi razlikovala. Bogatost vrst in njihova številčnost sta pokazali velike razlike v fenološkem razvoju muh trepetavk v letih 2012 in 2013. Te razlike so povezane z razlikami v minimalni temperaturi zraka v teh letih. Rezultati so obravnavani v povezavi z gospodarjenjem z mestnimi gozdovi, primernostjo muh trepetavk kot kazalnika biotske pestrosti in možnostjo za razširitev predlagane metodologije na druge skupine vrst.

Ključne besede: biološke lastnosti, ekosistemske storitve, gospodarjenje z gozdovi, saproksilne vrste, muhe trepetavke, Syrphidae, mestni gozdovi

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1 INTRODUCTION

1 UVOD

The urbanisation of landscapes has a strong negative effect on biodiversity (McKinney, 2006; McKinney, 2008). The species richness of plants, fungi and animals decreases dramatically towards the centres of cities (McKinney, 2008). The species composition of species groups becomes homogenised, with generalists and larger species occurring more frequently in city centres (McKinney, 2006; Lizée et al., 2011). To decrease the negative effects of urbanisation on biodiversity, there is an increasing awareness among urban planners of the necessity of establishing more green spaces in cities and towns (Dwyer et al., 1992). These green spaces serve multiple purposes, such as recreation and the protection of biodiversity (Chiesura, 2004). However, these different purposes have different requirements that may conflict (Chiesura, 2004).

Urban forests are one of the more natural green spaces found in cities and function as refuges for plants and animals in the urban environment. For example, in Singapore, more than 90% of the butterfly species in the city occur in urban forests (Koh and Sodhi, 2004). However, many factors influence species richness in urban forests. Most urban forests are relatively small and can therefore accommodate a limited number of species (Niemela et al., 2002; Croci et al., 2008). Isolated parks have low numbers of species because their colonisation rate is low (Knaapen et al., 1992). There is a large effect of pollution from neighbouring roads and houses (Pickett et al., 2001). Many people visit these forests, disturbing vulnerable species (Grandchamp et al., 2000). In addition, forest management of urban forests differs from that in rural forests because dead trees and branches are often removed from urban forests for aesthetic and safety reasons (Tyrväinen et al., 2003), affecting endangered species that inhabit these dead wood microhabitats (Speight, 1989). Together, these factors result in strong pressures on the populations of plants and animals (Pickett et al., 2001).

To assess and address the threats to biodiversity and habitats in urban forests, indicators must be identified. Biodiversity indicators should consist of species groups that are known to be affected by disturbances and are easily recognised by non-professionals and whose analysis provides qualitative information about the condition of urban forest habitat. For example, birds and butterflies display similar trends in response to urbanisation, while the species richness of plants increases in suburban areas and is lowest in heavily urbanised areas (McKinney, 2008). By contrast, carabid beetle species richness and composition are unaffected by urbanisation (Niemela et al., 2002). In many assessments, bioindicator groups such as butterflies, dragonflies and grasshoppers have been used (Maes and Van Dyck, 2005); however, these groups are not common in forests and are therefore not informative for these habitats. In addition, to cover a large segment of forest biodiversity, more species groups with different niches (Croci et al., 2008; Smith et al., 2009; Bräuniger et al., 2010) or a few selected species groups with a large spectrum of niches and biological traits (Speight and Castella, 2001; Lizée et al., 2011) should be used as biodiversity indicators.

We suggest using hoverflies (Diptera: Syrphidae) and their biological traits as indicators for the status of biodiversity in urban forests. Hoverflies are known to be good environmental indicators and to provide important benefits to ecosystems (Sommaggio, 1999). Adult hoverflies are important pollinators of plants and trees (Rader et al., 2009). In addition, hoverfly species have different larval feeding modes, such as feeding on bacteria, feeding on plants and predating on aphids, ants, bees and wasps (Rotheray, 1993). Predatory larvae are important agents for the biocontrol of aphids (Smith et al., 2008), and because they are dependent on aphids, they are also a good indicator of the abundance of this insect group. In addition, hoverflies include a large subset of species that occupy a range of niches in the forest. Another important characteristic of hoverflies as indicator species is that they are relatively easy to identify, as it is a very well-studied group of species, and literature and identification keys for many tribes and genera are available. A previous study established a set of hoverfly species that can be identified in the field (Graham-Taylor et al., 2009). Many hoverfly species are known to be vulnerable to habitat degradation (Speight et al., 2020; Vujić et al., 2022), particularly saproxylic species (Speight, 1989), large species with short flight periods (Sullivan et al., 2000) and species with a long development time. Hoverflies are already used as indicators for the quantity of dead wood (Reemer, 2005), other forest management factors (Nol et al., 2006; Deans et al., 2007; Smith et al., 2009), forest patch size (Ouin et al., 2006), forest age (Speight et al., 2020), climate change (Graham-Taylor et al., 2009; Miličić et al., 2018), the effect of urbanisation (Bates et al., 2011) and changing landscapes (Popov et al., 2017). Although the effect of urbanisation on hoverflies has been reported previously (Bates et al., 2011), this study examines the use of hoverflies for assessing the biodiversity in the habitats of isolated urban forests rather than investigating the influence of urbanisation on hoverflies.

In this study, we demonstrate a) how the biological traits and species composition of hoverfly species assemblages can be used to assess biodiversity in the habitats of urban and peri-urban forests and b) that hoverflies are sensitive enough to react to changes in weather conditions between years and are consequently good indicators of climatic change. The Rožnik urban forest in Ljubljana and the Mestni log (Ljubljana) and Brdo (Kranj) peri-urban forests were used as case studies. To assess the status of the forest habitats, the species and functional composition of the hoverflies in the urban and peri-urban forests were compared with those in less disturbed rural forests. The biological traits of the hoverfly species, such as development time, feeding mode, saproxylic life history and total species composition, were investigated. We hypothesised that when the peri-urban and urban forests were not managed in favour of biodiversity, there would be a low number of saproxylic species, a low number of species with a long development time and a different ratio of feeding modes. In addition, we assessed whether the peri-urban and urban forests contained different species than the rural forests. Furthermore, we also investigated whether hoverflies reflect year-to-year changes in weather conditions and determined which climatic variable was the most influential. To this end, hoverflies were monitored in 2012 and 2013 in Rožnik using different methods.

2 MATERIALS AND METHODS

2 MATERIALI IN METODE

2.1 Area description

2.1 Opis ploskev

In this study, Rožnik, a natural forest in the City of Ljubljana, was chosen as an example of an urban forest. This forest is on an approximately 3.54 km^2 hill surrounded by settlements. It is a mixed forest with many coniferous and deciduous tree species. The most common tree species are Norway spruce (*Picea abies* L. Karst.), European beech (*Fagus sylvatica* L.), Scots pine (*Pinus sylvestris* L.) and sessile oak (*Quercus petraea* Liebl.). The forest is visited by 1,750,000 people each year (Smrekar et al., 2011). It is a part of the Tivoli, Rožnik and Šišenski hrib landscape park, which has been a nature protected area since 1984 (SRS, 1984; RS, 2010; RS, 2015). In terms of forest management priorities, social and ecological functions are prioritised over wood production (ZGS, 2015).

Two forests were chosen as examples of peri-urban forest: Mestni log and Brdo. Mestni log is approximately 1.91 km^2 and is located on the edge of Ljubljana. It is a mixed lowland forest with both coniferous and deciduous species. The main tree species are Norway spruce, pedunculate oak (*Quercus robur* L.) and black alder (*Alnus glutinosa* L.). This forest is visited less frequently than Rožnik. The size of the natural forest complex in Brdo is approximately 7.78 km^2. It is located on the edge of Kranj and is a part of the park associated with the Brdo pri Kranju mansion. This forest complex contains several wet and dry forest types. The main tree species are Norway spruce, black alder, European beech and Scots pine. This forest complex is partly fenced for visitors and is used for hunting tourism; consequently, it is heavily grazed by fallow deer (*Dama dama* L.) and roe deer (*Capreolus capreolus* L.). The accessible section of the park is visited by people mainly during weekends.

Eight rural forest sites (Prevalje, Sovodenje, Modraže, Pokljuka, Krim, Tomišelj, Zevanjšca, Planinca) were chosen. They are spread across Slovenia in two ecoregions: the Dinaric region and the sub-alpine region. Slovenian temperate forests typically extend over large areas. Their composition is mixed and contains many coniferous and deciduous tree species. The main tree species are Norway spruce, silver fir (*Abies alba* L.) and European beech. These forests are mainly used for wood production but also serve other functions, such as recreation and non-wood product collection. The fundamental principles of forest treatment and management practiced here are sustainable management, close-to-nature management and multi-purpose management (RS, 1993).

2.2 Survey protocol

2.2 Metodologija

To compare the urban and peri-urban forests to the rural forests, a hoverfly species list was compiled at each site. The species on these lists had been collected over the previous ten years, so it can be assumed that there were no local extinctions. All forests were sampled for the entire season over one or more years. The Rožnik urban forest was sampled in 2012 and 2013 from the beginning of April to the end of October. Krim, Tomišelj, Zevanjšca, Planinca and Sovodenj were sampled in 2010 from the beginning of April to the end of October. In Modraže and Pokljuka, the data were sampled in 2011 from the beginning of April to the end of October. In Prevalje, the hoverflies were sampled in 2012 from the beginning of April to the end of October. Hoverflies were sampled in Brdo in 2009 and in Mestni log in 2011. Sampling was done with sweep nets and malaise traps.

Differences between years were investigated in the Rožnik urban forest. The monitoring of hoverflies in this urban forest was conducted in 2012 and 2013. Hoverfly abundance was assessed with a malaise trap and a transect. The malaise trap was placed in a mixed section of Norway spruce and beech. The trap was emptied every 13 to 15 days from the beginning of April until the end of October in both 2012 and 2013. The transect was established on a forest path and had a length of 220 m. All species within 2.5 m of each side of the transect were counted. The transect was located approximately 50 m from the malaise trap, and counting was only conducted between 10:00 and 15:00 h when the weather was sunny and the wind speed was low (< 2 Beaufort). We repeated the transect counts once a month. Both methods were performed in canopy openings, as hoverflies are known to be more abundant in warm areas with more sun (Smith et al., 2009). Species were identified in the field when possible; otherwise, they were taken to the laboratory and identified using identification keys (Van Veen, 2004) or compared with specimens in the collection in the Slovenian Forestry Institute. For some individuals, other experts were consulted for identification.

2.3 Analysis

2.3 Analiza

The compiled species lists of hoverflies were divided into the classes "urban forest", "peri-urban forest" and "rural forest". For this study, only species that occur primarily in forests were considered. The "Syrph the Net" database was used to determine the traits of the different species (Speight et al., 2020; Vujić et al., 2022). The following traits were considered: saproxylic life history, development time (<2 months, 2-6 months, 7-12 months, >12 months) and feeding mode (microphagous, predatory, phytophagous).

Dissimilarity in hoverfly species composition was assessed with a multivariate statistical method called non-metric multi-dimensional scaling. The Jaccard index was used to compute the dissimilarity between sites in different forest classes. In addition, the number of forest hoverfly species, the number of saproxylic species, the number of species with different development times and the number of species with different feeding modes were compared between the different forest classes.

Table 1: Differences in species richness and functional trait compositions in the hoverfly communities of the urban forest, peri-urban forests and rural forests

Preglednica 1: Razlike v vrstnem bogastvu in sestavi funkcionalnih lastnosti v skupinah muh trepetavk v mestnem, primestnih in podeželskih gozdovih

	Forest type	Total number of species	Average number of species	Standard deviation	Min	Max
Species richness	Urban forest	50	50			
	Peri-urban forest	60	42	7.07	37	47
	Rural forest	126	43	12.83	26	65
Saproxylic species	Urban forest	12	12			
	Peri-urban forest	14	8	0	8	8
	Rural forest	28	9	1.91	8	12
Development time						
<2 months	Urban forest	10	10			
	Peri-urban forest	15	13	3.54	10	15
	Rural forest	17	8	3.20	3	12
2-6 months	Urban forest	17	17			
	Peri-urban forest	24	16	4.24	13	19
	Rural forest	45	17	4.67	11	25
7-12 months	Urban forest	21	21			
	Peri-urban forest	19	12	0.71	11	12
	Rural forest	59	17	5.68	10	27
>12 months	Urban forest	2	2			
	Peri-urban forest	2	2	0	2	2
	Rural forest	5	2	0.89	1	3
Trophic levels						
microphagous	Urban forest	18	18			
	Peri-urban forest	24	17	0.71	16	17
	Rural forest	46	14	4.74	7	20
phytophagous	Urban forest	3	3			
	Peri-urban forest	2	1	0	1	1
	Rural forest	9	3	1	2	4
predator	Urban forest	28	28			
	Peri-urban forest	35	24	6.36	19	28
	Rural forest	72	26	7.84	18	38

The trends in hoverfly abundance and number of species in the years 2012 and 2013 were compared using different methods. The dissimilarity in the hoverfly species compositions as determined by the malaise trap and transect counts was assessed with the Jaccard index and plotted with a dendrogram. A generalised linear model with a Poisson distribution was used to relate the number and abundance of species derived from the malaise trap data with climate variables and the year. The climate variables were measured between the first and last day of sampling and included average daily air temperature, maximum daily air temperature, minimum daily air temperature, minimum daily air temperature measured 5 cm above the ground and total precipitation. The most parsimonious models were selected on the basis of the lowest Akaike information criterion (AIC) (Burnham and Anderson, 2002). Transect data were not modelled due to insufficient data.

3 RESULTS
3 REZULTATI

A total of 145 hoverfly species were identified in the different forest classes (Appendix 1). The rural forests accounted for 87%, the urban forest for 34% and the peri-urban forests for 41% of these species. The number of species in the urban forest was higher than the average number of species in the rural forests (Table 1). The average number of species found in the peri-urban forests was lower than that in the rural forests. The analysis of species composition revealed that the hoverfly species found in the rural forests did not overlap with those found in the urban and peri-urban forests (Fig. 1a). The hoverfly species found in the two peri-urban forests formed an outgroup and were the most dissimilar to those found in the rural forests.

The number of saproxylic species in the urban forest was higher than the average found in the rural fo-

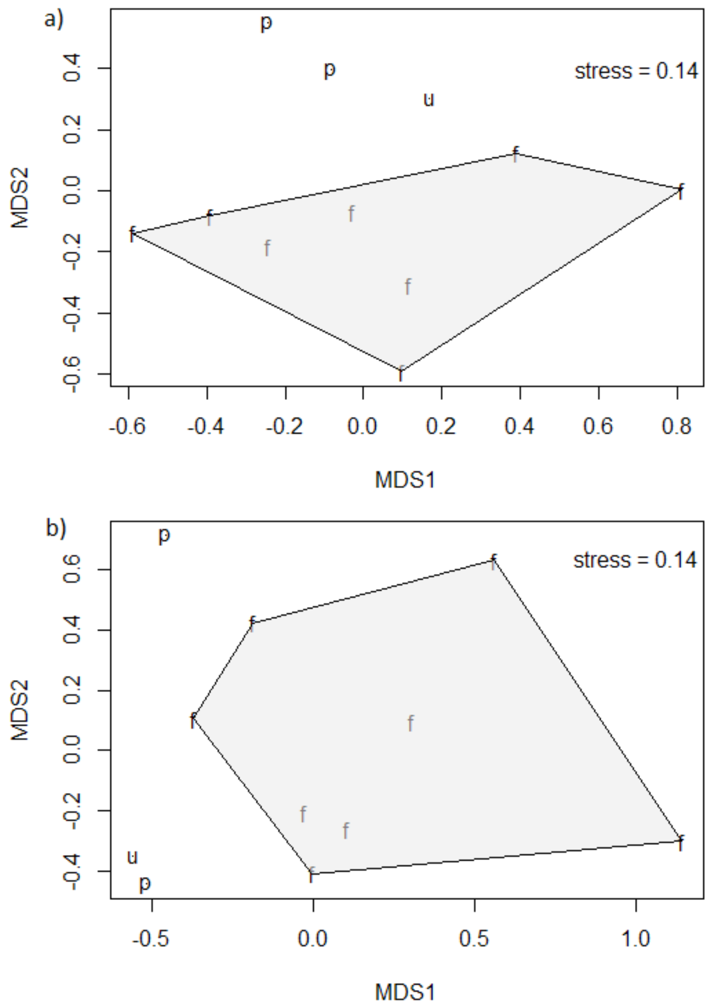

Fig. 1: NMDS plot of the dissimilarity in total (a) and saproxylic hoverfly species composition (b) between the urban forest (u), peri-urban forests (p) and rural forests (f). The grey area shows the sites that are in the rural forests.

Slika 1: Prikaz NMDS-razlik v skupni vrstni sestavi (a) in saproksilni vrstni sestavi muh trepetavk (b) za mestne gozdove (u), primestne gozdove (p) in podeželske gozdove (f). Siva barva označuje območja v podeželskih gozdovih.

rests, while the number of saproxylic species in the peri-urban forests was lower than that in the rural forests (Table 1). The species composition differed between the urban and rural forests (Fig. 1b).

Most of the observed hoverfly species had development times of 2 to 12 months (Table 1). Compared to species with other development times, fewer species with a development time of more than one year were observed. The average number of species with a development time of less than 2 months was higher in the peri-urban forests than in the rural forests. The average number of species with development times of 2 to 6 months was equal in the urban forest and rural forests, while the average number of species with a development time of 7 to 12 months was higher in the urban forest than in the rural forests. The average number of species with a development time of less than 2 months was higher in the urban forest than in the rural forests. In the urban forest, the composition of species with a development time of less than two months was more similar to that in the rural forests than that in the peri-urban forests (Fig. 2a). The composition of species with a development time between 2 and 12 months in the urban forest differed from that in the rural forests (Fig. 2b, c). The composition of species with development times of more than 1 year was similar for all forest classes (Fig. 2d).

Regarding feeding mode, species with predatory larvae comprised the largest number of species, while the number of species with phytophagous larvae was the lowest (Table 1). The average numbers of species with microphagous larvae and predatory larvae were higher in the peri-urban forests than in the rural forests. The number of species with phytophagous larvae in the urban forest was equal to that found in the rural forests. The peri-urban forests had lower numbers of species with phytophagous larvae and species with predatory larvae compared to the rural forests. While

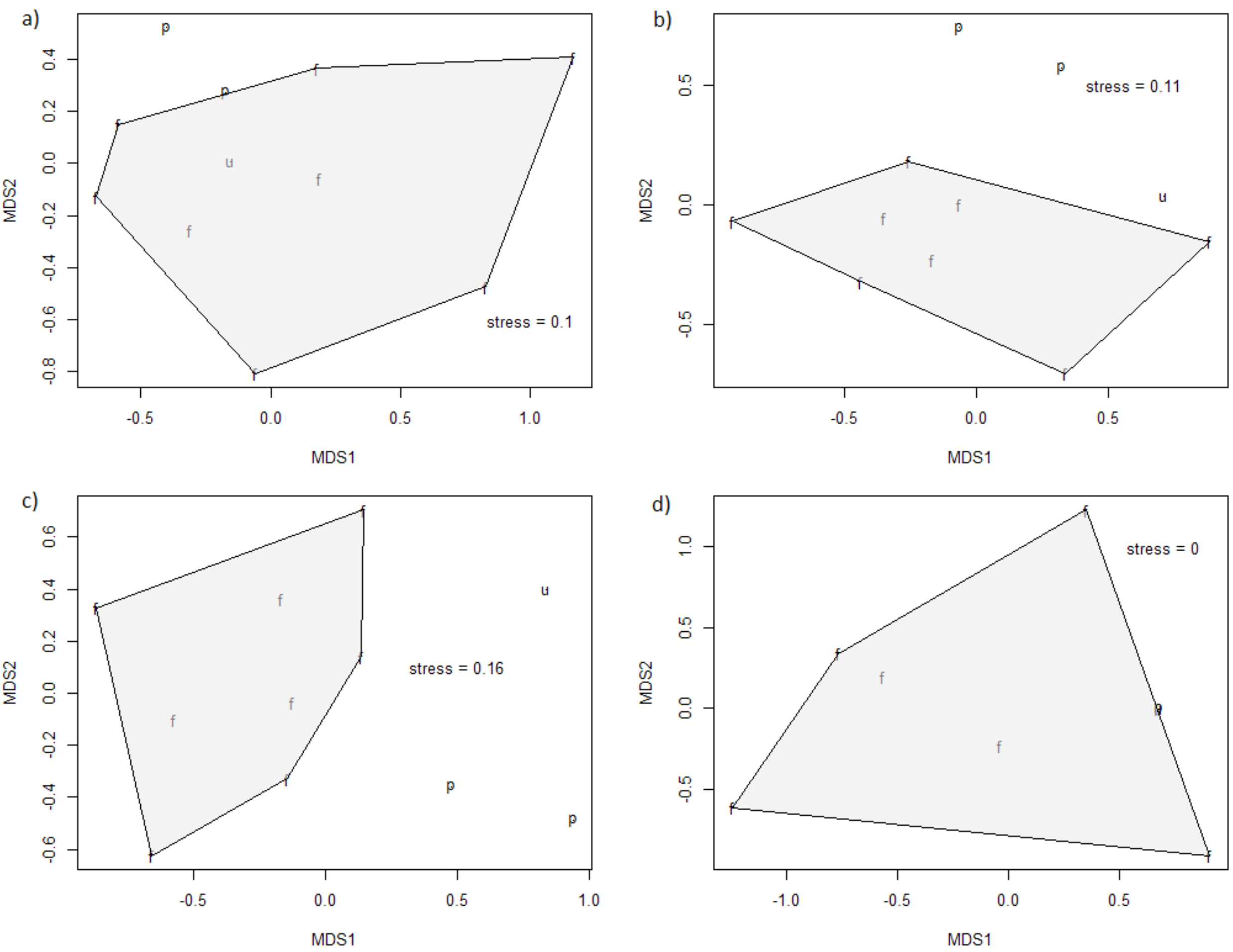

Fig. 2: NMDS plot of the dissimilarity in the species composition of hoverfly species with different development times, i.e. (a) < 2 months, (b) 2-6 months, (c) 7-12 months and (d) > 12 months, between the urban forest (u), peri-urban forests (p) and rural forests (f). The grey area shows the sites that are in the rural forests.

Slika 2: Prikaz NMDS-razlik v vrstni sestavi muh trepetavk z različnim trajanjem razvoja (a) < 2 meseca, (b) od 2 do 6 mesecev, c) od 7 do 12 mesecev in (d) > 12 mesecev, med mestnimi gozdovi (u), primestnimi gozdovi (p) in podeželskimi gozdovi (f). Siva barva prikazuje območja v podeželskih gozdovih.

the average number of species with microphagous larvae was greater in the peri-urban forests than in the rural forests, there were some sites in the rural forests that contained more species with microphagous larvae. The compositions of species with microphagous larvae and species with phytophagous larvae were less similar in the urban and peri-urban forests than in the rural forests (Fig. 3a, b). The compositions of species with phytophagous larvae did not differ between the peri-urban and rural forests.

During the hoverfly monitoring, we found that the phenological development data obtained from the malaise trap and transect counts for species and individuals were generally similar (Fig. 4). With respect to sampling with the malaise trap, it was found that the main peak in the number of individuals was later and lower in 2013 than in 2012. In 2012, there was a peak in the number of species and individuals at the end of August (Fig. 4a, b). In 2012, the transect counts started at the end of May, and the number of species and individuals decreased thereafter (Fig. 4c, d). In 2013, the number of species peaked two weeks earlier than the peak in the number of individuals. In addition, a small peak was observed in both the number of species and

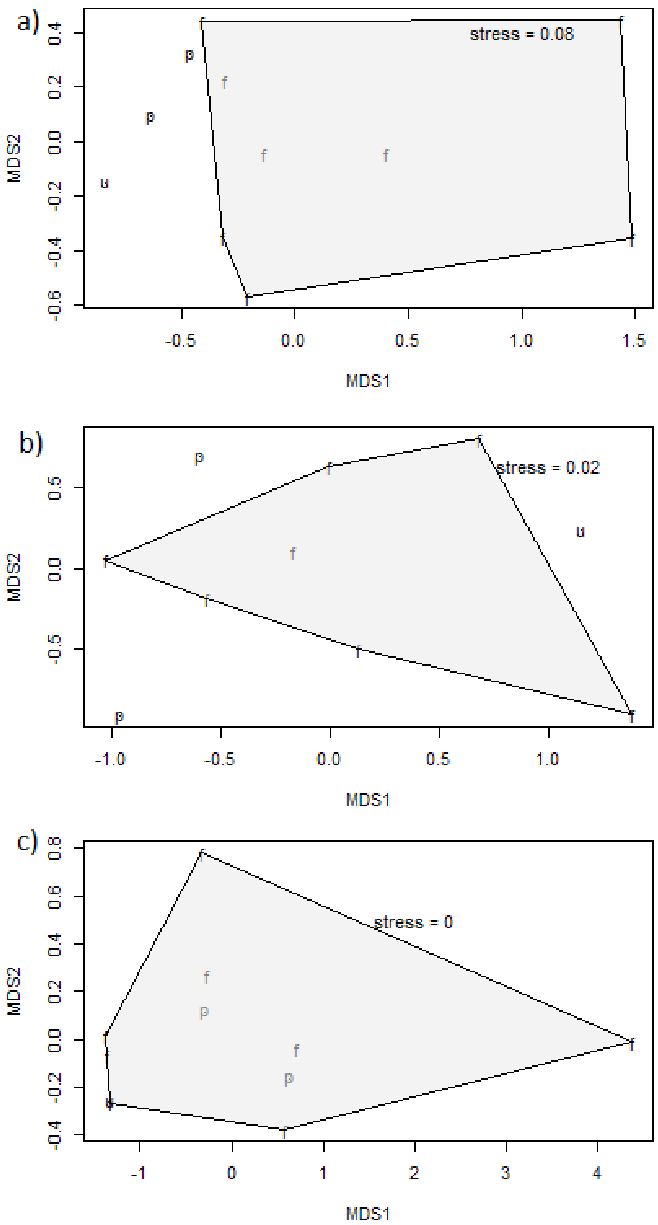

Fig. 3: NMDS plot of the dissimilarity in the species composition of hoverfly species with different feeding modes, i.e. (a) microphagous, (b) phytophagous and (c) predators, between the urban forest (u), peri-urban forests (p) and rural forests (f). The grey area shows the sites that are in the rural forests.

Slika 3: Prikaz NMDS-razlik v vrstni sestavi muh trepetavk z različnimi načini prehranjevanja: (a) mikrofagni, (b) fitofagni in (c) plenilski - med mestnimi gozdovi (u), primestnimi gozdovi (p) in podeželskimi gozdovi (f). Siva barva prikazuje območja v podeželskih gozdovih.

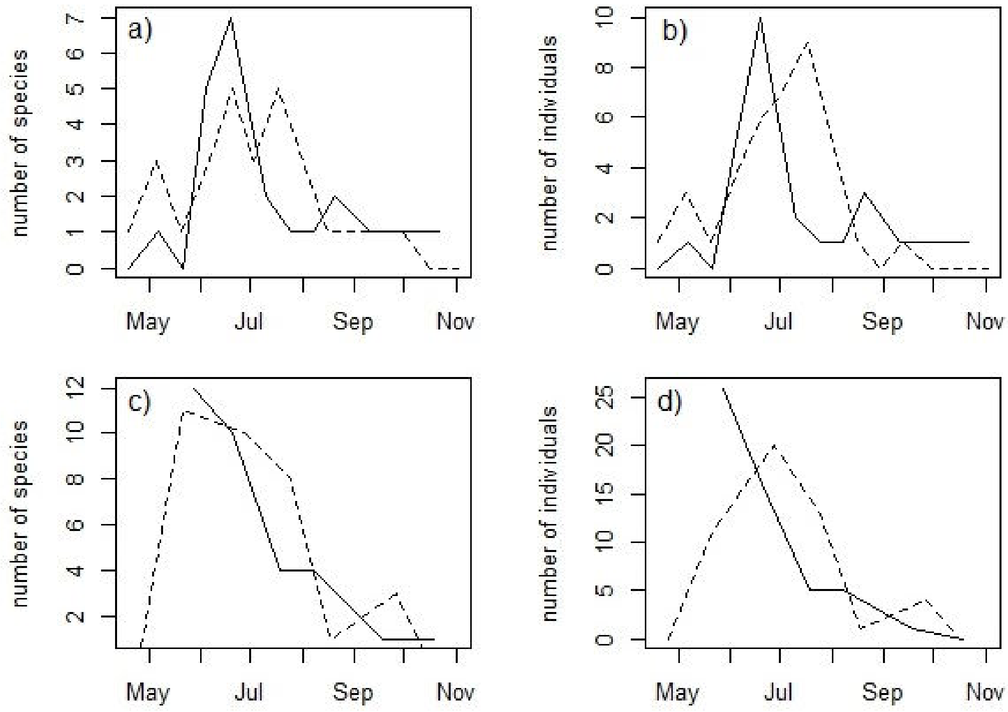

Fig. 4: Numbers of hoverfly species and individuals from the malaise trap (a, b) and the transect counts (c, d) in 2012 (solid line) and 2013 (dashed line)

Slika 4: Število vrst in osebkov muh trepetavk iz malaisove pasti (a, b) in transektnega štetja (c, d) v letih 2012 (neprekinjena črta) in 2013 (prekinjena črta)

the number of individuals in October 2013. These differences could be explained by the weather conditions in 2012 and 2013 (Fig. 5). There was a large difference in the average daily temperature and precipitation in 2012 and 2013. The most parsimonious models for the number and abundance of species used the minimum air temperature measured 5 cm above the ground (Appendix 2). There was a strong positive relationship between abundance and minimum air temperature (z=3.34, p<0.001), but the relationship between the number of species and the minimum air temperature was less strong (z=2.56, p<0.05). The analysis of species composition demonstrated larger differences between survey methods than between years (Fig. 6).

4 DISCUSSION

4 RAZPRAVA

4.1 Forest biodiversity status in the investigated urban and peri-urban forests

4.1 Stanje biotske pestrosti v obravnavanih mestnih, primestnih in podeželskih gozdovih

The number of hoverfly species with the investigated traits was similar between the urban, peri-urban and rural forests, but the species composition differed

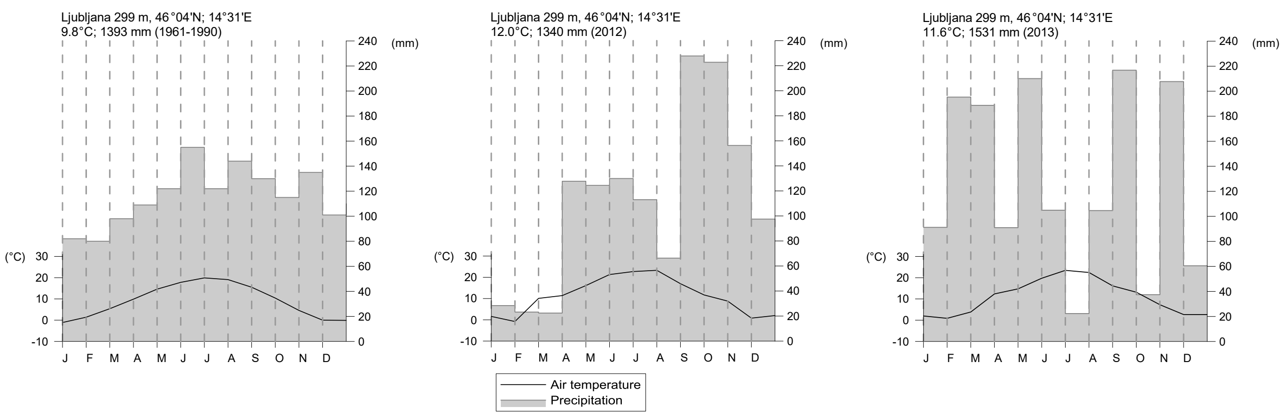

Fig. 5: Average monthly air temperature and total monthly precipitation at climatological station Ljubljana in a) the period 1961 – 1990 (ARSO archive), b) 2012 and c) 2013

Slika 5: Povprečna mesečna temperatura zraka in količina padavin na klimatološki postaji Ljubljana a) v obdobju od 1961 do 1990 (arhiv ARSO), b) v letu 2012 in c) v letu 2013

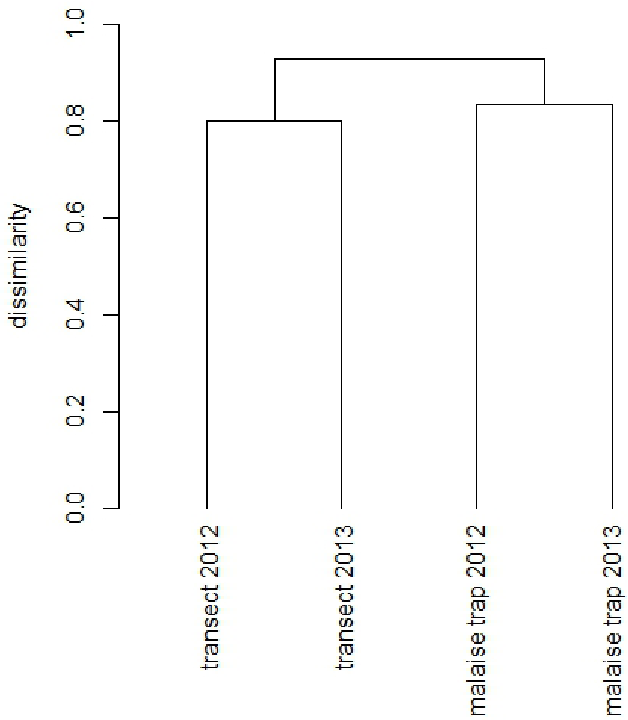

Fig. 6: Dendrogram of the dissimilarity in species composition between the years 2012 and 2013 and between the methods (malaise traps and transect counts). The Jaccard index was used as a dissimilarity index.

Slika 6: Dendrogram razlik v vrstni sestavi muh trepetavk med letoma 2012 in 2013 ter med metodami (malaisova past in transektno štetje). Kot indeks nepodobnosti je bil uporabljen Jaccardov indeks.

between the forest types. In addition, species richness and abundance differed greatly between years.

Saproxylic species are good indicators of the amount of dead wood in a forest. In the urban forest, there was a relatively high number of saproxylic species compared to the peri-urban and rural forests. The realisation of forest management plans for the urban forest has been hindered by the large number of private forest owners and the small average size of their forest land, which is often fragmented into a number of non-adjacent cadastral plots (Tavčar, 2010). Therefore, dead wood is not cleared, and ill or dead trees are not always cut if they are not dangerous. This type of dead wood management is very beneficial for saproxylic species (Reemer, 2005).

The ratio of species with different development times was similar in the urban and peri-urban forests and in the rural forests. Hoverfly species with longer development times should be most affected by intensive forest management. However, a reduction in species with longer development times was not observed in the investigated peri-urban and urban forests. Therefore, it seems that the conditions of these forests are such that the populations of species with longer development times are maintained.

The size of the forest determines the number of forest-dependent hoverfly species (Ouin et al., 2006). In total, 47 forest species were found in the Rožnik urban forest, 36 were found in the Mestni log peri-urban forest and 45 were found in the Brdo peri-urban forest; however, we predicted only 14, 12 and 18 species in Rožnik, Mestni log and Brdo, respectively, based on the sizes of the forests according to the model by Ouin et al. (2006). The large differences between the expected and observed numbers indicate that the number of forest hoverfly species in the peri-urban and urban forests in our study was influenced by other factors, such as habitat heterogeneity. In and near cities, forest stands tend to be fragmented, cover smaller areas, have different owners and comprise different tree species, in contrast to rural forests. In addition, urban forests often include open areas, which increase species richness (Gittings et al., 2006). Increased habitat heterogeneity is frequently associated with an increased number of species, and thus habitat heterogeneity in addition to forest size might have influenced species richness in this assessment.

The species compositions of the urban forest, peri-urban forests and rural forests were dissimilar. These differences might be due to differences in habitat between the selected forest classes or the omission of species that were not observed in the rural forests. Years of study are required to determine the total species composition of an area (Owen and Gilbert, 1989), and extinction and colonisation are continuous factors (Hanski, 1998). However, after one or two years, most species occurring in an area can be identified by using one method (Owen and Gilbert, 1989), and the use of a variety of methods ensures greater species coverage (Velli et al., 2010). However, to get a complete overview of the fauna, more years of surveys are recommended, as new species can appear due to a change in management or climate change (Reemer et al., 2003; Reemer, 2005)

In the peri-urban and urban forests in our study, there were many wet forest habitats, which were less prevalent in the rural forests. Wet habitats often contain specialist species that do not occur in other forests (Bankowska, 1980). In addition, wet forest habitats in Slovenia are often near cities and villages and therefore often under urbanisation pressure, which emphasises the importance of preserving these habitats to protect the species that inhabit them.

Our results indicate that the investigated urban and peri-urban forests have a similar richness of species with different traits or similar balances in the development times and feeding modes of species. These similarities indicate that the condition of the habitats in the urban and peri-urban forests is similar to that in the surrounding forests, and thus the biological traits of the hoverfly species are not subject to homogenisation in the urban and peri-urban forests.

4.2 Hoverflies as indicators
4.2 Muhe trepetavke kot indikatorji

Hoverflies are good indicators of environmental change (Reemer, 2005; Graham-Taylor et al., 2009; Bates et al., 2011). Our results demonstrate that differences in climatic conditions between years are reflected in species abundance and richness. In 2012, there was a rainy period that suppressed the number of hoverflies; however, in May, there was a dramatic increase in the number of hoverflies as the weather became warmer. By contrast, in 2013, a small peak occurred in spring, while the main peak occurred later in the season than in 2012. In May, there was a long cold and rainy period that suppressed the number of flying insects and delayed the peak. These responses are characteristic of species that can be used as indicators of climatic conditions. Graham-Taylor et al. (2009) demonstrated that hoverflies have reactions to climatic warming that are similar to those of other species such as butterflies.

The use of biological traits to assess the condition of urban forest habitats is appropriate, particularly when considering the traits of vulnerable species that are known to be affected by changes in forest management (Mörtberg and Wallentinus, 2000; Lizée et al., 2011). These species react more quickly to environmental change than more generalist species do, facilitating the assessment of the condition of an urban forest habitat (see results). Other forest habitat assessment methods have also included hoverflies (Speight and Castella, 2001). Speight and Castella (2001) have suggested using potential lists of species for an area based on its existing (micro-) habitats and comparing these lists with the actual species list. This method is appropriate when all potential (micro-) habitats in the particular area are known and the management goals for the area are unclear. However, species can often be absent because of biogeography and isolation rather than a decrease in habitat quality. Therefore, we decided to focus on biological traits, which are more vulnerable to disturbance, as an indicator. Compared to species composition, biological traits are easier for non-professionals to assess and understand.

The difference in the species composition detected using the malaise trap and transect counts demonstrates that some species are more easily detected with one method than the other. With transect counts, large distances can be assessed, and greater numbers of animals are often detected; however, transect counts must be repeated frequently to detect a large share of the species pool. With the malaise trap, hoverflies are caught continuously in one place, which increases the opportunity to detect rare species not easily observed with transect counts, such as *Brachypalpus* Macquart, 1834 species. Conversely, the malaise trap only covers a small area and is a very visible trapping method, which is particularly important in public places such as urban forests, where there is a high risk of vandalism. To obtain an adequate overview of the hoverfly species present in an area and to potentially monitor them in the future, multiple methods should be used to observe changes in composition.

4.3 Urban forest management and biodiversity
4.3 Gospodarjenje z mestnimi gozdovi in biotska pestrost

Based on our assessment using hoverflies as biodiversity indicators, recommendations for management plans can be proposed to maintain or improve the biodiversity of urban forests. First, the amount of dead wood should be maintained at a high level (above 20% of the wood stock) and should comprise different types (dead logs, dead trees, etc.) to maintain saproxylic biodiversity (Jonsson et al., 2005; Brunet et al., 2010). When forest management changes, saproxylic biodiversity changes. In the Netherlands, both the number of species and the number of observations of saproxylic species increased within 50 years after a change in the management of dead wood and ill trees (Reemer, 2005). Second, flower-rich open areas and forest edges should be promoted, as hoverflies and bees forage in open areas or forest edges with many flowers (Gittings et al., 2006), while like other species groups, they also use forest roads as corridors or even as habitats (Fayt et al., 2006). Third, habitats in forests that are very vulnerable, such as wet forest habitats, should receive special attention, as they maintain certain habitat specialist populations. Finally, a monitoring system should be established to follow the reaction of biodiversity to changes in the management of urban forests. These measures would enhance the diversity of hoverflies and of species with similar niches in urban forests.

In conclusion, this assessment demonstrated that hoverflies are a very useful insect group as indicators of the condition of urban forest habitats. Hoverflies are very sensitive to habitat and climatic changes. Therefore, the information they provide can be used to develop best management guidelines for urban forests. Although hoverflies are a suitable indicator of the condition of urban forest habitats, other insect groups, such as beetles, that have additional habitat preferences or biological traits should also be considered.

5 POVZETEK
5 SUMMARY

Urbanizacija krajine zelo negativno vpliva na biotsko pestrost. Bogatost rastlinskih in živalskih vrst izrazito upada od roba proti središčem mest. Vrstna sestava znotraj skupin postaja vedno bolj enotna, pri čemer se v središčih mest pojavljajo generalisti in večje vrste živali. Med urbanisti narašča zavedanje o pomenu zelenih površin oziroma zelenega prostora v mestih, ki lahko pripomore k zmanjšanju negativnih vplivov urbanizacije na biotsko pestrost. Mestni in primestni gozdovi so pomembni habitati za ohranjanje biotske pestrosti v mestih. Vendar na bogatost vrst v mestnih gozdovih vpliva veliko dejavnikov. Mestni gozdovi so povečini razmeroma majhni in ponujajo habitat le omejenemu številu vrst. V izoliranih mestnih parkih živi majhno število vrst, saj je stopnja njihove kolonizacije majhna. Na mestne gozdove negativno vplivajo tudi onesnaževanje in motnje številnih obiskovalcev. Pogosto se z mestnimi gozdovi drugače gospodari kot s podeželskimi, saj se odmrla drevesa in veje odstranjuje iz varnostnih in estetskih vidikov.

V tem članku predstavljamo metodo za uporabo muh trepetavk (Diptera: Syrphidae) kot kazalnikov biotske pestrosti v urbanih gozdnih habitatih. Muhe trepetavke so znane kot dober okoljski kazalnik ter pomembno prispevajo k ohranjanju ekosistemov. Odrasli osebki so pomembni opraševalci rastlin in dreves. Njihovih ličinke se glede na vrste, ki jim pripadajo, različno hranijo. Nekatere se hranijo z bakterijami ali rastlinami, druge pa plenijo mravlje, čebele, ose in listne uši, ter so tako dober kazalec številčnosti te skupine žuželk. Poleg tega je za muhe trepetavke značilno veliko število različnih vrst, ki zasedajo cel spekter različnih niš v gozdu, hkrati pa jih je razmeroma enostavno identificirati oziroma določiti vrsto. Za veliko vrst muh trepetavk je znano, da so občutljive za degradacijo habitatov, še posebej saproksilne vrste, velike vrste s kratkimi razdaljami letenja ter vrste, katerih razvoj dolgo traja.

V tej raziskavi smo predstavili: a) kako lahko na podlagi bioloških lastnosti in vrstne sestave skupin vrst muh trepetavk ugotavljamo biotsko pestrost habitatov v mestnih, primestnih in podeželskih gozdovih v Sloveniji; b) da so muhe trepetavke dovolj občutljive, da se odzovejo na različne vremenske razmere med leti in so posledično dobri kazalniki podnebnih sprememb. Kot mestni gozd je bil izbran Rožnik (Ljubljana), kot primestni gozd sta bila izbrana Mestni log (Ljubljana) in Brdo (Kranj), kot podeželske gozdove v različnih ekoloških regijah v Sloveniji pa smo izbrali osem gozdnih območij. Ugotavljali smo biološke lastnosti vrst muh trepetavk, kot so trajanje razvoja, način prehranjevanja, saproksilna življenjska zgodovina in skupna vrstna sestava. Domnevali smo, da bo v primestnih in mestnih gozdovih, ki niso gospodarjeni z namenom povečevanja biotske pestrosti, majhno število saproksilnih vrst, majhno število vrst z dolgim trajanjem razvoja in različno razmerje med vrstami glede na način prehranjevanja. Poleg tega smo ugotavljali, ali se v primestnih in mestnih gozdovih pojavljajo drugačne vrste muh trepetavk kot v podeželskih gozdovih. Ugotavljali smo tudi, ali se muhe trepetavke odzivajo na različne vremenske razmere med leti ter določili, katera vremenska spremenljivka je najbolj vplivala nanje. V ta namen smo v letih 2012 in 2013 z različnimi metodami spremljali vrstno sestavo muh trepetavk na Rožniku: malaisova past in štetje v transektu. Za vremenske spremenljivke smo pridobili podatke o povprečni dnevni temperaturi zraka, najvišji dnevni temperaturi zraka, najnižji dnevni temperaturi zraka, najnižji dnevni temperaturi zraka, izmerjeno 5 cm nad tlemi, in skupni količini padavin med prvim in zadnjim dnem vzorčenja.

Skupno smo v obravnavanih gozdovih ugotovili 147 različnih vrst muh trepetavk. 87 % odstotkov vseh vrst je bilo ugotovljenih v podeželskih gozdovih, 34 % v mestnih in 41 % v primestnih gozdovih. Število

vrst z raziskanimi biološkimi lastnostmi v mestnih in primestnih gozdovih je bilo v podobnem razponu kot v podeželskih gozdovih. Vendar so bile v podeželskih gozdovih ugotovljene druge vrste muh trepetavk kot v mestnih in primestnih gozdovih. Število saproksilnih vrst je bilo večje v mestnih in manjše v primestnih gozdovih kot v podeželskih gozdovih. To nakazuje, da so obravnavani primestni in mestni gozdovi v takšnem stanju, da omogočajo ohranitev populacijam vrst muh trepetavk z daljšim trajanjem razvoja. Deleži vrst z različnimi načini prehranjevanja in različnim trajanjem razvoja so bili podobni med mestnimi, primestnimi in podeželskimi gozdovi. Deleži vrst, katerih razvoj traja manj kot dva meseca ali več kot eno leto, ter deleži plenilskih vrst so bili podobni v mestnih in primestnih gozdovih, ne pa tudi v podeželskih gozdovih. Vrstna sestava drugih bioloških lastnosti se je med primestnimi in mestnimi ter podeželskimi gozdovi razlikovala. Bogatost vrst in številčnost sta pokazali velike razlike v fenološkem razvoju muh trepetavk v letih 2012 in 2013. Te razlike so povezane z razlikami v minimalni temperaturi zraka v teh letih. To potrjuje primernost uporabe muh trepetavk kot kazalnikov podnebnih sprememb. Prav tako se je za oceno stanja habitatov mestnih gozdov kot primerno izkazala uporaba bioloških lastnosti muh trepetavk, zlasti ob upoštevanju lastnosti ranljivih vrst, za katere je znano, da nanje vplivajo spremembe v načinu gospodarjenju z gozdovi. Te vrste se hitreje odzivajo na okoljske spremembe kot generalisti, kar olajša oceno stanja habitatov mestnih gozdov.

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Appendix 1: Species lists from the investigated urban forest and peri-urban forests in Slovenia.
Priloga 1: Seznami vrst muh trepetavk v obravnavanih mestnih in primestnih gozdovih v Sloveniji.

Species name	urban forest	peri-urban forest	
	Rožnik	Brdo	Mestni log
Baccha elongata (Fabricius, 1775)	1	1	
Brachyopa testacea (Fallen, 1817)		1	
Brachypalpoides lentus (Meigen, 1822)		1	
Brachypalpus laphriformis (Fallen, 1816)	1		
Chalcosyrphus nemorum (Fabricius, 1805)	1	1	
Chalcosyrphus piger (Fabricius, 1794)	1		
Cheilosia soror (Zetterstedt, 1843)	1		
Cheilosia vulpina (Meigen, 1822)			1
Chrysogaster solstitialis (Fallen, 1817)			1
Chrysotoxum bicinctum (Linnaeus, 1758)		1	1
Chrysotoxum elegans Loew, 1841	1		
Chrysotoxum festivum (Linnaeus, 1758)		1	1
Chrysotoxum verralli Collin, 1940	1		
Dasysyrphus venustus (Meigen, 1822)	1	1	1
Didea alneti (Fallen, 1817)		1	
Didea intermedia Loew, 1854	1	1	
Epistrophe eligans (Harris, 1780)		1	
Epistrophe melanostoma (Zetterstedt, 1843)	1		
Epistrophe obscuripes (Strobl, 1910)		1	
Episyrphus balteatus (De Geer, 1776)	1	1	1
Eristalis arbustorum (Linnaeus, 1758)		1	1
Eristalis nemorum (Linnaeus, 1758)	1	1	1
Eristalis pertinax (Scopoli, 1763)		1	1
Eristalis similis (Fallen, 1817)	1	1	
Eristalis tenax (Linnaeus, 1758)	1	1	1
Eumerus flavitarsis Zetterstedt, 1843	1		
Eupeodes corollae (Fabricius, 1794)		1	
Eupeodes lapponicus (Zetterstedt, 1838)	1	1	
Eupeodes latifasciatus (Macquart, 1829)	1		
Eupeodes nielseni (Dušek & Láska, 1976)	1		
Ferdinandea cuprea (Scopoli, 1763)		1	
Helophilus pendulus (Linnaeus, 1758)		1	1
Leucozona glaucia (Linnaeus, 1758)			1
Melangyna lasiophthalma (Zetterstedt, 1843)	1		
Melanostoma mellarium (Meigen, 1822)		1	
Melanostoma mellinum (Linnaeus, 1758)	1	1	1
Melanostoma scalare (Fabricius, 1794)	1	1	1
Meligramma cincta (Fallen, 1817)	1		
Meligramma cingulata (Egger, 1860)			
Meliscaeva auricollis (Meigen, 1822)	1	1	
Merodon avidus (Rossi, 1790)		1	
Merodon equestris (Fabricius, 1794)		1	
Merodon rufus Meigen, 1838	1		
Microdon mutabilis (Linnaeus, 1758)	1	1	1
Myathropa florea (Linnaeus, 1758)	1	1	1
Neoascia podagrica (Fabricius, 1775)	1	1	1
Paragus haemorrhous Meigen, 1822	1		1
Paragus pecchiolii Rondani, 1857	1		
Parasyrphus annulatus (Zetterstedt, 1838)	1	1	1
Parasyrphus punctulatus (Verrall, 1873)	1		
Pipiza festiva Meigen, 1822		1	
Pipizella viduata (Linnaeus, 1758)		1	
Pipizella virens (Fabricius, 1805)			1
Platycheirus europaeus Goeldlin, Maibach & Speight, 1990		1	
Platycheirus fulviventris (Macquart, 1829)			1
Platycheirus occultus Goeldlin, Maibach & Speight, 1990		1	
Pyrophaena rosarum (Fabricius, 1787)		1	1
Sphaerophoria chongjini Bankowska, 1964			1

Sphaerophoria interrupta (Fabricius, 1805)		1	
Sphaerophoria scripta (Linnaeus, 1758)	1	1	1
Sphegina clunipes (Fallen, 1816)	1		1
Sphegina latifrons Egger, 1865	1		
Sphegina sibirica Stackelberg, 1953	1	1	
Sphegina verecunda Collin, 1937			
Syritta pipiens (Linnaeus, 1758)	1	1	1
Syrphus ribesii (Linnaeus, 1758)	1	1	1
Syrphus torvus Osten-Sacken, 1875	1	1	
Syrphus vitripennis Meigen, 1822	1	1	1
Temnostoma bombylans (Fabricius, 1805)	1		1
Temnostoma vespiforme (Linnaeus, 1758)	1		1
Volucella bombylans (Linnaeus, 1758)			1
Volucella inflata (Fabricius, 1794)			1
Volucella pellucens (Linnaeus, 1758)		1	1
Volucella zonaria (Poda, 1761)	1		1
Xanthogramma dives (Rondani, 1857)	1		
Xanthogramma laetum (Fabricius, 1794)	1		
Xanthogramma pedissequum (Harris, 1776)	1		
Xanthogramma stackelbergi Violovitsh, 1975	1		
Xylota abiens Meigen, 1822		1	
Xylota jakutorum Bagatshanova, 1980	1		
Xylota segnis (Linnaeus, 1758)	1	1	1
Xylota sylvarum (Linnaeus, 1758)	1		1

Appendix 2: The model selection table of the models with the climatic variables which affect the abundance and number of species. The model selection was done on the basis of the second order Akaike Information Criterion (AICc). minT 5cm: minimum temperature measured 5 cm above the ground; minT: minimum temperature; maxT: maximum temperature. The weight shows the importance of the model compared to the other models.

Priloga 2: Tabela za izbiro modelov za modele vremenskih spremenljivk, ki vplivajo na število vrst in njihovo številčnost. Izbira modela je temeljila na informacijskem kriteriju Akaike drugega reda (AICc). minT 5cm: minimalna temperature zraka, izmerjena 5 cm nad tlemi; minT: minimalna temperature zraka; maxT: maksimalna temperatura zraka. Utež prikazuje pomembnost modela v primerjavi z drugimi modeli.

Abundance						
Variables	**K**	**df**	**AIC**	**AICc**	**ΔAICc**	**weight**
minT 5cm	1	2	118.71	118.74	0.00	0.33
minT 5cm, year	2	3	119.66	119.74	1.00	0.20
minT	1	2	120.72	120.75	2.01	0.12
minT, year	2	3	121.17	121.25	2.51	0.09
minT 5cm* year	3	4	121.48	121.64	2.90	0.08
average day temp	1	2	122.32	122.34	3.61	0.05
average day temp, year	2	3	122.75	122.83	4.09	0.04
minT* year	3	4	122.79	122.96	4.22	0.04
average day temp* year	3	4	124.42	124.59	5.85	0.02
precipitation* year	3	4	126.44	126.60	7.86	0.01
maxT	1	2	127.50	127.53	8.79	0.00
maxT, year	2	3	127.87	127.95	9.21	0.00
precipitation	1	2	129.00	129.02	10.28	0.00
maxT* year	3	4	129.75	129.92	11.18	0.00
precipitation, year	2	3	130.20	130.28	11.54	0.00
Species						
Variables	**K**	**df**	**AIC**	**AICc**	**ΔAICc**	**weight**
minT 5cm	1	2	91.86	91.89	0.00	0.33
minT	1	2	92.85	92.88	0.99	0.20
average day temp	1	2	93.91	93.93	2.05	0.12
minT 5cm, year	2	3	93.86	93.94	2.05	0.12
minT, year	2	3	94.81	94.89	3.01	0.07
average day temp, year	2	3	95.86	95.94	4.05	0.04
minT 5cm* year	3	4	95.82	95.98	4.09	0.04
maxT	1	2	96.79	96.82	4.93	0.03
minT* year	3	4	96.67	96.83	4.94	0.03
average day temp* year	3	4	97.72	97.88	5.99	0.02
precipitation	1	2	98.36	98.39	6.50	0.01
maxT, year	2	3	98.73	98.81	6.93	0.01
precipitation, year	2	3	100.36	100.44	8.56	0.00
maxT* year	3	4	100.56	100.72	8.84	0.00
precipitation* year	3	4	100.57	100.73	8.84	0.00