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Climate-induced seasonal activity and flight period of cerambycid beetles in the Zselic forests, Hungary

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Abstract

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The longhorn beetle fauna (Coleoptera: Cerambycidae) was studied in the Zselic region (Somogy county) in Hungary in seven consecutive years (2009–2015). In total 2,931 specimens were observed and the presence of 83 species was identified during the sampling period. The most abundant species were: *Plagionotus arcuatus* (Linnaeus, 1758) (p_i = 10.542); *Cerambyx scopoli* Füssli, 1775 (p_i = 8.359), *Dorcadion aethiops* (Scopoli, 1763) (p_i = 6.653) and *Strangalia melanura* (Redtenbacher, 1867) (p_i = 6.209). According to our examinations, individual meteorological factors, particularly temperature, directly influenced the dispersal and the activity of longhorn beetles (P = 0.038) as well as the species richness (P = 0.047), as did weather systems formation and movement of air masses, cold and warm fronts. It is also shown that the activity of the insects is influenced by daily weather conditions. The activity of arthropods was higher during warm, dry days and less pronounced during cold, wet ones coupled with high air pressure values. A conspicuous relationship was observable between the appearance of cerambycid beetles and their time period. According to the results of Principal Coordinate Analysis four major groups can be distinguished: early-flight, late spring-flight, summer-flight and late-flight species.

Keywords: abiotic factors; abundance; Cerambycidae; activity of adults; faunistic data

Longhorn beetles play a significant role in forest ecosystems through decomposition processes which are of utmost importance as they continuously release nutrients into forest soil (Pimentel et al. 1992; Martius 1997; Evans et al. 2004; Ohsawa 2008). Thus, the abundance of this species has always drawn the attention of entomologists. Consequently, numerous studies have been launched to analyse this feature of arthropod populations in various forest communities and forest ecosystems (Noguera et al. 2002; Peris-Felipo et al. 2011; Raje et al. 2012).

In Central Europe, including Hungary, the pattern of deciduous forest habitats reveals areas frequently intersected by brushwood, arable lands or settlements (Borhidi 1984; Salamon-Albert, Horváth 2008). However, in close proximity of these areas, zones occur which have regained their highly diverse natural communities subsequently upon cessation of human activities (Myers et al. 2000; Raupp et al. 2010; Heino, Alahuhta 2015). Besides, lowland rich saproxylic communities are dependent on human-maintained habitats e.g. coppice, pasture, forest etc. Since most endangered saproxylic beetles including longhorns need sun-exposed trees, abandoning the management of lowland (especially oak) forests (former pasture forest, coppices etc.) leads to decreasing the diversity of saproxylic beetles (Bense 1995; Horak et al. 2014).

The majority of xylophagous species including longhorn beetles feed mainly under the bark or in the heartwood of dead trees/dead branches of living trees; only a few species inhabit living trees and branches (Hanks 1999; Evans et al. 2004). Nevertheless, in Hungary 80% of the longhorn beetle species inhabit woody plants, whereas the remaining 20% feed on stalks and roots of herbaceous plants (Bense 1995). The females of some species must feed on high energy-content organic matter so as to become sexually mature (Hanks 1999). The diet of adult longhorn beetles is versatile: they feed on pollen, leaves, pieces of dead or fresh bark, stalks of herbaceous plants, or on wood sap and fermenting fruits.

According to Evans et al. (2004) and Paro et al. (2012), the activity of adults and the observability of these species were heavily dependent on meteorological effects bolstering observations presented in previous reports. Holdefer et al. (2014) found that relative humidity had a negative influence on the activity of longhorn beetles, whereas the daily maximum temperature positively affected most species. The results of Paro et al. (2012) showed that the occurrence of the adults of these beetles was strongly seasonal, and abundance data showed a correlation with climatic factors. According to Baselga's (2008) observations, species diversity could mostly be expounded by a temperature gradient eliciting a decreasing diversity gradient along the south-to-north axis. Additionally, some recent studies (Lacasella et al. 2015; Horák et al. 2016) have demonstrated that major factors of the presence/activity of the adults of Cerambycidae in a given area depends on the landscape structure (forest border, gap size in canopy, presence of flowers etc.).

The objectives of this study were: (*i*) to gain insight into the effects of climate conditions (temperature, precipitation, air pressure) on the activity of adult longhorn beetles, (*ii*) to provide data concerning the species abundance and taxa richness in the Zselic region (Hungary), (*iii*) to increase our knowledge about adult flight periods and phenological characteristics of these saproxylic insects.

MATERIAL AND METHODS

Study area. Samples were collected in the Zselic region of Somogy County (south-western Hungary, Fig. 1). Located in the eastern part of Somogy, the studied area extends over 9,361 ha with an average altitude of 250–300 m a.s.l. Notwithstanding that Zselic represents the most forested landscape in South-Transdanubia, some of its regions are characterised by intense anthropogenic disturbances. Its woodlands are very diverse, ranging from sub-mountainous mesophilous beech forests to dry, closed and open woodland patches. The most frequent woody habitat types of this region are alder and ash swamp woodlands, riverine ash-alder woodlands, sessile oak-hornbeam woodlands, hornbeam-beech woodlands, turkey oak-sessile oak woodlands, intermittent with hardwood forests and plantations (Salamon-Albert, Horváth 2008).

The precipitation regime of the region is sub-Mediterranean, with an annual rainfall of 730 to 760 mm. Based on average temperatures recorded throughout the year (9.8–10°C) and the low average rainfall, this region reckons among the moderately warm and moderately humid climate districts in Hungary (Bartholy et al. 2004; Csima, Horányi 2008).

Sampling. Specimens were hand-collected from plant branches and wood piles, and by using insect net and beating sheet. Sampling took place weekly (from March to August) from 2009 to 2013, with a few exceptions due to technical unfeasibility (on average 18–20 excursions per year). Sampling sites were selected according to the predominant habitat of the species: wood pile, undisturbed biocoenosis, which can be localised in and next to forest habitats. The captured specimens were killed with ethyl acetate and subsequently poured onto small patches of cotton wool placed at the bottom of small glass vials. Prepared specimens were identified by the authors via the monograph of Kaszab (1971) and Hoskovec and Rejzek (2005). The collected specimens were deposited in the insect collection of the Kaposvár University.

Applied indices and statistical methods. The data [number of individuals (n_i), relative abundance (p_i), and frequency (f), i.e. how many times that species could be found] were used to analyse the species richness.

The values of abiotic environmental factors – weekly average temperature (°C), air pressure (hPa) and total precipitation (mm), from March to August for the area included in the studies were obtained from the Kaposvár University, Hungary (http://idojaras.sic.ke.hu/). The data were analysed using regression curve estimation of the SPSS software (11.5, 2009); the observed species and individual numbers being the dependent variables while abiotic factors being the independent variables. The total effect of registered species and specimen numbers was analysed by multiple regression analysis ($P \leq 0.05$).

The data were processed by Principal Coordinate Analysis in order to find putative relationships between the activity of the longhorn beetles and time period, average temperature, precipitation and air

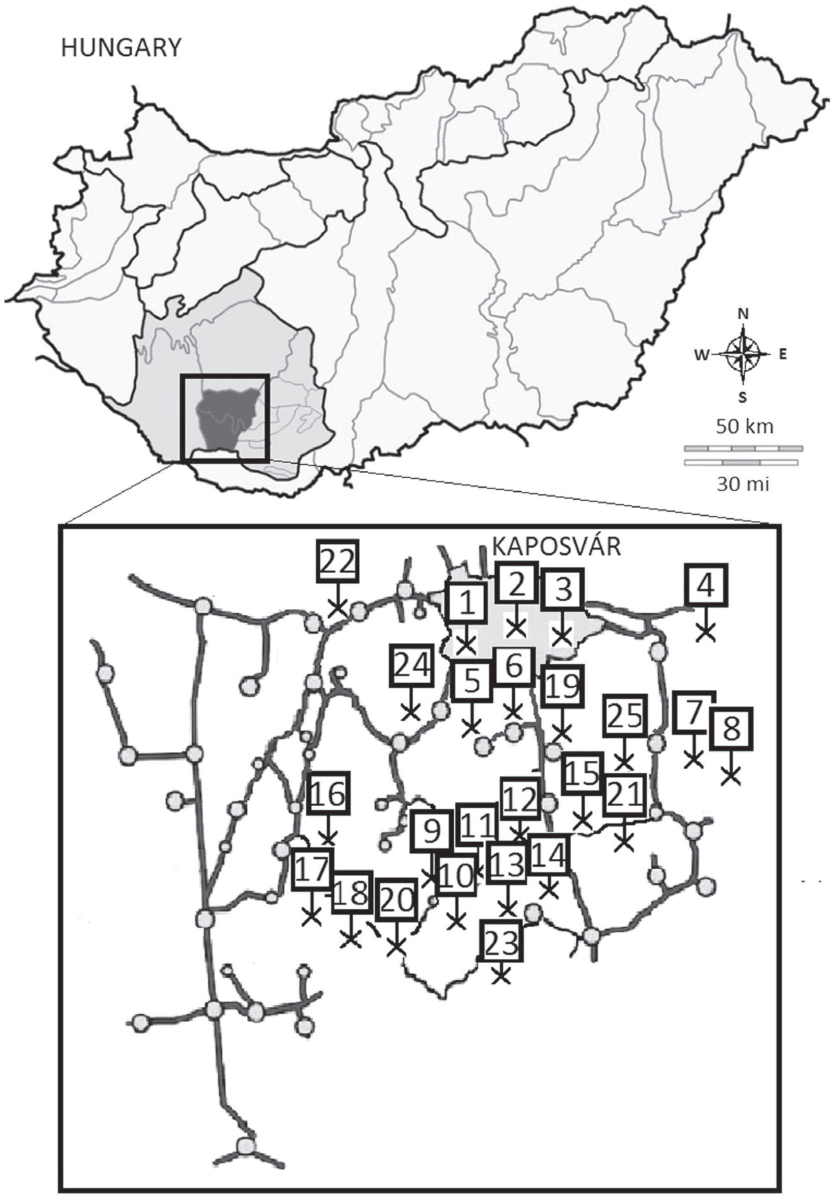

Fig. 1. The location of the geographical subregion of Zselic and macroregion of Dunántúl-hills within the subdivision of Hungary. Study sites and road networks in the Zselic region during surveys in 2009–2015

Geographical coordinates of study sites:
1: 46°21'25.30"N, 17°45'51.66"E;
2: 46°21'32.88"N, 17°48'28.37"E;
3: 46°22'08.28"N, 17°48'22.35"E;
4: 46°21'51.62"N, 17°53'50.83"E;
5: 46°17'47.97"N, 17°46'47.64"E;
6: 46°19'48.05"N, 17°47'58.62"E;
7: 46°18'45.64"N, 17°54'50.72"E;
8: 46°18'42.62"N, 17°55'09.94"E;
9: 46°15'22.54"N, 17°45'00.06"E;
10: 46°14'26.63"N, 17°46'06.82"E;
11: 46°15'14.53"N, 17°46'54.47"E;
12: 46°15'35.96"N, 17°47'53.40"E;
13: 46°15'15.41"N, 17°48'08.64"E;
14: 46°15'15.13"N, 17°49'04.30"E;
15: 46°15'55.92"N, 17°49'36.94"E;
16: 46°15'59.72"N, 17°40'50.08"E;
17: 46°19'02.26"N, 17°48'50.96"E;
18: 46°14'49.85"N, 17°41'32.28"E;
19: 46°14'19.12"N, 17°42'18.10"E;
20: 46°13'49.50"N, 17°44'06.81"E;
21: 46°22'05.27"N, 17°42'09.63"E;
22: 46°13'11.36"N, 17°47'59.97"E;
23: 46°19'47.89"N, 17°45'32.33"E;
24: 46°14'46.14"N, 17°53'31.14"E;
25: 46°17'54.20"N, 17°48'42.88"E

pressure. All basic data (average from all localities) were recorded by one-week intervals. The Principal Coordinate Analysis was implemented on the basis of Matsushita function with the NuCOSa software (Version 1.05, 1993) (Tóthmérész 1993).

RESULTS

During the seven-year period of this survey, 2,931 longhorn beetles, representing 83 species, were captured (Table 1). The most abundant species were: *Plagionotus arcuatus* (Linnaeus, 1758) with 309 specimens collected (10.54% of the total; $f = 18$), *Cerambyx scopoli* Füssli, 1775 (8.35%; $f = 29$) with 245 specimens, *Dorcadion aethiops* (Scopoli, 1763) with 195 specimens (6.65%; $f = 18$) and *Strangalia melanura* (Redtenbacher, 1867) with 182 specimens (6.26%; $f = 17$). In herbaceous habitats Pontomediterranean faunal elements occurred like *Calamobius filum* (Rossi, 1790), *Agapanthia viti* Rapuzzi & Sama, 2012 and *Theophilea subcylindricollis* Hladil, 1988. Specimens of several threatened species (IUCN) were observed such as *Morimus funereus* Mulsant, 1863, *Rosalia alpina* (Linnaeus, 1758), and *Cerambyx cerdo* Linnaeus, 1758. In addition, some dangerous pests were collected: *Pyrrhidium sanguineum* (Linnaeus, 1758), *Phymatodes testaceus* (Linnaeus, 1758), *Hylotrupes bajulus* (Linnaeus, 1758), and *Plagionotus* spp. Particularly noteworthy is the recording of an invasive longhorn beetle, *Trichoferis campestris* (Faldermann, 1835).

The influence of temperature on the activity of longhorn beetles was not significant in the linear

Table 1. List of species captured, number of individuals (n_i), relative abundance (p_i), and frequency (f)

No.	Species	n_i	$p_i \times 100$	f	No.	Species	n_i	$p_i \times 100$	f
1	*Aegosoma scrabricorne* (Scopoli, 1763)	3	0.102	3	43	*Neodorcadion bilineatum* (Germar, 1824)	21	0.716	5
2	*Agapanthia cardui* (Linnaeus, 1767)	88	3.002	18	44	*Oberea oculata* (Linnaeus, 1758)	1	0.034	1
3	*Agapanthia dahli* (Richter, 1821)	10	0.341	5	45	*Pachytodes erraticus* (Dalman, 1817)	14	0.478	6
4	*Agapanthia intermedia* Ganglbauer, 1883	3	0.102	1	46	*Pachytodes cerambyciformis* (Schrank, 1781)	69	2.354	15
5	*Agapanthia maculicornis* (Gyllenhal, 1817)	1	0.034	1	47	*Phymatodes fasciatus* (Villers, 1789)	3	0.102	3
6	*Agapanthia viti* Rapuzzi & Sama, 2012	76	2.593	14	48	*Phymatodes testaceus* (Linnaeus, 1758)	60	2.047	10
7	*Agapanthia villosoviridescens* (DeGeer, 1775)	20	0.682	8	49	*Phytoecia cylindrica* (Linnaeus, 1758)	5	0.171	4
8	*Agapanthia violacea* (Fabricius, 1775)	22	0.751	5	50	*Phytoecia icterica* (Schaller, 1783)	2	0.068	1
9	*Alosterna tabacicolor* (DeGeer, 1775)	23	0.785	5	51	*Phytoecia nigricornis* (Fabricius, 1781)	19	0.648	4
10	*Anaglyptus mysticus* (Linnaeus, 1758)	11	0.375	5	52	*Phytoecia pustulata* (Schrank, 1776)	3	0.102	2
11	*Aromia moschata* (Linnaeus, 1758)	2	0.068	2	53	*Phytoecia virgula* (Charpentier, 1825)	42	1.433	7
12	*Asemum striatum* (Linnaeus, 1758)	6	0.205	3	54	*Plagionotus arcuatus* (Linnaeus, 1758)	309	10.542	18
13	*Calamobius filum* (Rossi, 1790)	18	0.614	5	55	*Plagionotus detritus* (Linnaeus, 1758)	70	2.388	7
14	*Callidium violaceum* (Linnaeus, 1758)	10	0.341	4	56	*Plagionotus floralis* (Pallas, 1773)	36	1.228	5
15	*Callimus angulatus* (Schrank, 1789)	1	0.034	1	57	*Poecilium alni* (Linnaeus, 1767)	30	1.024	6
16	*Cerambyx cerdo* Linnaeus, 1758	10	0.341	6	58	*Pogonocherus hispidulus* (Piller & Mitterpacher, 1783)	1	0.034	1
17	*Cerambyx scopoli* Füssli, 1775	245	8.359	29	59	*Pogonocherus hispidus* (Linnaeus, 1758)	3	0.102	3
18	*Chlorophorus figuratus* (Scopoli, 1763)	11	0.375	5	60	*Prionus coriarius* (Linnaeus, 1758)	1	0.034	1
19	*Chlorophorus varius* (O.F. Müller, 1766)	54	1.842	10	61	*Pseudovadonia livida* (Fabricius, 1776)	22	0.751	6
20	*Clytus arietis* (Linnaeus, 1758)	32	1.092	14	62	*Pyrrhidium sanguineum* (Linnaeus, 1758)	86	2.934	7
21	*Cortodera humeralis* (Schaller, 1783)	2	0.068	2	63	*Rhagium inquisitor* (Linnaeus, 1758)	35	1.194	9
22	*Dinoptera collaris* (Linnaeus, 1758)	12	0.409	5	64	*Rhagium sycophanta* (Schrank, 1781)	16	0.546	5
23	*Dorcadion aethiops* (Scopoli, 1763)	195	6.653	18	65	*Rhopalopus clavipes* (Fabricius, 1775)	23	0.785	9
24	*Dorcadion fulvum* (Scopoli, 1763)	33	1.126	11	66	*Rhopalopus macropus* (Germar, 1824)	21	0.716	6
25	*Dorcadion pedestre* (Poda, 1761)	3	0.102	1	67	*Rosalia alpina* (Linnaeus, 1758)	71	2.422	13
26	*Dorcadion scopoli* (Herbst, 1784)	17	0.580	6	68	*Saperda octopunctata* (Scopoli, 1772)	20	0.682	13
27	*Exocentrus lusitanus* (Linnaeus, 1767)	6	0.205	6	69	*Saperda scalaris* (Linnaeus, 1758)	7	0.239	2
28	*Grammoptera ruficornis* (Fabricius, 1781)	95	3.241	7	70	*Spondylis buprestoides* (Linnaeus, 1758)	2	0.068	2
29	*Hylotrupes bajulus* (Linnaeus, 1758)	5	0.171	3	71	*Stenopterus rufus* (Linnaeus, 1767)	21	0.716	6
30	*Isotomus speciosus* (Schneider, 1787)	1	0.034	1	72	*Stenopterus flavicornis* Küster, 1846	1	0.034	1
31	*Lamia textor* (Linnaeus, 1758)	4	0.136	4	73	*Stenostola ferrea* (Schrank, 1776)	97	3.309	11
32	*Leiopus nebulosus* (Linnaeus, 1758)	9	0.307	8	74	*Stictoleptura scutellata* (Fabricius, 1781)	24	0.819	10
33	*Leptura aurulenta* Fabricius, 1793	2	0.068	1	75	*Strangalia bifasciata* (Müller, 1766)	10	0.341	4
34	*Leptura maculata* Poda, 1761	106	3.617	16	76	*Strangalia melanura* (Redtenbacher, 1867)	182	6.209	17
35	*Leptura rubra* (Linnaeus, 1758)	23	0.785	10	77	*Strangalia nigra* (Linnaeus) Mulsant, 1863	46	1.569	12
36	*Leptura sanguinolenta* Linnaeus, 1761	27	0.921	8	78	*Strangalia septempunctata* (Fabricius, 1793)	117	3.992	14
37	*Leptura sexguttata* Fabricius, 1775	29	0.989	7	79	*Theophilea subcylindricollis* Hladil, 1988	89	3.037	11
38	*Mesosa curculionoides* (Linnaeus, 1761)	51	1.740	13	80	*Trichoferus pallidus* (Olivier, 1790)	2	0.068	1
39	*Molorchus minor* (Linnaeus, 1758)	1	0.034	1	81	*Trichoferis campestris* (Faldermann, 1835)	1	0.034	1
40	*Monochamus sartor* (Fabricius, 1787)	2	0.068	1	82	*Xylotrechus antilope* (Schönherr, 1817)	52	1.774	9
41	*Morimus funereus* Mulsant, 1863	21	0.716	14	83	*Xylotrechus rusticus* (Linnaeus, 1758)	5	0.171	4
42	*Musaria affinis* (Harrer, 1784)	2	0.068	1					

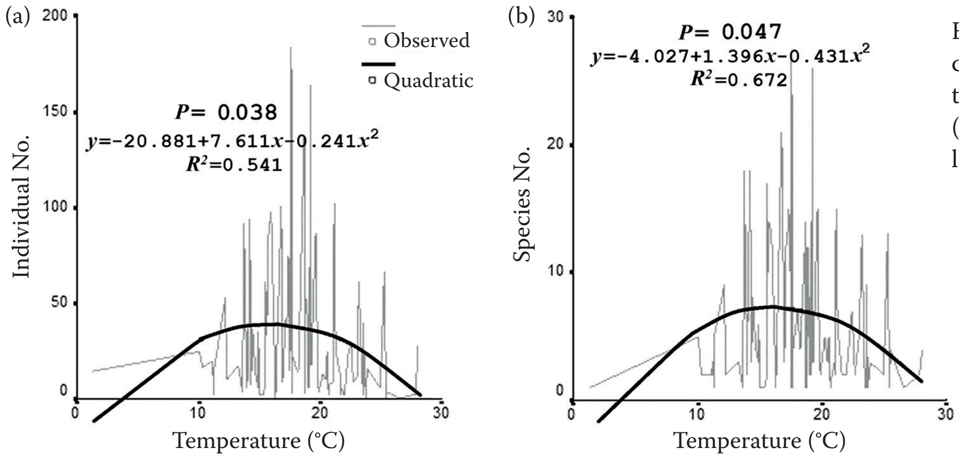

Fig. 2. Results of regression curve analysis ($P \leq 0.05$) of temperature and specimen (a), species (b) number of longhorn beetles

regression analysis. However, the polynomial regression using x and x^2 in Fig. 2 was significant for specimen (P = 0.038) and species (P = 0.047). No statistically significant correlation was observable between precipitation and air pressure.

The results of the regression analysis can be seen in Fig. 2. The numbers of the individuals and that of the species of longhorn beetles were expressed as a function of the examined abiotic factors. The presence of adults shows certain regularities, accurately e.g. an exact quadratic dispersion. Nonetheless, the statistical examination could not confirm a significant correlation between the number of observed individuals (P = 0.131)/that of species (P = 0.092) and the weekly average temperatures.

The activity of longhorn beetles started when the average temperature exceeded 10–11°C and was intensified when the average temperature reached 19–20°C and eventually decreased between 20 and 30°C. Our results showed a non-significant, negative correlation between the observed individuals/number of species and the precipitation and air pressure values. Correlation and multiple regression analyses were conducted to examine the relationship between abiotic factors and the occurrence of the observed longhorned species and specimens. The total effects of examined abiotic factors on the registered species (P = 0.415) and specimen numbers (P = 0.407) were not correlated. The period of adults' activity ranged from the fourth week of March until the second week of August. The main activity of adults spanned the second and third week of May (Fig. 3).

A conspicuous relationship was observable between the appearance of insects (which could be

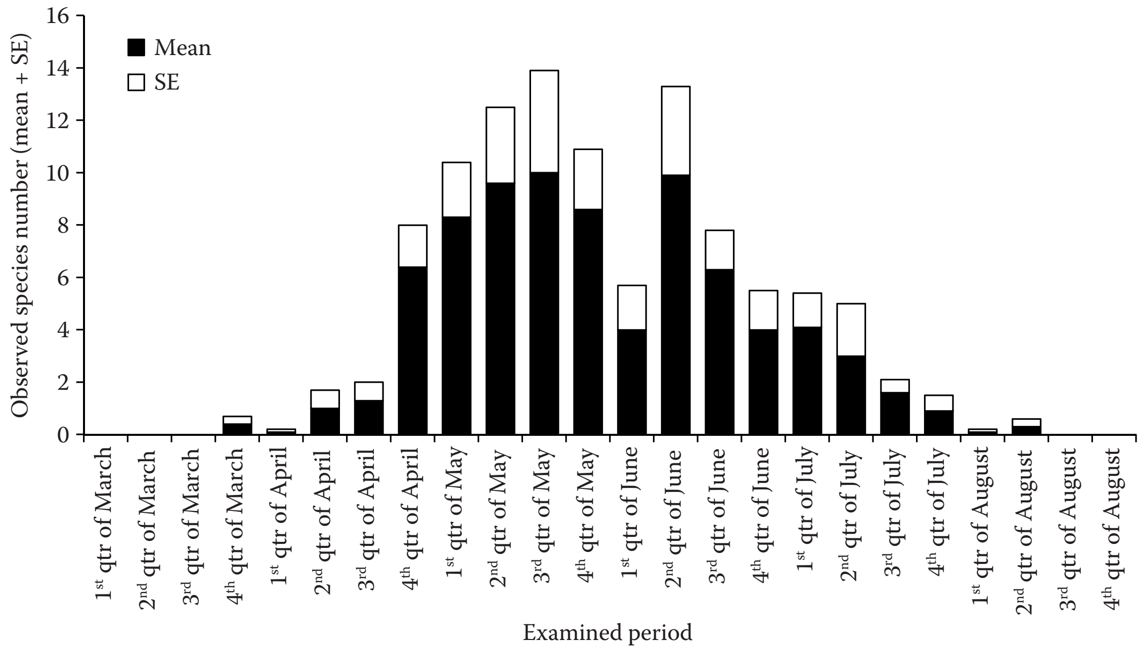

Fig. 3. Quarter (qtr) monthly observed species numbers of longhorn beetles during surveys, 2009–2015. The numbers refer to the observation occasions not specimens number

SE – standard error

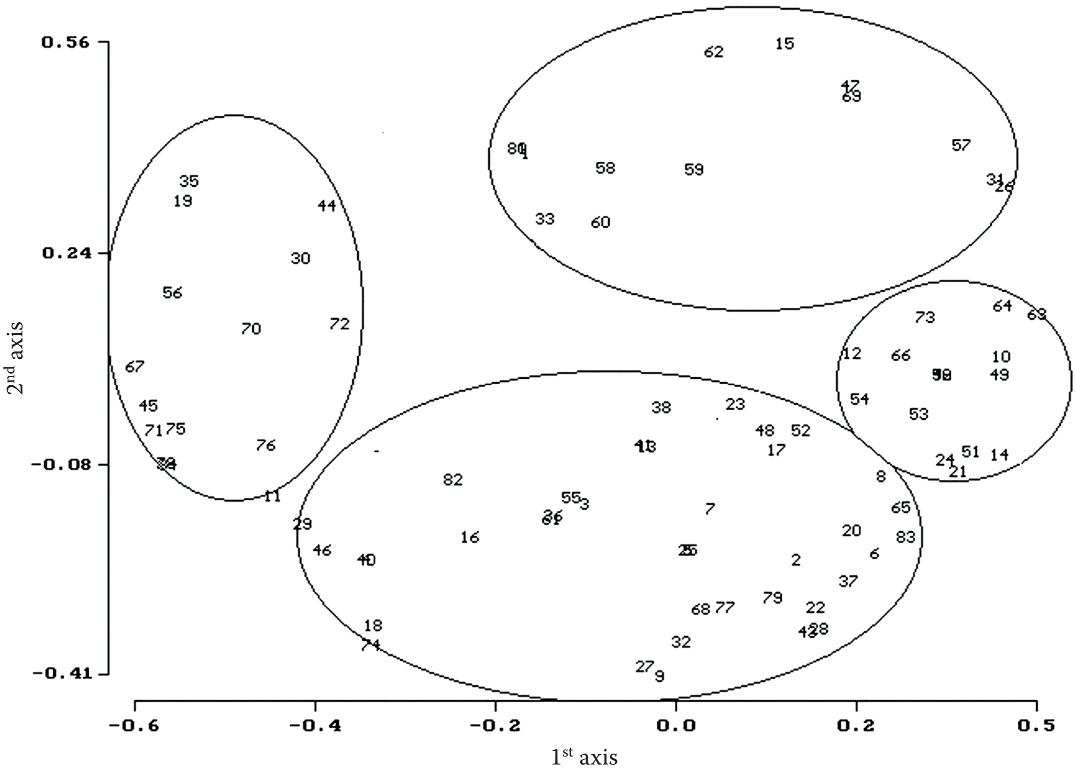

Fig. 4. Principal Coordinate Analysis of the longhorn beetle activity in one-week time periods with Matsushita function. Species represented by numbers of Table 1

divided into four major groups) and the time period examined (Fig. 4). The first group contains the early-flight species, starting with *Callimus angulatus* (Schrank, 1789), *Pogonocherus hispidulus* (Piller & Mitterpacher, 1783) and *P. sanguineum*, flying only in April, and ending with *Dorcadion scopoli* (Herbst, 1784), *Lamia textor* (Linnaeus, 1758) and *Poecilium alni* (Linnaeus, 1767), flying from the end of April until the 3rd week of May. The late spring-flight species also flocked together, starting with *Rhagium inquisitor* (Linnaeus, 1758), *Rhagium sycophanta* (Schrank, 1781), *Anaglyptus mysticus* (Linnaeus, 1758) and *Phytoecia cylindrica* (Linnaeus, 1758), flying mainly in May, and ending with *Phytoecia virgula* (Charpentier, 1825) and *Dorcadion fulvum* (Scopoli, 1763), flying from May to the 2nd week of June. The largest group contains the summer-flight species with many data of their activity between the 4th week of May and the 2nd week of July. The majority of the longhorn beetles belong to this group. Another group includes the late-flight species, starting with *Prionus coriarius* (Linnaeus, 1758) and *Aegosoma scrabricorne* Scopoli, flying only in the 1st and the 2nd week of August, respectively, and ending with *R. alpina*, *Pachytodes erraticus* (Dalman, 1817) and *Stenopterus rufus* (Linnaeus, 1767), flying from the second week of June till the end of July.

DISCUSSION

The presence of 83 species was determined during the seven-year sampling period, which constitutes 51.87% of all longhorn beetles described in the Zselic region (Kovács et al. 2001). Additionally, several rare and protected species were observed. From a faunistical point of view these rare species were observed: *Agapanthia maculicornis* (Gyllenhal, 1817), *C. filum*, *C. cerdo*, *Isotomus speciosus* (Schneider, 1787), *M. funereus*, *R. alpina*, *Saperda scalaris* (Linnaeus, 1758), *T. subcylindricollis* (Kovács et al. 2001; Merkl, Vig 2009).

The proportion of the pestiferous longhorn beetles (*P. sanguineum*, *P. testaceus*, *H. bajulus*, and *Plagionotus* spp.) is rather meaningful (18.11% of the total) (Ciesla 2011). Observation of *T. campestris* has confirmed the presence of a stable population of this alien invasive species since the first record in Hungary (Hegyessy, Kutasi 2010). According to the geographic range of these records and their temporal distribution, the species might be already established in several European countries and seemingly have been spreading fast westwards (Dascălu et al. 2013).

According to our findings individual meteorological factors, particularly temperature, directly influence the dispersal and the activity of longhorn beetles as well as the species richness, as do weather systems formation and movement of air masses, cold and warm fronts, and air flows associated with topographical features. This observation was confirmed by several related studies (McManus 1988; Baselga 2008; Khaliq et al. 2014). It was also shown that the activity of the insects is influenced by daily weather conditions. The activity (and consequently the observability) of arthropods was greater during warm dry days and less pronounced during cold and wet ones coupled with high air pressure values. Substantially, insects strove to avoid unfavourable circumstances (drying, drowning, falling down, disability) by means of inactivity. The retrogression observed in the numbers of species and that of specimens can be attributed to rising temperatures and can be explained by the diminution of the lifespan of the adults, which coincided with warmer months. These results bolster the observations made by Kaszab (1971) and Hoskovec and Rejzek (2005).

Regrettably, the lack of dead trees has significant consequences on the beetle assemblage. Saproxylic insects are strongly influenced by temperature but also they require specific dead wood features, and thus an interaction between the two factors appears likely. Observations and experimental data corroborate that an increasing temperature compensates at least partly for the lower amount of dead wood (Müller et al. 2015).

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