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Effect of black walnut (*Juglans nigra*) on the understorey vegetation – a case study of South Moravian forests (Czech Republic)

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Abstract

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The article analyses the influence of black walnut on forest phytocoenosis in South Moravian forests and assesses how its representation may affect the understorey vegetation of the forest ecosystems. In July 2014, 31 relevés were processed in the South Moravian forests. These were stands of pure black walnut (*Juglans nigra*) as well as black walnut with small-leaved lime *(Tilia cordata)*, along with neighbouring autochthonous stands (pure ash – European and narrow-leaved), oak (summer oak), or their mixtures. Ellenberg's indicator values reveal differences in the plant communities under black walnut comparing those under native tree species for the variables nitrogen, soil reaction and temperature. In addition, total cover is significantly higher under walnut. Other differences are visible from the detrended correspondence analysis ordination. The study also confirmed that in the stands of black walnut the preference of some species is suppressed, for example *Brachypodium sylvaticum* and *Poa nemoralis* in alluvial forests and *Melica uniflora* in hilly forests.

Keywords: Ellenberg's indicator values; herb layer; indigenous species; ordination; relevés

Black walnut (*Juglans nigra*) represents a very important tree species in the natural range of its distribution, where it naturally occurs on more than one half of the USA territory. It was introduced into Europe in 1629 (Herman 1987) and planted in many European countries including Great Britain, Poland, Italy, Slovakia, Moldova, Croatia, Rumania, Germany, France, Hungary, Ukraine and Russia (Garavel 1960; Seneta 1976; Ciancio et al. 1981–1982; Benčať 1982; Evans 1984; Junghietu, Bucaţel 1987; Bartsch 1989; Kulygin 1990; Sarvary 1996; Nicolescu 1998; Kremer et al. 2008). This species was primarily planted in parks and in alleys in the first half of the 19th century, and later in windbreaks in lowlands. It was also planted in forest stands for its excellent production, higher in comparison with the natives, i.e. English oak and ashes (European ash – *Fraxi-*

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nus excelsior and narrow-leaved ash – *Fraxinus angustifolia*), e.g. Šálek et al. (2012).

In the Czech territory, the first stand of the black walnut was documented in 1823 (Mráček 1925). At present this species covers about 526 ha (Hrib 2004), representing approximately 0.02% of the forest lands and 0.0067% of the country area. Although it will always represent a minor species in the Czech forests, it can considerably contribute to their production potential in specific conditions with respect to both the quantity and the quality of production (Hrib et al. 2003; Šálek et al. 2012), especially in the area of alluvial forests.

There are two potential problems connected with the introduction of the black walnut. The first is associated with its high susceptibility to many harmful biotic factors, especially in the native range, such as the fungus *Geosmithia morbida*, proliferated by the scolytid bark beetle *Pityophtorus juglandis* (Kolařík et al. 2011). Both species have been registered in Italy since 2013 (Montecchio, Faccoli 2014).

The second problem is connected with all species in the genus *Juglans* and involves allelopathic effects of juglone on other vegetation (Willis 2000). De Scisciolo et al. (1990), Willis (2000), Virginia Cooperative Extension (2001), Scott and Sullivan (2007), and Shibu and Holzmüller (2008) focused on allelopathic effects of *J. nigra* on various species of flora and fauna. It was discovered that an allelopathic effect of juglone in the stands of *J. nigra* inhibited some species, while it stimulated others – especially grasses (Virginia Cooperative Extension 2001; Shibu, Holzmüller 2008). A distinct physiognomy of vegetation in black walnut stands, compared with the undergrowth of autochthonous forests and common oak (Pedunculate oak) in South Moravian meadows, was researched by Maděra and Hrib (2002).

The aim of the present paper is to document the impact of black walnut on the state of forest phytocoenosis in South Moravia and assess to what extent the given representation may adversely affect the understorey vegetation of the forest ecosystems.

MATERIAL AND METHODS

In July 2014, 31 relevés were taken in the area of South Moravian forests (Fig. 1), including: an alluvial forest of the Jihlava river (plots marked with V), an alluvial forest of the Svratka river (plots marked with Ž), an alluvial forest of the Dyje river

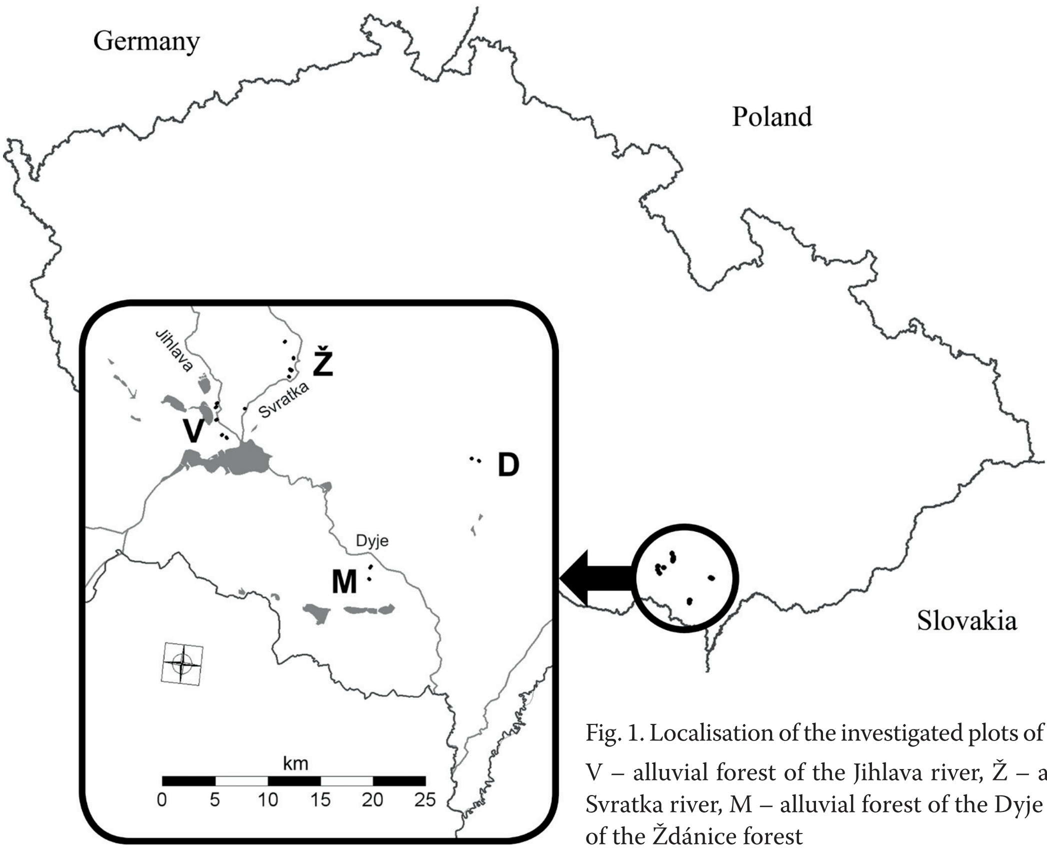

Fig. 1. Localisation of the investigated plots of V, Ž, M and D series
V – alluvial forest of the Jihlava river, Ž – alluvial forest of the Svratka river, M – alluvial forest of the Dyje river, D – hilly area of the Ždánice forest

Table 1. A survey of the species and breakdown of their occurrences on sites with dominant black walnut or oak and ashes (native trees)

	Plots		
	in total	with black walnut dominance	with oak and ash dominance
All species	90	68	59
All woody species	19	12	16
Understorey layer	69	54	42
Grasses (*Poaceae* + *Cyperaceae*)	16	12	12

(plots marked with M) and a hilly area of the Ždánice forest (plots marked with D). The areas were selected in the stands of pure black walnut, black walnut mixture with European and narrow-leaved ashes *F. excelsior* and *F. angustifolia* and black walnut and small-leaved lime – *Tilia cordata*, simultaneously with adjacent autochthonous stands (pure ash – both European and narrow-leaved ashes), oak stands (summer oak), or their mixtures (Appendices 1 and 2). For further processing, the relevés that had been the basis of the work by Maděra and Hrib (2002) were used (relevés were marked with the plot name and with "_01"), as some of the plots were examined in 2014 (names marked with "_14"), offering the opportunity for comparison.

The data were entered into the DBreleve program (Matějka 2016). Prior to a numerical analysis, the data were transformed as follows: the scale of abundance-dominance – according to Zlatník's scale (Zlatník 1978), used in the acquisition of relevés was converted to an average coverage. Different layers (moss – E_0, herb – E_1, shrub – E_2, tree – E_3) in the coverage were then transformed in order to make their sum for a respective layer equal the total layer cover. Further, the data were processed using the Ward method of classification (Ward 1963) and the TWINSPAN procedure (Hill 1979). Detrended correspondence analysis (DCA) ordinations were performed by the CANOCO program (Version 4.5, 2002) (ter Braak, Šmilauer 2002).

Cover-weighted averages of indicator values for individual plants according to Ellenberg et al. (1992) were calculated for each relevé in the DBreleve software. Differences for both years (2001 and 2014) in repetitive plots were identified.

Differences in a parameter of communities (Ellenberg's indicator values, total cover of the layer and stand age) under walnut and under native tree species were statistically tested using Monte Carlo permutation test in the DBreleve program (Matějka 2016).

The plant taxonomy was used according to Kubát (2002).

RESULTS

Table 1 showing a survey of species documents that on all 31 plots there were 90 species, out of which 19 were woody plants. In the undergrowth there were 69 species (without trees), out of which 16 were grasses. Studying the plots dominated by black walnut and the plots dominated by oak or ash trees (indigenous economic growth), it is obvious that the sites with predominant black walnut trees have fewer woody species but have a higher number of different species per stand than locations with autochthonous commercial stands (Table 1). The number of grass species remains the same.

However, at a closer look at the species composition of E_1 layer (Appendix 2), we find that the most obvious differences are in grasses. In areas with the dominant black walnut, the species of the family *Cyperaceae* (*Carex acutiformis*, *Carex digitata*, *Carex remota* and *Carex sylvatica*) either do not occur at all or have very low coverage. In contrast, grasses of the family *Poaceae* (*Brachypodium sylvaticum*, *Dactylis glomerata* and *Deschampsia caespitosa*) are significantly dominant. Another striking feature is the occurrence and sometimes dominance of the invasive species *Solidago gigantea*. Simultaneously, spontaneous hybrids of black and Persian walnuts (*J. nigra* × *Juglans regia* = *Juglans* × *intermedia)* were observed, which were described previously herein (Hrib et al. 2002).

Average Ellenberg's indicator values for environmental factors (Table 2) correspond to the localities in the Central European alluvial forests, i.e. especially habitats rich in soil nitrogen, constantly moist soils, from slightly acidic to slightly alkaline. Table 3 shows the differences in the values of these factors in plots with repeated relevés after 13 years (plots: V01–V04, V09–V12, Ž01–Ž05). It is obvious that no significant changes occurred in these plots. There is a trend towards a reduction of the content of soil nitrogen, however, based on the resulting values those are rather minor changes of possible species abundances from which the calculation was done. The only exceptions are plots

Table 2. Average Ellenberg's indicator values for relevés of all plots from 2001 and 2014. Plots are divided into groups according to the presence of black walnut (*Juglans nigra*) in the tree layer

Juglans nigra	Plot	Factor											
		continentality		light		temperature		soil					
								nitrogen		reaction		moisture	
		2001	2014	2001	2014	2001	2014	2001	2014	2001	2014	2001	2014
	V01	3.23	3.59	5.51	4.82	5.96	5.65	7.60	6.78	6.77	6.45	5.89	5.64
	V03	4.30	4.55	5.22	5.33	5.94	5.78	4.56	3.93	5.95	5.59	5.56	6.07
+	V06		4.79		7.59		6.00		7.10		6.95		6.00
	V07		3.76		5.28		5.59		6.26		6.30		5.51
	V09	3.85	4.40	4.82	5.11	5.80	5.31	5.82	5.20	6.35	5.52	5.31	5.23
	V11	3.97	3.88	4.56	5.90	5.74	5.92	5.69	5.61	6.16	6.30	5.47	5.32
	V02	3.38	3.80	4.93	4.97	5.59	5.23	8.68	8.36	6.97	6.99	6.07	6.05
	V04	3.37	3.78	5.14	5.01	5.65	5.55	8.26	8.05	6.87	6.84	5.87	5.88
	V05		3.86		5.07		5.18		8.00		7.00		5.97
	V08		3.80		5.57		5.45		6.24		6.91		5.30
	V10	3.65	3.70	4.96	5.25	5.31	5.28	7.49	7.08	7.05	7.26	5.86	6.66
	V12	3.11	3.40	4.76	5.75	5.45	5.85	7.45	8.44	6.90	6.83	5.93	5.97
	Ž01	3.96	4.17	4.76	4.78	5.66	5.97	5.95	5.80	6.37	6.06	5.28	5.50
	Ž02	3.62	3.52	4.82	4.50	5.65	5.35	7.52	7.19	7.04	6.61	5.48	5.65
	Ž04	4.48	3.78	4.91	4.97	5.56	5.77	5.77	6.57	6.10	6.25	5.29	5.60
+	Ž05	3.77	3.28	4.52	5.53	5.68	5.70	6.40	7.45	6.50	6.74	5.40	5.77
	Ž07		3.83		4.45		5.63		5.70		6.08		5.14
	Ž09		3.39		5.16		5.71		7.08		6.64		5.79
	Ž10		4.21		5.54		6.00		5.61		5.44		5.18
	Ž03	3.61	3.73	5.41	5.67	5.53	5.28	8.60	7.51	7.13	7.39	5.96	5.96
	Ž06		3.30		5.60		6.08		6.98		7.34		5.15
	Ž08		3.66		5.38		5.70		8.11		6.84		6.03
	Ž11		3.57		4.73		5.22		7.77		6.98		5.91
+	D01		4.01		4.27		5.15		7.22		7.77		5.17
	D03		3.70		3.30		5.49		6.13		6.56		5.02
	D02		3.76		4.31		5.36		6.35		7.31		4.97
	D04		3.57		3.86		5.29		6.01		6.71		4.97
+	M01		3.29		4.97		5.20		5.78		6.43		5.73
	M03		4.00		5.70		5.60		5.09		6.38		5.02
	M02		3.61		6.43		5.44		6.92		7.00		5.41
	M04		4.17		5.53		5.27		6.47		6.98		5.11

V12 and Ž05, where there is an increase in the soil nitrogen factor. However, the change is associated with increased light intensity in the undergrowth (Table 3), which would probably be associated with a change of the tree crown cover.

Significantly different are average Ellenberg's indicator values for nitrogen, soil reaction and temperature. Some differences were revealed in the total cover of herb layer (higher under walnut) and lower walnut tree age compared to the age of native tree species (Table 4).

The DCA ordination of all plots showed three very distinct ones (relevés V06_14, D03_14, D04_14). When investigating the causes – the results of species DCA ordination – it was revealed that the plot V06_14 was significantly affected by the coverage of the invasive species *S. gigantea*, while D03_14 and D04_14 plots were affected by a great coverage of the species *Melica uniflora* and *Asarum europaeum*, which either do not occur in other plots or their occurrences are negligible. For these reasons, the three above-mentioned relevés were excluded from the further DCA ordination as shown in Figs 2 and 3. The DCA (Fig. 2) shows rather differences in locations. Relevés D01_14 and D02_14 are not located in an alluvial forest, but they are found in the local hilly area. Unlike other plots found in an alluvial forest near the Jihlava and Svratka rivers, the plots of relevés M01_14 and M04_14 are in an alluvial forest of the Dyje river. Species distribution within the DCA space (Fig. 3) illustrates factors influencing positions of the plots. *Viola mirabilis*,

Table 3. Differences between the years 2014 and 2001 in Ellenberg's indicator values for plots with repeated relevés. Plots are divided into groups according to the presence of black walnut (*Juglans nigra*) in the tree layer

Juglans nigra	Plot	Differences between 2014 and 2001					
		continentality	light	temperature	soil		
					nitrogen	reaction	moisture
+	V01	0.36	–0.69	–0.31	–0.82	–0.33	–0.25
	V03	0.52	0.10	–0.16	–0.63	–0.36	0.51
	V09	0.55	0.29	–0.49	–0.62	–0.83	–0.08
	V11	–0.08	0.54	0.18	–0.07	0.15	–0.14
	Ž01	0.22	0.02	0.31	–0.15	–0.31	0.22
	Ž02	–0.10	–0.33	–0.31	–0.34	–0.43	0.18
	Ž04	–0.70	0.06	0.21	0.80	0.16	0.31
	Ž05	–0.50	**1.01**	0.02	**1.05**	0.25	0.37
	V02	0.42	0.03	–0.36	–0.34	0.02	–0.01
	V04	0.41	–0.13	–0.11	–0.21	–0.02	0.01
	V10	0.05	0.30	–0.03	–0.41	0.21	–0.20
	V12	0.29	**0.99**	0.41	**0.99**	–0.06	0.03
	Ž03	0.11	0.26	–0.25	–0.55	0.26	0.00

the most significant differences in bold

M. uniflora, *Fragaria vesca* and *C. digitata* are the species of hilly oak forests, which have higher coverage in relevés D01_14 and D02_14. In contrast, e.g. *C. acutiformis*, *F. angustifolia* and *C. remota* are the species often found in flooded meadows, which are typical of the Dyje river basin. The Svratka and Jihlava meadows are only rarely flooded and the local moisture is due to a more planar topography and higher groundwater level (Novák, Hrdina 1932).

Although there were only 13 plots where re-sampling was carried out (Table 3), from the resulting DCA (Fig. 4) it is possible to infer trends that occurred there. Based on the lengths of line segments, we can see different changes. The direction however shows that the plots V01–V04 and V09–V12 show an opposite trend to that of the plots Ž01 to Ž05. The ordination graph with the position of relevés can be interpreted by the respective graph showing the position of species (Fig. 5), suggesting that the trends are related to changes in moisture. V01–V04 and V09–V12 plots from the sites of the Jihlava river floodplain forest decreased in moisture, whereas Z01–Z05 plots in the locations of the floodplain forest of the Svratka river increased in

Table 4. Differences between the parameters of relevés from 2014 in a set of stands with and without dominance of black walnut

Parameter	Δ	*P*
Herb layer cover (%)	18.5	0.991
Age (yr)	–14.1	0.059
Ellenberg's indicator values		
Continentality	0.199	0.929
Light	–0.142	0.316
Nitrogen	–1.088	< 0.001
Soil reaction	–0.669	< 0.001
Temperature	0.195	0.973
Soil moisture	–0.105	0.219

Δ – average difference, *P* – probability of Monte Carlo permutation tests

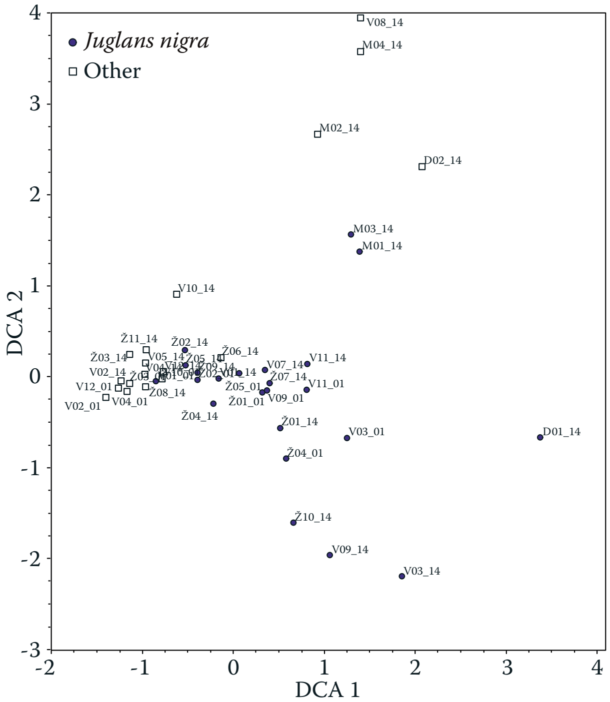

Fig. 2. Detrended correspondence analysis (DCA) ordination space with positions of all relevés (excluding the most distinct relevés V06_14, D03_14, and D04_14). Relevés with dominant *Juglans nigra* and with other species in the tree layer are distinguished, for details see Appendix 1

_01 – plots examined in 2001, _14 – plots examined in 2014

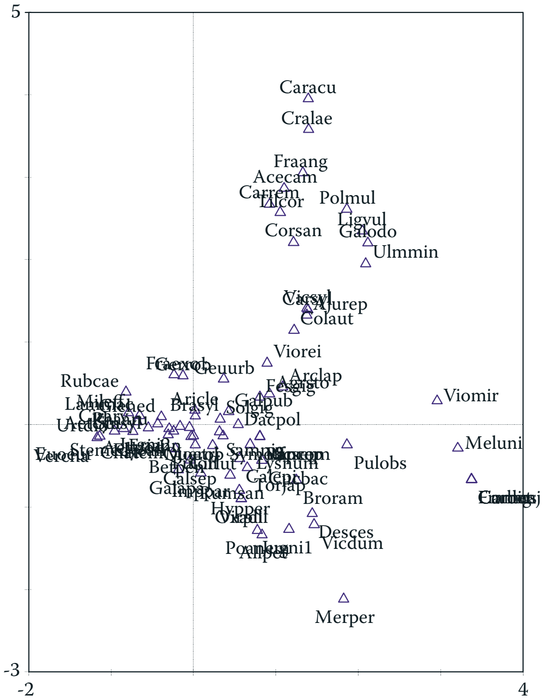

Fig. 3. Detrended correspondence analysis ordination space with positions of species (all data excluding relevés V06_14, D03_14, and D04_14), for species abbreviations see Appendices 2a and b

moisture (Table 3). The explanation is apparently related to the size of both streams while the Jihlava downstream is one of the Svratka tributaries.

The TWINSPAN classification (Fig. 6) clearly separated floodplain areas (plots V, Ž and M) from hilly areas (area D), as evidenced by the high-level division. The indicator species of the division point to the presence (and higher coverage) of *M. uniflora*, *Galium odoratum*, and *Polygonatum odoratum* (Appendix 2). The second level of the division distinguishes the floodplain habitats. In one group the defining tree landmark was the black walnut (*J. nigra*), with *Dactylis polygama*, *D. caespitosa* and *Poa nemoralis* dominant in the herb layer. The second group consisted of plots dominated by oak (*Quercus robur*), ash (*F. excelsior*) with possible co-dominance of small-leaved lime (*T. cordata*) with herbal dominants (especially *Urtica dioica*). In both the first and the second group, there were exceptions which were demonstrated during the division of the third level. In the group of the walnut, floodplain plots with the occurrence of narrow-leaved ash (*F. angustifolia*) – plot M – were separated from other plots. In the group of oak – ash – lime (*Q. robur*, *F. excelsior*, *T. cordata*), a plot with significant dominance of the invasive species *S. gigantea* in the herb layer was allocated.

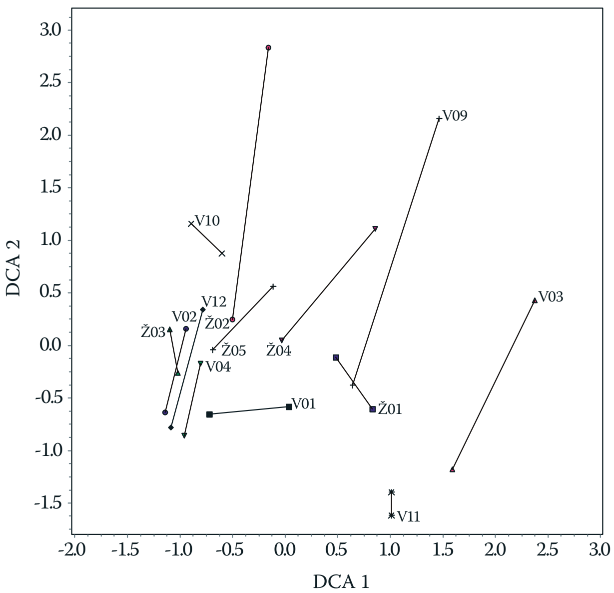

Fig. 4. Detrended correspondence analysis (DCA) ordination of plots examined in both 2001 and 2014, the solid lines show changes in ordination scores (plot marking refers to the situation in 2014), for details see Appendix 1

The Ward's dendrogram (Fig. 7) divided plots into six groups:

(*i*) Group A – plots V01_01 to Ž03_01 with the typical species combination of constant species *U. dioica*, *Galium aparine*, *Glechoma hederacea* (+ *Q. robur* in E_3);

(*ii*) Group B – plots V10_01 to Ž06_14 with the typical species combination of constant species *B. sylvaticum*, *D. polygama*, *Lamium macula-*

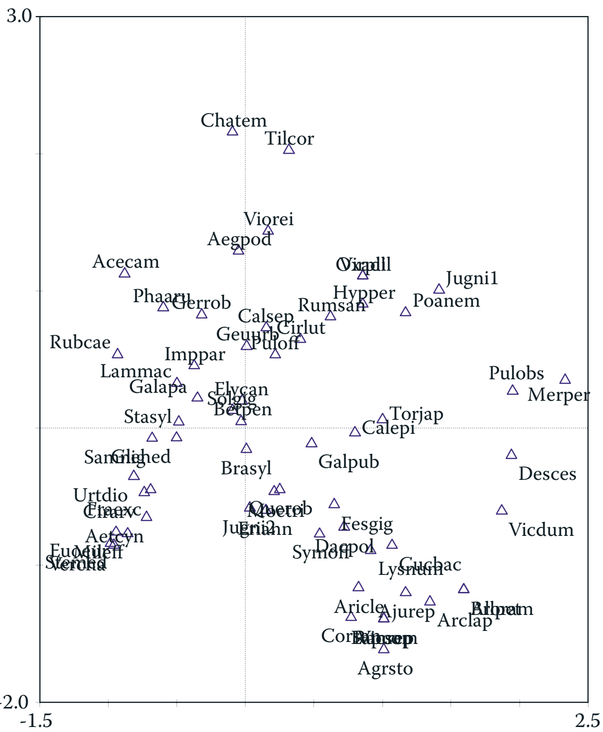

Fig. 5. Detrended correspondence analysis ordination with positions of species, data of plots examined in both 2001 and 2014, for species abbreviations see Appendices 2a and b

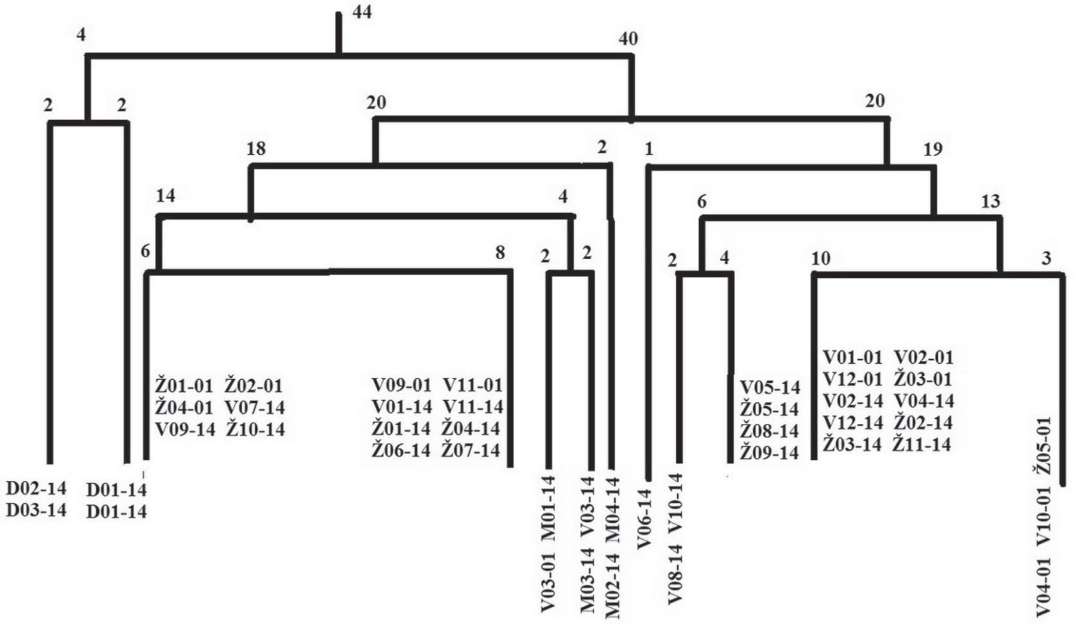

Fig. 6. The TWINSPAN classification tree (the numbers on the arms refer to the numbers of plots in the respective branch), for details see Appendix 1

-01 – plots examined in 2001, -14 – plots examined in 2014

tum, *G. hederacea*;

(*iii*) Group C – plots Ž02_01 to D04_14 with the typical species combination of constant species *B. sylvaticum*, *Geum urbanum*;

(*iv*) Group D – plots Ž04_01 to V03_14 with the typical species combination of constant species *P. nemoralis*, *D. polygama*, *J. nigra* juv.;

(*v*) Group E – plots V02_14 to V05_14 with the typical species combination of constant species *L. maculatum*, *U. dioica*;

(*vi*) Group F – plots V03_01 to V07_14 with the typical species combination of constant species *D. polygama*, *B. sylvaticum*, *Circaea lutetiana*.

DISCUSSION

As the results of mean Ellenberg's indicator values showed, the planting of the introduced black walnut species does not alter the ecological characteristics of the environment. Both the black walnut stands and the stands of autochthonous species in autochthonous forest tree stands showed similar values (Table 3). It was especially the soil factors, i.e. moisture, soil reaction and soil nitrates, which proved the most important factors for further observations. These qualitative indicators did not show any substantial changes even for the period of 13 years in areas with entries from 2001 and 2014. Changes leading to the increase in nitrate content in the two areas were apparently caused by the canopy reduction in this period (an increase in the light factor), which resulted in the increased breakdown of accumulated litter. Although Ellenberg's indicator values did not show any greater changes in the moisture of the habitat for repeatedly examined plots, DCA (Figs 4 and 5) ordinations showed a trend of moisture changes associated with different water regime of the Jihlava and Svratka rivers, which is not serious, but it is reflected by the herb layer.

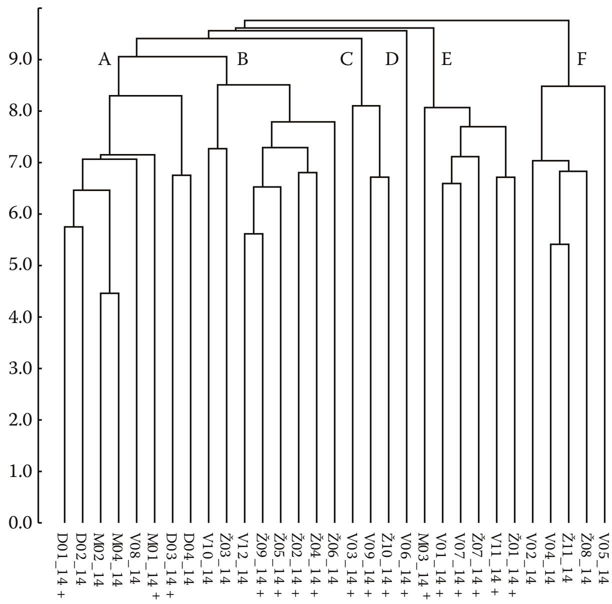

Fig. 7. The dendrogram of the Ward classification of relevés taken in 2014, relevés marked with + are dominated by black walnut in the tree layer, for details see Appendix 1

Although the black walnut is an allochthonous species (from North America), in the understorey its unmixed stands generically „copy" habitats of indigenous production forests – ground vegetation in floodplains is generically the same as in the hilly areas (Figs 2 and 3), which was shown in the study by Tokár and Kukla (2009). On the other hand, in the black walnut stands, some species of the understorey are suppressed or preferred, which is shown in the TWINSPAN classification (Fig. 6) and in detail in Appendix 2.

It shows that the pure stands of black walnut suppress the herbal character of the undergrowth, which gains a rather grassy appearance. In our case, it is mainly the species *B. sylvaticum*, *D. polygama*, and *P. nemoralis* in the alluvial forests and *M. uniflora* in the hills. This fact is fully in line with the results of an extensive publication by Willis (2000), who showed that it is the juglone secreted from the exudates of black walnut that suppresses herbaceous species at the expense of grass. Šenkýř (2015) stated that the black walnut presence increases the richness of species, but it does not favour non-native species. Light conditions are similar to local native forests, and the leaf litter of black walnut improves soil conditions by increasing the pH and calcium and phosphorus content. Composition of the herb layer under the walnut stand is significantly different from the herb layer under native tree species as can be seen in the ordination result (Fig. 2). Ecological requirements of the herb species from the walnut plantations are significantly different from those growing in nearby forests with natural species composition of the tree layer, with forest grasses such as *P. nemoralis* or *D. polygama* occurring somewhat more in meads while most of the other species are typical for hard undergrowth of floodplains. This confirms our findings that the juglone secreted from the exudates of black walnut suppresses herbaceous species at the expense of grass. Similar results were also obtained by Rietveld (1983), Dana and Lerner (1994), and Csiszár et al. (2013). It is this effect that is used in agroforestry when planting maize, i.e. grasses (Boutin et al. 2002).

If there is no extension of major pests which are already destroying stands of the black walnut in Italy, this could be an introduced species.

Appendix 1. List of the investigated plots

Plot	Latitude	Longitude	Altitude (m a.s.l.)	Exposure	Slope (°)	Stand canopy (%)	Forest site type (Viewegh 2003)
V01	48°56.358'	16°34.035'	173	flat	0	80	1L4
V02	48°56.419'	16°34.071'	173			70	1L4
V03	48°56.573'	16°34.079'	174			70	1L2
V04	48°56.596'	16°34.137'	174			75	1L4
V05	48°56.464'	16°36.315'	172			70	1L9
V06	48°56.463'	16°36.270'	172			70	1L9
V07	48°54.869'	16°35.153'	169			70	1L2
V08	48°54.920'	16°35.117'	169			80	1L2
V09	48°55.021'	16°34.761'	172			70	1L2
V10	48°54.997'	16°34.735'	172			80	1L2
V11	48°55.760'	16°34.219'	173			85	1L4
V12	48°55.719'	16°34.167'	173			85	1L4
Ž01	48°58.316'	16°39.486'	176			70	1L2
Ž02	48°58.343'	16°39.443'	176			80	1L2
Ž03	48°58.643'	16°39.576'	176			80	1L2
Ž04	48°58.675'	16°39.599'	176			70	1L2
Ž05	48°58.709'	16°39.522'	176			100	1L2
Ž06	48°58.680'	16°39.488'	176			70	1L2
Ž07	48°58.717'	16°39.453'	176			50	1L2
Ž08	48°59.271'	16°39.624'	177			80	1L2
Ž09	48°59.317'	16°39.641'	177			90	1L2
Ž10	49°00.068'	16°38.824'	178			80	1L4
Ž11	49°00.113'	16°38.852'	178			90	1L4
D01	48°55.141'	16°54.250'	300	east	5	95	2H2
D02	48°55.154'	16°54.208'	300			80	2H2
D03	48°55.073'	16°54.787'	250	south	3	95	2H2
D04	48°55.062'	16°54.830'	250		5	85	2H2
M01	48°48.490'	16°47.279'	161	flat	0	80	1L9
M02	48°48.446'	16°47.317'	161			80	1L9
M03	48°49.037'	16°47.265'	162			80	1L8
M04	48°49.121'	16°47.349'	162			85	1L9

Appendix 2a. Phytocoenological relevés in the plots of the V and Ž series, Zlatník's (1978) scale is used

	Plot																						
	V01	V03	V06	V07	V09	V11	V02	V04	V05	V08	V10	V12	Ž01	Ž02	Ž04	Ž05	Ž07	Ž09	Ž10	Ž03	Ž06	Ž08	Ž11
Tree layer (E_3)																							
Fraxinus angustifolia																							
Fraxinus excelsior										−5	−2											+3/–4	+2
Juglans nigra	+4/–5	+4	+4	+4	+4	−2							+4	−5	+4	−4	+3/–4	+5	−5				
J. nigra × *Juglans regia*	1/−2																						
Quercus robur							+4	+4/–5	+4		+4	−5								−5	+4	−3	+4
Tilia cordata									1−2					−2		−5		1/–2					
Shrub layer (E_2)																							
Acer campestre										−2	+												
F. excelsior								+3			1/–2	1/–2											+2
J. nigra		1/–2			1/–2	1/–2							–2/+2		1/–2						1/–2		
J. nigra × *J. regia*				+																			
Prunus spinosa								+															
Sambucus nigra									+2													−2	
T. cordata														+3				−3					
Herb layer (E_1)																							
A. campestre (Acecam)										−5	+2												
Aegopodium podagraria (Aegpod)	r			−2	+2	r	−2		−2	−2	+2							−2				−2	
Agrostis stolonifera (Agrsto)						−2																	
Ajuga reptans (Ajurep)		r				r																	
Alliaria petiolata (Allpet)																			+				
Arctium lappa (Arclap)				r																			
Aristolochia clematitis (Aricle)	+					−2											r		r		+3		+
Betula pendula (Betpen)															r								
Brachypodium sylvaticum (Brasyl)	−4	+		-4	1	−2		1		+2	+2	1		+4	−3	−2	+3	+2		1	−2		−2
Calamagrostis epigejos (Calepi)											r						1						
Calystegia sepium (Calsep)	r	r		r											+		r						
Carex acutiformis (Caracu)										−2													
Circaea lutetiana (Cirlut)	+			−2	+	r		+					+	r	r		r			+	1		
Cirsium arvense (Cirarv)											r						r						
Colchicum autumnale (Colaut)																			r				
Cornus sanguinea (Corsan)	+			−2		−2				+4			r	r	+								
Cucubalus baccifer (Cucbac)		+				r							r		r								
Dactylis polygama (Dacpol)	+4	−2		+4	+	+5		−2		1	1	r	−5	1	+3	+	−5	−2	−2	−2	+2		1
Deschampsia caespitosa (Desces)	−2	−5		−2		+							1										
Erigeron annuus (Eriann)	−3	+				r								+1							+1		
Euonymus europaeus (Euoeur)												r											
Festuca gigantea (Fesgig)	+							r					1										
F. excelsior (Fraexc)				1		1		−2				+	r	1			+			+	r		−3
Galeopsis pubescens (Galpub)				1															r			r	
Galium aparine (Galapa)	−2	1	+	+2	−2		1	−2				+2							+3	1		+2	
Geranium robertianum (Gerrob)		r	1							1				−2				+	+			r	
Geum urbanum (Geuurb)	1	1				+		1	+	r		r		+2		−2		1		+			+
Glechoma hederacea (Glehed)			1			−2			1		+2	−4	1	+3	−4	+4		+4	+2	+2	−4	1	−2
Hypericum perforatum (Hypper)		r		+											+		r		r				
Impatiens parviflora (Imppar)																r		+	−2	+	+		
J. nigra (Jugni1)		+2		+	+3	−2							1	+	+	1		−2	+2		1		
J. nigra × *J. regia* (Jugni2)	+																						
Lamium maculatum (Lammac)	+3		−2	+2	1	1	+5	−4	+5	−2	+3	+3	+2	−5	+3	−2	−2	+3	1	1		+4	−4
Lysimachia nummularia (Lysnum)						−3							+3				r						
Mercurialis perennis (Merper)		−2																					

Appendix 2a. to be continued

	Plot																						
	V01	V03	V06	V07	V09	V11	V02	V04	V05	V08	V10	V12	Ž01	Ž02	Ž04	Ž05	Ž07	Ž09	Ž10	Ž03	Ž06	Ž08	Ž11
Herb layer (E_1)																							
Mercurialis perennis (Merper)		−2																					
Milium effusum (Mileff)										r								r					
Phalaris arundinacea (Phaaru)				+																			
Poa nemoralis (Poanem)	+	−4		1	−5						+		+3		+3		−2		+5				
Pulmonaria obscura (Pulobs)		+								+			r		r		+				1		
Pulmonaria officinalis (Puloff)					r	+																	
Q. robur (Querob)								r															
Rubus caesius (Rubcae)										1	+4	−2	r							−5	−2/+2		−2
S. nigra (Samnig)									1							−2							
Solidago gigantea (Solgig)			+5	+3							r				+1		r						
Stachys sylvatica (Stasyl)	+2			−2	+		−2		+		r		1	1/−2	−2	+	+			−2		1	1
Stellaria media (Stemed)				1																			
Symphytum officinale (Symoff)						r																	
T. cordata (Tilcor)																		r					
Torilis japonica (Torjap)		r		+													r +					r	
Urtica dioica (Urtdio)	+3			r	r	1	−5	−4	+				−3	+2	+3	+2	−2		1	−4	+	+2	+3
Vicia dumetorum (Vicdum)		r																					
Viola reichenbachiana (Viorei)		+																	r				
Moss layer (E_0)																							
Plagiomnium affine					r																		
Thuidium tamariscinum		−2				+2																	

V – alluvial forest of the Jihlava river, Ž – alluvial forest of the Svratka river, for details see Appendix 1

Appendix 2b. Phytocoenological relevés in the plots of the D and M series, Zlatník's (1978) scale is used

	Plot							
	D01	D03	D02	D04	M01	M03	M02	M04
Tree layer (E_3)								
Fraxinus angustifolia								−5
Fraxinus excelsior				−4				
Juglans nigra	+5	+5			−5	−5		
Quercus petraea agg.			−5					
Quercus robur							−5	1/−2
Tilia cordata				+2/−3				
Shrub layer (E_2)								
Acer campestre			−3	+2				−2/+2
Carpinus betulus	−2	−2		−2				
Cornus sanguinea					+2	−4	+5	
Corylus avellana			−2					
Crataegus laevigata								+
F. excelsior			−2/+2					
J. nigra	1/−2				−2	−2		
Sambucus nigra	−2/+2		−3					
T. cordata				−2	−2	+		−2/+2
Ulmus minor	+		1/−2					

Appendix 2b. to be continued

	Plot							
	D01	D03	D02	D04	M01	M03	M02	M04
Herb layer (E_1)								
A. campestre (Acecam)	1		−3	+			1	+2
Agrostis stolonifera (Agrsto)					1			
Ailanthus altissima (Ailalt)				+				
Ajuga reptans (Ajurep)					+3	+		
Arctium lappa (Arclap)					r	r		r
Asarum europaeum (Asaeur)		+4		+3				
Brachypodium sylvaticum (Brasyl)	1	+	r	+	1	+	+	+
Carex digitata (Cardig)	r			r				
Carex remota (Carrem)							+	
Carex sylvatica (Carsyl)					+3			+
C. betulus (Carbet)	−2	+		−2				
Circaea lutetiana (Cirlut)					1	+	+	
Colchicum autumnale (Colaut)					r	+		
Convallaria majalis (Conmaj)	+							
C. sanguinea (Corsan)					−3	−4	−3	+3
C. laevigata (Cralae)								+
Dactylis polygama (Dacpol)	r			+	−2	+5		+
Deschampsia caespitosa (Desces)					−3	+	+	r
Erigeron annuus (Eriann)						r		
Festuca gigantea (Fesgig)		+	r	+	−2	+		
Fragaria moschata (Framos)	r							
Fragaria vesca (Fraves)				−2				
F. angustifolia (Fraang)					1		1	+2
F. excelsior (Fraexc)		+	−3	+3				
Galeopsis pubescens (Galpub)					+			
Galium aparine (Galapa)					1		1	
Galium odoratum (Galodo)	r		1	1				
Geranium robertianum (Gerrob)		−2				r		
Geum urbanum (Geuurb)	1	−2	−2		−2	1		−3
Glechoma hederacea (Glehed)					−2		+2	−2
Impatiens parviflora (Imppar)	+	−2	r		r	r		r
J. nigra (Jugni1)	−3	1			+			
Lamium maculatum (Lammac)					+2			1
Ligustrum vulgare (Ligvul)			1					r
Lithospermum purpurocaeruleum (Litpur)				r				
Lysimachia nummularia (Lysnum)					1			
Melica uniflora (Meluni)	1	+4	+	−4				
Milium effusum (Mileff)						r		r
Polygonatum multiflorum (Polmul)	r		r					+
Polygonatum odoratum (Polodo)				1				
Pulmonaria obscura (Pulobs)	−2	1			+			
Pulmonaria officinalis (Puloff)								+
Q. petraea agg. (Quepet)				r				
Rubus caesius (Rubcae)							1	r
S. nigra (Samnig)	−2							
Stachys sylvatica (Stasyl)	1				1			
T. cordata (Tilcor)		+		−3				−2
Torilis japonica (Torjap)								r
U. minor (Ulmmin)	+		1				+	
Urtica dioica (Urtdio)					−2			+
Vicia sylvatica (Vicsyl)					1		r	
Viola mirabilis (Viomir)	−4		−3	1				
Viola reichenbachiana (Viorei)		−2	1	+3	−2			
Moss layer (E_0)								
Plagiomnium affine					+			+
Thuidium tamariscinum					−3			

D – hilly area of the Ždánice forest, M – alluvial forest of the Dyje river, for details see Appendix 1

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