Estimating the community-level impact of the riparan alien species *Mimulus guttatus* by using a replicated BACI field experiment

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Summary

The community-level consequences of the invasion by *Mimulus guttatus* were studied. Twenty experimental plots were established in May 2006. *Mimulus guttatus* was removed from 10 plots, the remaining 10 served as control. Species composition was recorded repeatedly in the plots and the cover of all species estimated in order to identify changes following *M. guttatus* removal from the invaded community. The data were analyzed using split-plot ANOVA, DCA and RDA. The (a) square roots of species numbers (b) Shannon diversity H and (c) Shannon evenness E were used as importance values in the univariate analysis. The multivariate analysis was carried out on (a) species covers, to reveal changes in the proportions of species in the studied plots, and (b) binary data of species presence/absence to reveal the trends in species composition. Neither the univariate ($p = 0.947$, $p = 0.16$, $p = 0.12141$, DF = 3) nor multivariate ($p = 0.832$; $p = 0.986$) analysis revealed significant differrences in the community characteristics studied, following the removal of *M. guttatus*. It remains debatable whether this lack of response is due to the little or no real effect of the removal of *M. guttatus* or to the limited extent of the data. However, the control (invaded) plots had slightly higher mean number of species than treated plots, so it is very unlikely that the invasion of *M. guttatus* reduces species richness. The occurrence of *M. guttatus* in the Czech Republic is limited to sites frequently disturbed by flooding. Therefore, the occurrence of resident species seems to be constrained by the disturbance regime rather than competition with the invasive *M. guttatus*.

Key words: community composition, impact, invasive species, *Mimulus guttatus*, riparian habitats, species diversity

1. Introduction

The research on plant invasion has made a substantial progress in the past decades and has improved our knowledge of the patterns of invasion and understanding of the process (Lonsdale 1999; Rejmánek et al. 2005). Species invasivenness, community invasibility and the vectors of invasion are traditionally the keystone topics of invasion ecology. However, much attention has recently been paid to adverse effects of the invaders on resident vegetation and/or ecosytem functioning (Williamson 1998, 2001; Parker et al. 1999; Byers et al. 2002; Simberloff et al. 2003). Invasive species that change the conditions of an ecosystem over a substantial area are called transformers (Richardson et al. 2000; Davis 2003). This happens via excessive use of resources, donation of a scarce resource, fire promotion or suppression, changes in erosion dynamics and accumulation of soil or litter (Richardson et al. 2000). At the community level, suppression of native plants is associated with the invader's dominance in the community. Surprisingly,

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studies measuring the community level consequences of plant invasions are rather scarce (Tickner et al. 2001), probably due to methodological problems: long-term observations are often needed, it is rarely possible to document an ongoing invasion from the beginning and natural experiments using alien species are constrained for ethical reasons.

Mimulus guttatus DC. (Scrophulariaceae) is an invasive species in the Czech Republic (Pyšek et al. 2002). It is a perennial polycarpic plant up to 1 m tall, spreading via light wind-dispersed seeds and also by rooting of rhizomes growing from the nodes on the stem. Native to North America, the species has been present in the flora of the Central Europe since the mid-19th century. Although it was first observed in Central Bohemian basin with thermophilous flora in 1853 (Pyšek et al. 2002), it soon spread to the submontane and montane areas with cooler and wetter climate (Slavík 1997). The records made in 1868 in SW and N Bohemia can be considered the start of the invasion to montane and submontane parts of Bohemia. *Mimulus guttatus* became established in riparian habitats along montane and submontane rivers and streams with rapid disturbance regimes. High-flow events were reported to support the spread of this species and contribute to its invasion (Elderd & Doak 2006, Elderd 2003, Truscott et al. 2006). In the Czech Republic, *M. guttatus* also occurs in wet places with anthropogenic influence, e.g. wet roadsides and disturbed places in higher altitudes. Its remarkable tolerance to heavy metals, especially copper (Samecka-Cymerman & Kempers 1999), enables *M. guttatus* to colonize industrial wastegrounds and other sites with extreme soil conditions. This invasive species has not yet shown a tendency to create large populations in the Czech Republic, except for frequently flooded river terraces. Riparian habitats are dynamic systems with complex disturbance regimes (Naiman & Decamps 1997) and are generally prone to plant invasions (Planty-Tabacchi et al. 1996; Pyšek & Prach 1993). This may be why the community-level impacts of invasions have been studied in these habitats recently (Hejda & Pyšek 2006; Hulme & Bremner 2006). However, among the few studies that deal with the community-level impact of *M. guttatus* none concerns the situation in Central Europe.

2. Materials and methods

Study area

The field experiment was conducted in the southwestern part of Bohemia (the Czech Republic) along the Otava river, which flows from the Šumava Mountains in the southern part of the country. The study site was about 250 m long and 20–60 m wide, located at the stream which is the tributary of the Otava river and flooded during high-flow events in the area. Local floods in 2006 complicated the realization of the experiment by reducing the number of originally established plots. However, it is very likely that the frequent disturbances enabled *M. guttatus* to form large populations. The climatic data of the study area are: annual precipitation 599.8 mm, annual temperature 8.0 °C, January temperature –2.0 °C, June temperature 15.9 °C (Klatovy meteorological station, 30-yrs average).

Design of the experiment and data analysis

The design of the experiment followed a replicated BACI design (Crawley 2002). In the beginning of May 2006, 20 experimental plots 1 × 1 m were established in the vegetation invaded by *M. guttatus*. The seedlings of *M. guttatus* were removed from 10 plots and 10 served as control. However, high-flow events destroyed the plots in early June and the experiment had to be re-established in the recovering vegetation, when the seedlings of *M. guttatus* were 2–5 cm tall. They are easy to distinguish even at the very early stage and the subtle root system makes it possible to remove the whole plant with minimum soil disturbance.

The plots were sampled four times (10 July, 30 July, 18 August, 8 September), all species present were recorded and their percentage cover estimated.

Univariate (Crawley 2002) and multivariate (ter Braak & Šmilauer 1998) methods were used to analyse the data; (a)

Table 1: Percentage covers (mean and range, n = 10) of species recorded in experimental plots on four sampling dates (Time I: 10 July, Time II: 30 July, Time III: 18 August, Time IV: 8 September 2006). Control plots are those invaded by *Mimulus guttatus*, treated plots those from which the invader was removed. Nomenclature follows Kubát et al. (2002). Species recorded only once are not shown.

	Control				Treated			
	Time I	Time II	Time III	Time IV	Time I	Time II	Time III	Time IV
Mimulus guttatus	23.5 (10-50)	30.0 (10-60)	25.5 (5-70)	33.5 (10-70)	–	–	0.5 (0-3)	0.2 (0-2)
Petasites hybridus	8.6 (0-30)	10.0 (0-30)	16.0 (0-50)	20.2 (0-60)	25.3 (3-80)	30.5 (5-80)	34.8 (0-100)	42.5 (0-100)
Rumex obtusifolius	0.4 (0-1)	0.7 (0-3)	0.5 (0-2)	0.8 (0-3)	0.8 (0-5)	1.1 (0-2)	0.2 (0-2)	1.6 (0-10)
Phalaris arundinacea	4.9 (0-25)	4.3 (0-15)	9.5 (0-50)	9.7 (1-30)	7.8 (0-25)	7.8 (0-40)	11.2 (0-40)	7.7 (2-30)
Myosotis palustris agg.	9.9 (0-30)	13.0 (0-30)	14.1 (0-60)	8.9 (0-40)	6.4 (0-20)	6.8 (0-20)	2.8 (0-10)	6.3 (0-20)
Cardamine amara	1.5 (0-5)	0.4 (0-2)	0.6 (0-3)	1.4 (0-5)	1.3 (0-5)	2.0 (0-10)	1.0 (0-5)	2.6 (0-15)
Chaerophyllum hirsutum	–	0.1 (0-1)	–	–	1.5 (0-5)	1.5 (0-10)	0.6 (0-3)	3.7 (0-25)
Ranunculus repens	0.2 (0-2)	0.1 (0-1)	0.2 (0-2)	0.2 (0-2)	0.7 (0-5)	0.5 (0-3)	0.7 (0-3)	0.5 (0-2)
Agrostis stolonifera agg.	18.5 (0-40)	11.0 (0-40)	13.0 (0-30)	16.0 (0-15)	14.3 (0-30)	7.5 (0-15)	11.5 (0-30)	13.8 (0-50)
Angelica sylvestris	–	–	–	–	–	3.0 (0-20)	1.0 (0-5)	–
Persicaria hydropiper	0.2 (0-1)	3.8 (0-25)	3.6 (0-20)	3.5 (0-15)	0.5 (0-3)	0.9 (0-3)	0.8 (0-3)	1.4 (0-3)
Mentha longifolia	5.0 (0-50)	6.3 (0-60)	4.3 (0-40)	5.8 (0-50)	2.5 (0-15)	7.5 (0-35)	5.7 (0-50)	3.4 (0-20)
Plantago major	–	–	0.1 (0-1)	0.1 (0-1)	0.1 (0-1)	0.2 (0-2)	0.2 (0-2)	0.3 (0-2)
Lycopus europaeus	1.2 (0-5)	1.3 (0-5)	1.8 (0-10)	2.2 (0-10)	0.2 (0-2)	0.8 (0-5)	0.8 (0-5)	0.3 (0-3)
Salix fragilis	0.6 (0-3)	0.8 (0-5)	0.5 (0-3)	2.0 (0-15)	0.1 (0-1)	0.3 (0-3)	0.6 (0-3)	1.3 (0-10)
Aegopodium podagraria	0.1 (0-1)	–	–	0.4 (0-2)	–	–	–	–
Taraxacum officinale agg.	0.1 (0-1)	–	–	–	–	0.1 (0-1)	–	–
Galium aparine	–	0.1 (0-1)	–	0.3 (0-3)	–	–	–	
Urtica dioica	–	0.2 (0-2)	0.3 (0-2)	0.3 (0-2)	0.5 (0-3)	0.8 (0-3)	0.6 (0-2)	0.5 (0-2)
Festuca gigantea	–	2.1 (0-15)	4.2 (0-30)	0.6 (0-3)	-	0.4 (0-2)	2.5 (0-20)	0.5 (0-3)
Salix purpurea	–	0.1 (0-1)	–	–	1.5 (0-15)	2.5 (0-25)	0.5 (0-5)	0.1 (0-1)
Mentha aquatica	1.0 (0-10)	1.5 (0-15)	2.5 (0-25)	–	5.7 (0-30)	5.0 (0-30)	6.8 (0-60)	–
Glyceria fluitans	0.9 (0-5)	0.4 (0-3)	1.0 (0-10)	0.1 (0-1)	4.2 (0-40)	2.5 (0-25)	5.0 (0-50)	0.5 (0-5)
Poa pratensis	–	0.2 (0-2)	2.0 (0-20)	–	–	–	–	–
Deschampsia cespitosa	–	0.3 (0-3)	–	0.5 (0-5)	–	1.0 (0-10)	0.5 (0-5)	0.5 (0-5)
Symphytum officinale	0.2 (0-2)	0.8 (0-3)	0.2 (0-2)	0.2 (0-2)	–	–	–	–
Rumex conglomeratus	0.3 (0-3)	0.3 (0-3)	–	0.2 (0-2)	–	–	–	0.1 (0-1)
Epilobium sp.	–	–	–	–	0.1 (0-1)	0.1 (0-1)	–	–
Lysimachia vulgaris	0.1 (0-1)	0.3 (0-3)	0.5 (0-5)	–	–	–	–	–
Poa trivialis	–	0.5 (0-5)	–	–	–	1.0 (0-10)	–	–
Artemisia vulgaris	–	–	0.1 (0-1)	0.1 (0-1)	–	–	–	–
Salix caprea	–	–	–	–	1 (0-10)	1.5 (0-15)	1.0 (0-10)	0.5 (0-5)
Solidago canadensis	0.3 (0-3)	0.5 (0-5)	0.3 (0-3)	0.3 (0-3)	–	–	–	–
Myosoton aquaticum	–	0.3 (0-3)	–	0.3 (0-3)	–	–	–	0.4 (0-2)
Mentha arvensis	–	–	–	1.5 (0-15)	–	–	–	3.0 (0-30)

square roots of species numbers, (b) Shannon diversity index H and (c) Shannon evenness index E were used as importance values. Split-plot ANOVA (Insightful Corporation, 2001) was used to reveal the differences in species richness between treated and control plots; in this design, individual plots represented the whole-plot level. The repeated measurements factor was nested in the experimental plots as the split-plot level. Treatment and plot were fixed as well as random factors, respectively. The interaction term between "treatment" and "repeated measures within experimental plots" was of the greatest interest because it indicates possible differences in the development of vegetation following *M. guttatus* removal.

The multivariate analysis was performed in two steps: (1) with species covers to reveal possible changes in the proportions of species following *M. guttatus* removal, and (2) with species presence/absence data to reveal qualitative changes in species composition following the treatment. Before performing the direct gradient analysis (RDA) to test the interaction between the treatment and repeated measures within plots, indirect gradient analysis (DCA) was used to reveal the main gradient in the data. This served as a basis for the decision whether to use a linear or unimodal model. Again, the interaction term between "treatment" and "repeated measures within plots" was used to reveal changes in species abundances and composition following the removal of *M. guttatus*. The terms "experimental plot" and "repeated measures within experimental plots" were included in the model as covariables. The significance of the model was tested using a Monte Carlo permutation test. *Mimulus guttatus* was excluded from all the analyses.

3. Results

In addition to *M. guttatus*, 43 species were recorded in treated and control plots (Tab. 1). Control plots with *M. guttatus* harboured 35 species, while the treated plots from which the invader was removed contained 31 species. The mean cover of *M. guttatus* in control plots was 28.1 % (range 5–70 %).

The plots with *M. guttatus* had slightly higher mean species numbers than treated plots at all sampling times (Fig. 1) but also a higher variation (mean coefficient of variation for four sampling dates was

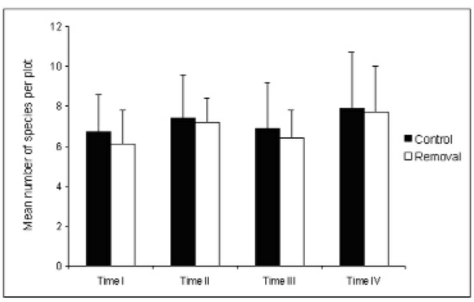

Fig. 1: Mean numbers of species (± S.D., n = 10) as recorded on four sampling dates at control plots invaded by *Mimulus guttatus* and removal plots from which the invader was removed.

Table 2: Summary table of multivariate analyses. The percentage of variability explained by the first (canonical) axis is attributable to the tested factor (treatment × repeated measures within plots interaction), the percentage of variability explained by the second (noncanonical) axis to the longest gradient in the data, independent of the tested factor. Sampling dates were Time I: 10 July, Time II: 30 July, Time III: 18 August, Time IV: 8 September 2006.

Data	**% variability explained**		**F-ratio**	**P-value**
	1st axis	2nd axis		
Species covers	0.9	24.2	0.537	0.832
Presence/absence	0.8	11.8	0.49	0.986

Table 3: Shannon diversity H and evenness E (mean ± S. D.). "Treated" plots are those from which *Mimulus guttatus* was removed, "control" plots were not subjected to any treatment and contained invading *M. guttatus*. (Time I: 10 July, Time II: 30 July, Time III: 18 August, Time IV: 8 September 2006).

	Time I	Time II	Time III	Time IV
Diversity (control)	1.3874 ± 0.2968	1.4833 ± 0.3788	1.2938 ± 0.4186	1.3239 ± 0.4335
Diversity (treated)	1.4294 ± 0.2813	1.5377 ± 0.3078	1.2905 ± 0.4189	1.3491 ± 0.4464
Evenness (control)	0.7471 ± 0.1136	0.7795 ± 0.1345	0.6900 ± 0.1360	0.6599 ± 0.1778
Evenness (treated)	0.7637 ± 0.0948	0.7940 ± 0.1087	0.6827 ± 0.1369	0.6704 ± 0.1763

31.7 % and 24.1 % for the control and treated plots, respectively). The difference in species numbers between treated and control plots was not significant, as indicated by the non-significant interaction between the treatment and repeated measures within plots (repeated measures split –plot ANOVA, $F = 0.122$, $P = 0.947$, $df = 3$). Shannon diversity H and evenness E (Tab. 3) were higher in control than in treated plots, but the difference was not significant ($F = 1.7808$, $p = 0.161$, $df = 3$ and $F = 2.0240$, $p = 0.121$, $df = 3$ respectively).

The indirect gradient analysis (DCA) exhibited a gradient of 3.047 for species covers and 2.784 for presence/absence data, indicating that the linear model (RDA) was appropriate for both measures of species occurrence. The interaction of treatment and repeated measures within plots was non-significant ($P = 0.832$ and 0.986 for cover and presence/absence data, respectively) (Tab. 2).

Discussion

In studies on the impact of invasive alien plants on species diversity of resident vegetation non-significant results need to be interpreted with caution, because of uncertainties over whether the effect is objectively absent or caused by the low number of observations, i.e. a lack in the level of freedom. In any case, our data suggest that, under given circumstances, the invasion by *M. guttatus* does not reduce the species richness of resident riparian communities. If there is any effect on species richness attributable to this invasion, it is rather a slight increase in species numbers (Fig. 1). The higher total number of species recorded in the plots with *M. guttatus* also suggests a higher beta-diversity of invaded vegetation compared to vegetation without invader.

Multivariate analyses yielded the same conclusion, i.e. that *M. guttatus* exerts substantial effects neither on relative species covers nor on species composition (Tab. 2). The markedly lower percentage of variation explained by the canonical rather than the non-canonical axis shows that there is a more important gradient in the data independent of the presence of *M. guttatus*, which could be the intensity of disturbances or the distance from the water, which are obviously strongly correlated.

These results clearly show that the effect of *M. guttatus* invasion on resident communities in our study system is minor. The study site is regularly flooded so the disturbance regime is very likely to limit the occurrence of plant species more seriously than the invasion by *M. guttatus*. The total cover in our experimental plots rarely reached 100%, which suggests that competition is unlikely to be the factor limiting diversity. Although the trend towards increased species numbers following the invasion turned out to be nonsignificant in our study, a similar situation was reported from NE Germany, where the stands of the alien invader *Pseudotsuga menziesii* harboured more species than native beech forests with *Fagus sylvatica* (Budde & Schmidt 2005). In another study, *Impatiens glandulifera*, invading riparian habitats in the temperate zone of Europe, was also shown to have very little impact on the characteristics of invaded communities (Hejda & Pyšek 2006), but the same species exerted a more serious impact on species richness in the United Kingdom (Hulme & Bremner 2006). It is likely that the minor effect of the invader on species richness and composition typically occurs when the diversity of the resident community is limited by other factors than invasion, be it rapid disturbances, such as in communities with *Mimulus guttatus*, or the presence of native tall and competitively strong species, as in communities with *Impatiens glandulifera* (Hejda & Pyšek 2006). These examples indicate that negligible impact of invasive alien species on the diversity of resident vegetation may be more common that previously thought.

The results of the present study should not be over-generalized. The population in our experimental site was the largest that we were able to find in the Czech Republic. It is possible that severe disturbances at this site provided *M. guttatus* with a competitive advantage and enabled this species to create a large population. Other populations of *M. gutattus* in the SW, N and central Bohemia are smaller than the one sampled in this study. This indicates that under the climatic regime of the Czech Republic, *M. guttatus* is not competitively superior to other species unless the community is exposed to severe disturbances. However, the effect of this invasion on riparian communities might be more serious in different regions and different resident communities.

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