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9. Impact of *Heracleum mantegazzianum* on invaded vegetation and human activities

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9.1 Introduction

Heracleum mantegazzianum Sommier & Levier is a monocarpic perennial tall forb of the *Apiaceae* family. Originating from the Western Greater Caucasus, the species was introduced to European botanic gardens in the nineteenth century and subsequently dispersed widely as an ornamental plant (see Jahodová *et al*., Chapter 1, this volume; Pyšek, 1991). Since its introduction, *H. mantegazzianum* has repeatedly escaped cultivation and during the second half of the twentieth century its incidence increased greatly in several European countries (Pyšek 1991, 1994; Ochsmann, 1996; Tiley *et al.* 1996; Wade *et al.* 1997). Stands of *H. mantegazzianum* can rapidly become dominant in particularly suitable habitats (see Thiele *et al*., Chapter 8, this volume). Therefore, *H. mantegazzianum* is commonly regarded as a hazardous invasive species (see Pyšek *et al*., Chapter 19, this volume).

Our results presented in this chapter are based on field studies in 20 study areas (1 km² landscape sections) in Germany. Data records from study areas included inventories of *H. mantegazzianum* stands in the field and mapping of all suitable habitats, whether invaded by *H. mantegazzianum* or not, based on aerial photographs.

9.2 Which habitat patches are most likely to become invaded?

A trivial prerequisite for invasion is that habitats are suitable for the invasive species. However, even in suitable habitats the probability of invasion of particular habitat patches is not equal. A logistic regression used to analyse which predictors determine whether *H. mantegazzianum* occurs in a habitat patch or not showed that the probability of invasion is determined by both local and landscape factors (Table 9.1).

Firstly, occurrences of *H. mantegazzianum* are spatially auto-correlated, i.e. habitat patches adjacent to invaded sites have an increased probability of invasion due to local seed dispersal. Furthermore, the vegetation structure of habitats affects the probability of invasion. Specifically, woody habitats (i.e. > 10% tree or shrub cover) have a lower probability of being invaded than completely herbaceous ones. On the one hand, this effect may be directly caused by shading, which reduces the amount of suitable habitat for recruitment and growth but, on the other hand, it may also be attributable to low disturbance intensities in these woody habitats, accompanied by increased competition from other tall herbs. Furthermore, large areas and elongated shapes of habitat patches increase the chance of *H. mantegazzianum* seeds being spread to them and, thus, the probability of invasion.

At the landscape scale, distances from transport corridors for *H. mantegazzianum* seeds (rivers, roads) and the connectivity of habitat patches have a marked effect on the probability of establishment. Probability of establishment decreases with increasing distance from rivers and road corridors. With regard to road corridors, only agricultural roads (including dirt tracks) had a significant effect in our logistic regression model, while the effect of large roads (including highways) was not significant. This might be due to greater maintenance effort (e.g. mowing twice a year) on verges of large roads compared to agricultural roads. Finally, the probability of invasion increases with habitat connectivity, which we assessed using the area-informed proximity index of McGarigal and Marks (1995) with a search radius of 100 m.

9.3 Impact on local plant communities

As described by Thiele *et al*. (Chapter 8, this volume) *H. mantegazzianum* stands have cover varying from 1 to almost 100%. While it can be assumed that a low cover percentage of *H. mantegazzianum* will not affect native plant communities substantially, a high cover percentage can be expected to lead to far-reaching alterations. These alterations concern the vegetation structure, abundance of resident species, and floristic composition. If *H. mantegazzianum* becomes established in vegetation types with a relatively low-growing herb layer, such as grasslands or ruderal pioneer vegetation, it introduces a new vegetation layers (tall-herb layer) above the resident herbs and grasses. This leads to shading of the resident herb layer, which increases with increasing cover of *H. mantegazzianum* or other colonizing tall herbs. When *H. mantegazzianum* attains high cover percentages the cover of other co-occurring plant species is constrained to low percentages. This affects low-growing herb species and grasses, e.g. *Ranunculus repens* L. and *Holcus lanatus* L., as well as tall-herb species, such as *Urtica dioica* L. and *Aegopodium podagraria* L. (see Thiele *et al*., Chapter 8, this volume).

High cover percentages of *H. mantegazzianum* can also decrease the number of vascular plant species per unit area. An analysis of 202 sampling plots (25 m²) with *H. mantegazzianum* from 20 study areas in Germany revealed a negative relationship between *H. mantegazzianum* cover percentage and number of vascular plant species (Fig. 9.1). Regression of species numbers on *H. mantegazzianum* cover percentage yielded a significant negative slope estimate of $b = -0.083$ ($P < 0.001$). This suggests that increasing *H. mantegazzianum* cover generally reduces resident species richness. However, significant regression slopes do not unambiguously imply a unilateral causal relationship between species numbers and *H. mantegazzianum* cover. In order to thoroughly assess impacts of *H. mantegazzianum* on plant species diversity it is necessary to distinguish different community types and to consider mechanisms of impact.

Species numbers differed between community types (ANOVA: $P < 0.001$). In particular, tall-herb communities (14.3 ± 6.1; $n = 78$) had lower species numbers than the other open community types, managed grasslands (24.5 ± 8.5; $n = 36$), ruderal grasslands (22.1 ± 9.1; $n = 53$) and ‘other’ open vegetation types (22.1 ± 9.1; $n = 16$; Tukey HSD tests: $P < 0.005$). In order to evaluate the relative importance of community type and *H. mantegazzianum* cover percentage for species numbers we applied a Generalized Linear

Model (Table 9.2). The model revealed a highly significant effect of community type ($P < 0.001$) while cover percentage of *H. mantegazzianum* had less significance ($P = 0.02$). Parameter estimates predicted that the number of species was reduced by 4.8 in tall-herb communities compared to the average and that an increase in *H. mantegazzianum* cover by 50 percentage points decreased the number of species by 2.4.

Separate regression analyses (Table 9.3) showed almost no significant relationships between *H. mantegazzianum* cover percentage and species numbers within particular community types. Marginal *P*-values were found for ruderal grasslands ($P = 0.06$) and ‘other’ community types (p = 0.04), which mostly comprised ruderal pioneer vegetation on disturbed ground (for definitions of community types see chapter 8). Similarly, comparing species numbers of open and dominant stands (> 50% cover) of *H. mantegazzianum* (Fig. 9.2) we found a marginally significant lower species richness in dominant stands for ruderal grasslands (Mann-Whitney U-test: $P < 0.05$) while no significant differences could be found for the remaining community types (Fig 9.3). Thus, negative trends in species numbers due to *H. mantegazzianum* cover were confined to ruderal grasslands and, presumably, ‘other’ open community types.

The main mechanism by which *H. mantegazzianum* can outcompete other plant species is shading out lower-growing species. *Heracleum mantegazzianum* efficiently places its leaves above resident herbs and grasses by extending its leaf stalks just as far as necessary (the emergent strategy of Hüls (2005)). Therefore, it is plausible that high cover percentages of *H. mantegazzianum* suppress or exclude light-demanding grasses and herbs in irregularly maintained or abandoned (i.e. ruderal) grasslands and in pioneer communities on disturbed grounds (community type ‘other’). In contrast, *H. mantegazzianum* does not significantly reduce species numbers in managed grasslands, tall-herb communities, and woodlands, i.e. where it is constrained by management or shading or where other tall-herbs are present.

Pyšek and Pyšek (1995) found significant differences in number of vascular plant species between uninvaded vegetation and dominant stands of *H. mantegazzianum*. This is in agreement with results from our plots in Germany, where species numbers of tall-herb communities, regardless of *H. mantegazzianum* cover, were considerably lower than in other community types. Altogether, it can be stated that community type corresponding to different successional stages (see Thiele *et al*., Chapter 8, this volume) is the key factor for species numbers while *H. mantegazzianum* cover percentage affects species numbers only in comparatively early successional stages of vegetation (ruderal grasslands, ruderal pioneer vegetation). A similar reduction in species numbers of herbaceous vegetation stands in the course of succession after abandonment of land-use or large-scale disturbance has also been observed in other studies of uncontrolled secondary successions in native vegetation (Schmidt, 1981; Neuhäusl & Neuhäuslová-Novotná, 1985; Meiners *et al.*, 2001).

In conclusion, the negative relationship between *H. mantegazzianum* cover percentage and number of vascular plant species per unit area is attributable to generally decreasing species numbers in the course of succession from low-growing and light-demanding vegetation types towards tall-herb stands and, finally, woodlands. This reduction in species numbers is mediated by native tall herbs as well as *H. mantegazzianum* or other neophytes. Thus, loss of plant species diversity in such cases is a general symptom of successional changes rather than a particular effect of invasive species.

9.4 Impact on regional flora

The assumed impacts of invasive plant species that attain high cover in indigenous vegetation are suppression and, possibly, local exclusion of native plant species. On the regional scale, a dominant plant invader could cause a decline of regional populations of native species. To make a native species endangered, in the sense of a high risk of regional extinction, would require that the invasive species dominates a large proportion of the habitat area of a particular indigenous population. Thus, since fairly common species normally co-occur with *H. mantegazzianum* (see Thiele *et al.*, Chapter 8, this volume), they would only be regionally endangered if the invader (i) attains high rates of habitat occupancy (i.e. percentage of suitable habitat patches invaded), (ii) builds up extensive stands, and (iii) commonly attains dominance which would, altogether, result in a (iv) high habitat saturation, i.e. percentage of total habitat area covered by the invader (Pyšek and Pyšek, 1995).

To assess the impact of *H. mantegazzianum* on regional flora, the current stage of invasion was surveyed in 20 study areas representing the most heavily invaded landscapes in Germany (Thiele and Otte, 2006a). For this purpose, all habitat types in which *H. mantegazzianum* was found during our field surveys were considered to be suitable habitats. After the field surveys, we mapped patches of suitable habitats from aerial photographs and calculated area sums for each habitat type in a GIS. *Heracleum mantegazzianum* was present in 15.9% of suitable habitat patches, while extensive stands (> 25 m²) occurred in 11.8% of all suitable habitat patches. Dominant stands (with > 50% cover of *H. mantegazzianum*) represented 36% of these extensive stands.

The resulting habitat saturation and invasion extent of *H. mantegazzianum* stands are presented in Table 9.4 for each habitat type separately. Habitat saturation is the percentage of total suitable habitat area covered by *H. mantegazzianum* plants, while invasion extent is the percentage of habitat area invaded by *H. mantegazzianum* stands. The area invaded by *H. mantegazzianum* stands may be considerably larger than the area covered by individual plants, depending on the cover percentage of *H. mantegazzianum* stands. The highest value of habitat saturation was 8.7%, found in abandoned grasslands, neglected grassland and field margins and tall-herb stands, followed by open (i.e. tree- and shrubless) railway margins (4.2%), open riverbanks (2.8%), ruderal areas (2.8%), and open roadsides (1.6%; Table 9.4). The ranking of habitat types was quite similar for invasion extent. The highest value was 18.5%, again found in abandoned grasslands, neglected margins and tall-herb stands. By far the largest proportions of habitat saturation and invasion extent were attributable to extensive stands of *H. mantegazzianum* (>25 m²) whereas the contribution of point-like (< 25 m²) and linear (narrower than 1 m) stands was generally negligible except for open roadsides where about 40% of the invaded area were attributable to these stand types.

Altogether, the current invasion extent and habitat saturation of *H. mantegazzianum* in the most heavily invaded landscapes of Germany were moderate for most habitat types. In its most preferred habitats, i.e. abandoned grasslands, neglected grassland and field margins, and tall-herb stands, *H. mantegazzianum* covers roughly 10% of the available habitat area. Impacts include local alteration of the vegetation structure, exclusion of light-demanding herbs from ruderal grasslands and pioneer communities on disturbed grounds, and reduction of abundance of native tall-herb species. As species that co-occur with *H. mantegazzianum* are generally widespread and abundant, it appears that regional populations of associated plant species have not been endangered at the current level of invasion. However, the invasion pattern of *H. mantegazzianum* in the study areas is merely a snapshot and does not provide a way to predict future development.

9.5 Other environmental impacts

In addition to impact on plant communities and populations, dense stands of *H. mantegazzianum* can lead to riverbank erosion. This is mediated through the suppression or exclusion of native species, which play an important role in riverbank stabilization (Caffrey, 1999). When *H. mantegazzianum* plants in dense stands die off in winter they leave behind bare soil that can be eroded by rainfall or winter floods (Williamson and Forbes, 1982; Tiley and Philp, 1994). Deposition of eroded silt can alter substrate characteristics in rivers and, for example, render gravel substrates unsuitable for salmonid spawning (Caffrey, 1999).

9.6 Potential for conflicts with nature conservation

In a Germany-wide questionnaire survey addressed to district nature conservation authorities (Thiele and Otte, 2006a), *H. mantegazzianum* was quite frequently reported to occur in nature reserves and even plant communities of conservation concern. However, no rare habitats, communities, or co-occurring plant species were found associated with *H. mantegazzianum* during our field studies in Germany. Furthermore, analysis of preferred site conditions showed that *H. mantegazzianum* is barely capable of invading sites offering suitable conditions (drought, wetness, poor nutrient status) for rare species and communities and, if so, *H. mantegazzianum* would be constrained to low abundances (Thiele and Otte, 2006b). Therefore, it seems that *H. mantegazzianum* cannot endanger plant communities and plant species of concern for nature conservation.

Explanations for reports of *H. mantegazzianum* in protected plant communities may be found in the details of spatial arrangement alongside environmental gradients. Given steep gradients (e.g. soil moisture), *H. mantegazzianum* might occur in the vicinity of protected communities, which might be misinterpreted as impending invasion. An example could be observed by comparing a report by nature conservation authorities with a case study of a nature reserve (Schepker, 1998). The authorities stated that *H. mantegazzianum* occurred within protected habitat types (calcareous marsh, acidic marsh, and salt meadows) whereas the case study showed that *H. mantegazzianum* was growing close to these plant communities but not within them.

However, in a few cases *H. mantegazzianum* was found at sites that formerly featured protected community types (e.g. nutrient-poor chalk grassland) but these sites had degenerated due to abandonment of appropriate management, eutrophication or other reasons. In such situations *H. mantegazzianum* is not the cause, but is rather a symptom of human-caused habitat deterioration. In conclusion, we would argue that *H. mantegazzianum* does not seriously conflict with the aims of nature conservation.

9.7 Impact on human health and activities

A particular impact on human health is photo-dermatitis elicited by furanocoumarins in the sap of *H. mantegazzianum* (e.g. Drever and Hunter, 1970; Lagey *et al.*, 1995; Jaspersen-Schip *et al.*, 1996; Wade *et al.*, 1997; Hattendorf *et al.*, Chapter 13, this volume). Photo-dermatitis occurs 24–48 hours after physical contact of skin with the sap of *H. mantegazzianum* when the skin is exposed to sunlight (UV light). The sap remains phototoxic for some hours after plants have been cut (Wade *et al.*, 1997). Symptoms of *H. mantegazzianum* dermatitis include mild to severe erythematous reactions (red colouring of the skin) with or without painful blisters depending on the quantities of sap and UV light received by the skin. Hyper-pigmentation of burned parts of the skin occurs within 3–5 days of contact and may persist for months or years.

To prevent photo-dermatitis it is advisable to avoid any contact with *H. mantegazzianum*. In cases where this is not possible people should wear appropriate clothing, which does not leave skin exposed. During management measures (cutting etc.), long-sleeved shirts, trousers, closed footwear, gloves and face-protecting devices should be used. If the skin comes in contact with the sap it should be thoroughly rinsed with water immediately. The sap will also remain toxic on exposed clothes for some hours, so these should be handled with caution.

Heracleum mantegazzianum can also have implications for recreational and economic human interests by restricting public access to sites such as riverbanks, amenity areas, and trails or paths (Williamson and Forbes, 1982; Lundström, 1984; Tiley and Philp, 1994) and thus can affect various interest groups. For example, obstruction of lake shores and riverbanks by stands of *H. mantegazzianum* affects anglers, water sportsenthusiasts, swimmers, bird watchers, hikers and those working along river systems (Wade *et al.*, 1997).

9.8 Economic impact

In a pilot study on economic implications of invasive species in Europe, Reinhardt *et al.* (2003) estimated annual costs of *H. mantegazzianum* in Germany based on several surveys that were extrapolated to the whole country. According to their estimates, accumulated annual costs of *H. mantegazzianum* amounted to 12.313.000 € which were distributed among the sectors health system (1.050.000 €), nature reserves (1.170.000 €), road management (2.340.000 €), municipal management (2.100.000 €), and district management (5.600.000 €).

9.9 Conclusions

Local impacts of *H. mantegazzianum* concern the vegetation structure, cover of resident plant species, and species composition of invaded plant communities. Impacts are especially marked in ruderal grasslands and ruderal pioneer vegetation. *Heracleum mantegazzianum* excludes typical plant species of these community types and reduces the local species richness in the course of succession towards tall herb communities. In tall-herb communities, high cover of *H. mantegazzianum* restricts the abundance of native species. However, a further reduction of species richness was not observed for tall-herb communities.

Impacts on plant communities and local plant species richness are largely driven by successional changes following abandonment of land-use or after large-scale disturbances. In the course of succession, competitive native tall herbs, such as *Urtica dioica*, have similar impacts on resident vegetation. Therefore, these impacts could be seen as symptoms of human-driven changes rather than a particular effect of *H. mantegazzianum*.

Impacts on local plant communities will affect regional populations of native plant species through the reduction or restriction of local cover percentages or local displacement of sub-populations. Although *H. mantegazzianum* affects up to 10% of the area of suitable habitat types in our study areas, it appears that regional populations of native plant species have not been endangered until now as these co-occurring species are very common.

Conflicts with nature conservation are unlikely as habitats of current conservation concern are not suitable habitats for *H. mantegazzianum*.

Impacts on humans, such as human health and recreational activities, are a major problem arising from *H. mantegazzianum*. Where conflicts with humans are imminent it is advisable to apply appropriate monitoring and management (Chapters 14–18, this volume).

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Table 9.1. Significant predictors of the probability of occurrence of *Heracleum mantegazzianum* in suitable habitat patches (n = 1555). Significance was tested by logistic regression. P-levels: * < 0.01; ** < 0.001; *** < 0.0001. The shape index was calculated as patch perimeter divided by the square root of patch area. Habitat connectivity was assessed by the area-informed proximity index of McGarigal and Marks (1995) with a search radius of 100 m.

Predictor	Effect	*P*-level
Cover percentage of *H. mantegazzianum* in adjacent patches	+	***
Distance from rivers	–	***
Distance from agricultural roads	–	**
Shape index	+	***
Habitat connectivity	+	**
Woody habitat (> 10% woody cover)	–	*
Patch area	+	*
Wald test of overall model significance: P < 0.001		

Table 9.2. Generalized Linear Model of numbers of vascular plant species in sampling plots (25 m²) on *H. mantegazzianum* cover percentage and plant community type.

Effect	Estimate	*P*-level
Intercept[2]	21.360	< 0.001
H. mantegazzianum cover percentage[1]	–0.047	0.019
Plant community type[1]		< 0.001
Managed grasslands[2]	3.913	< 0.001
Ruderal grasslands[2]	2.759	0.009
Tall-herb communities[2]	–4.781	< 0.001
Woodlands[2]	–3.436	0.020

[1] Significance tested by Type III likelihood ratio tests

[2] Significance tested by Wald tests.

Table 9.3. Results of simple regressions of the number of vascular plant species in sampling plots (25 m²) on the cover (%) of Heracleum *mantegazzianum*, conducted for different plant community types. Species numbers were standardized within communities prior to the analyses. Additionally, means and ranges of cover percentages of *H. mantegazzianum* within the community types are presented.

					H. mantegazzianum cover (%)		
Plant community type	Slope	R^2	P	n	Mean	Min.	Max.
Managed grasslands	0.0002	0.00	0.47	36	16.5	1	70
Ruderal grasslands	–0.0092	0.07	0.06	53	44.2	5	90
Tall-herb communities	–0.0026	0.01	0.47	78	48.1	5	95
Woodlands	–0.0148	0.09	0.21	19	23.2	5	70
Other open vegetation	–0.0291	0.27	0.04	16	16.7	2	70

Table 9.4. Invasion extent and saturation of habitats by *Heracleum mantegazzianum* recorded in 20 study areas (1 km² landscape sections) in Germany. Invasion extent is the percentage of the available habitat area that is invaded by *H. mantegazzianum* stands (the area sum of stands divided by the total available habitat area). Habitat saturation is the percentage of the available habitat area that is covered by *H. mantegazzianum* plants. Habitat areas were obtained from aerial photographs using GIS methods. Grassland margins were marginal areas of grassland parcels no longer used agriculturally and were, therefore, combined with abandoned grasslands. Tall-herb stands had to be combined with abandoned grasslands because it was not possible to discern them with certainty in aerial photographs.

	Total	Invasion extent		Habitat saturation	
	available habitat area (m²)	Area invaded (m²)	Invasion rate (%)	Area covered (m²)	Habitat saturation (%)
Abandoned grasslands, grassland margins and tall-herb stands	427,804	78,117	18.5	37,214	8.7
Open railway sides	19,647	1594	9.7	830	4.2
Open riverbanks	65,747	8614	13.8	1855	2.8
Ruderal areas	79,259	4513	5.8	2189	2.8
Open roadsides	67,001	1364	3.3	1085	1.6
(Partly) shaded riverbanks	219,569	4271	2.0	2108	0.7
Woodlands (including tree fallow, forestry plantings)	1,284,723	21,733	1.8	5760	0.7
(Partly) shaded railway margins	172 833	809	0.6	706	0.4
(Partly) shaded roadsides	212 431	1173	0.8	339	0.2
Forest margins	1 115 017	2028	0.2	393	0.04

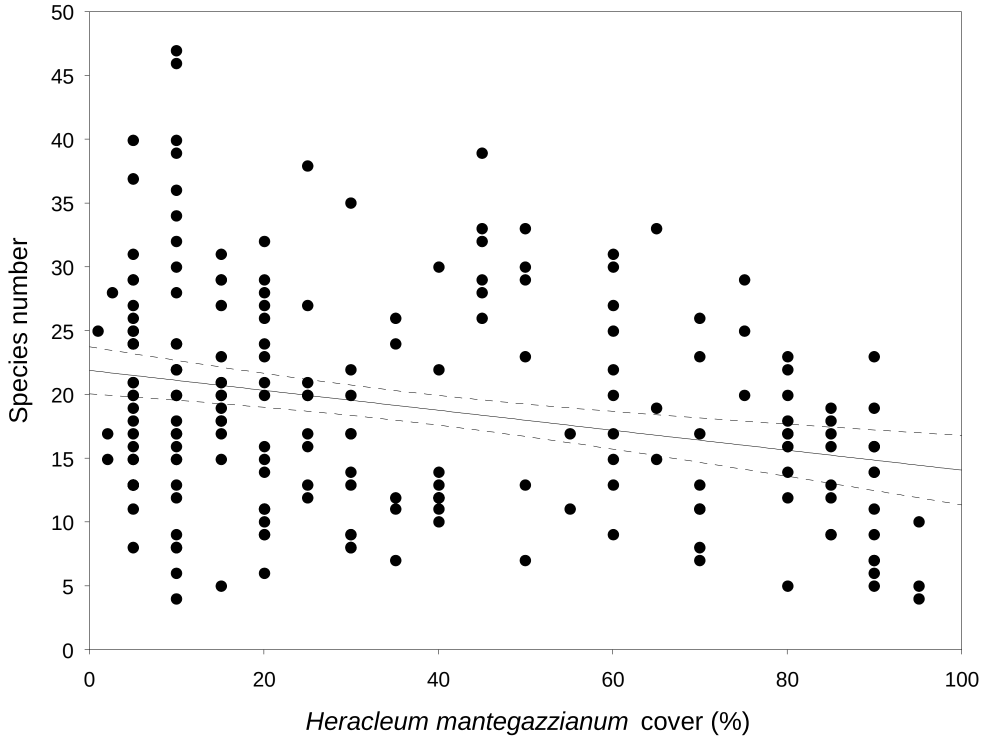

Fig. 9.1. Numbers of vascular plant species in plots 25 m² in size plotted against the cover of *Heracleum mantegazzianum*. The regression slope of –0.083 differed significantly from zero ($P < 0.001$; $R^2 = 0.07$). Dashed lines indicate 95% confidence interval of estimates. Data are from 202 plots in 20 study areas in Germany.

A.

B.

Fig. 9.2. (A) Open stand and (B) dominant stand of *Heracleum mantegazzianum* at an abandoned grassland site near the city of Kassel, Germany.

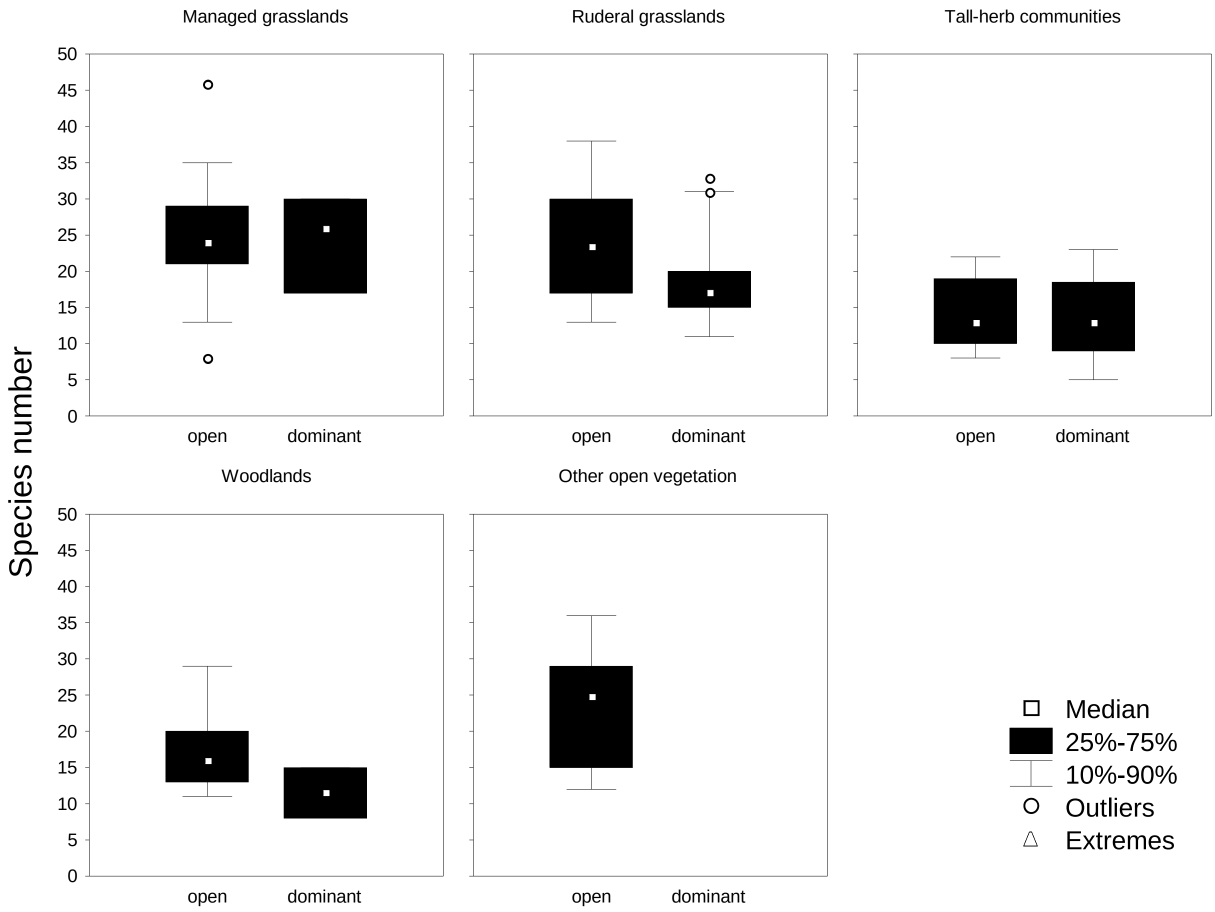

Fig. 9.3. Number of vascular plant species in 25 m² plots sampled in five vegetation types. Plots are classified according to cover percentage of *Heracleum mantegazzianum* into open stands (< 50% ground cover) and dominant stands (> 50% ground cover). The only significant difference in species numbers between open and dominant stands was found for ruderal grasslands (Mann-Whitney U-test: $P < 0.05$). Dominant stands in managed grasslands ($n = 3$) are recently abandoned grassland sites that were phyto-sociologically classified as 'managed grasslands'. Data are from 202 plots in 20 study areas in Germany (see Chapter 8 for details). Sample sizes for community types: managed grasslands = 36, ruderal grasslands = 53, tall-herb communities = 78, woodlands = 19, other open vegetation = 16.