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Effects of the annual invasive plant *Impatiens glandulifera* on the Collembola and Acari communities in a deciduous forest

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ABSTRACT

Invasive plants can disturb interactions between soil organisms and native plants and thereby alter ecosystem functions and/or reduce local biodiversity. Collembola and Acari are the most abundant microarthropods in the leaf litter and soil playing a key role in the decomposition of organic material and nutrient cycling. We designed a field experiment to examine the potential effects of the annual invasive plant *Impatiens glandulifera* on species diversity, abundance and community composition of Collembola and Acari in leaf litter and soil in a deciduous forest in Switzerland. Leaf litter and soil samples were obtained from plots invaded by *I. glandulifera* since 6 years, from plots in which the invasive plant had been removed for 4 years and from plots which were not yet colonized by the invasive plant. The 45 leaf litter and soil samples were equally distributed over three forest areas, which were differently affected by a wind throw 12 years prior to sampling representing a natural gradient of disturbance. Collembola species richness and abundance in the leaf litter and soil samples were not affected by the presence of the invasive plant. However, the species composition of Collembola was altered in plots with *I. glandulifera*. The abundance of leaf-litter dwelling Acari was increased in invaded plots compared to the two other plot types. Furthermore, the presence of the invasive plant shifted the composition of Acari individuals belonging to different groups. Our field experiment demonstrates that an annual invasive plant can affect microarthropods which are important for nutrient cycling in various ecosystems.

Introduction

Non-native species may affect ecosystems by changing the species diversity, community structure and interactions between organisms, sometimes even causing the extinction of native species (Mooney and Hobbs 2000; Kourtev et al. 2002; Fitzpatrick et al. 2010). Impacts of plant invasion on native plant communities are relatively well known, while their effects on different trophic levels are still poorly studied (reviews in Vila et al. 2011; Pŷsek et al. 2012). In particular, the potential impact of invasive plants on native leaf litter-dwelling invertebrates and soil microarthropods received little attention, despite their important role for ecosystem function (Seastedt 1984).

Collembola and Acari are among the most abundant and diverse microarthropods in the litter and soil of numerous ecosystems accounting for about 95% of the total number of arthropods in these strata (Hardings and Stuttard 1974; Maraun and Scheu 2000). The microarthropods play a key role in functional processes including organic matter decomposition and mineralization (Seastedt 1984), nutrient cycling (Irmler 2000) and soil formation (Persson 1983).

Studies investigating the effects of invasive plants on arthropod species richness and abundance yielded conflicting results. Some studies have reported a reduced arthropod diversity or abundance in invaded areas (Topp et al. 2008; Wu et al. 2009), while others found an increased diversity or abundance in invaded habitats (Sax 2002; Pearson 2009; Liu et al. 2012) or even no effect on arthropod abundance (Wardle et al. 1995; John et al. 2006). The inconsistent results may reflect different responses of arthropod groups or species to the invasive plants investigated and site-specific differences in the invasion history. For example, Kappes et al. (2007) found that the invasive plant *Fallopia japonica* reduced the abundance of Isopoda, whereas the abundance of Diplopoda was not affected by the invasive plant at the same sites.

Impatiens glandulifera (Himalayan balsam), native in the western Himalaya, was introduced as garden ornamental plant to Europe and North America in the middle of the 19th century (Beerling and Perrins 1993). It became naturalized and invasive in riparian and disturbed habitats (Hejda and Pŷsek 2006). In the

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Table 1
Characteristics of the three forest areas which were differently disturbed by a windstorm 13 years prior to sampling.

	Intensity of disturbance			*P*
	Little	Moderate	High	
Canopy closure (%)[a]	80 (50–80)	50 (50–70)	2.5 (0–10)	–
Forest vegetation type[b]	Galio oderati-Fagetum luzuletosum	Luzulo sylvaticae-Fagetum typicum	Galio oderati-Fagetum luzuletosum	–
Soil type[c]	Eutric haplic luvisol	Haplic luvisol	Haplic luvisol	–
Ground vegetation cover (%)[a]	75 (40–95)	90 (60–95)	75 (25–95)	0.125
Density of *I. glandulifera* (individuals per m^2)[a,d]	173 (56–246)	94 (75–125)	45 (38–62)	**0.033**
Biomass of *I. glandulifera* (dry weight, gm^{-2})[d]	249.1 ± 32.1	206.2 ± 17.9	188.9 ± 32.6	0.482
Soil moisture (%)	29.5 ± 0.6	27.6 ± 1.5	32.3 ± 1.0	**<0.001**
Soil pH	4.53 ± 0.02	4.47 ± 0.02	4.63 ± 0.03	0.723
Total soil organic matter (%)	12.3 ± 0.6	11.6 ± 0.8	10.2 ± 0.2	0.667
Total soil phosphorus[e]	212.6 ± 5.7	209.9 ± 6.7	243.7 ± 6.2	**0.021**

Mean values ± SE, n = 15 plots for each disturbance intensity. *P*-values resulting from one-way ANOVA or Kruskal–Wallis-tests indicate differences between the three forest areas.
(significant *P*-values (≤ 0.05) are presented in bold).
[a] Median and range (Min., Max.)
[b] Burnand and Hasspacher (1999).
[c] Walthert et al. (2004).
[d] n = 5 plots.
[e] Total soil phosphorus; $\mu g\ PSO_4\ g^{-1}$ soil.

last decade, *I. glandulifera* has increasingly invaded deciduous and coniferous forests disturbed by wind throws and/or intensive forest management (Nobis 2008). Dense stands of *I. glandulifera* can reduce species richness of native plants and/or cause shifts in plant species composition in riparian habitats (Maule et al. 2000; Hejda and Pŷsek 2006). Leaves and roots of *I. glandulifera* contain naphthoquinones which are released into the soil where they inhibit growth of mycorrhizal fungi and germination of plant seeds (Ruckli et al. 2014a). Leaves of *I. glandulifera* have a C/N ratio ranging from 9.8 to 12.8 and from 8.6 to 11.8 in roots dependent on the age of the invasive plant (Rusteholz, unpubl. data).

Studies revealed that *I. glandulifera* competes successfully with native plants for pollinators, which could lead to a reduced plant fitness (Chittka and Schurkens 2001). Up to now, there are few studies that assessed the impact of *I. glandulifera* on micro- and macroinvertebrates (for exceptions see Beerling and Dawah 2002; Ruckli et al. 2013). Recently, Tanner et al. (2013) compared the above- and below-ground invertebrate communities in plots invaded by *I. glandulifera* with those in uninvaded plots and found that ground-dwelling herbivores, detritivores and predators were less abundant in the leaf litter of invaded plots. However, these functional groups in the upper soil layer were not affected by the invasive plant or even showed a positive association with the presence of *I. glandulifera.*

We designed a balanced field experiment to examine whether the invasion of *I. glandulifera* changed the native microarthropods in leaf litter and the topsoil layer in a beech forest which has been disturbed by a wind throw. We set-up plots in patches of *I. glandulifera* existing since 6 years, in patches from which the invasive plant was regularly removed for 4 years and in plots which were not yet colonized by the invasive plant. The three plot types were equally distributed over three forest areas that were differently affected by a wind throw 12 years prior to the experiment, creating a natural gradient of disturbance. We compared the Collembola and Acari communities in the different plot types to test the following hypotheses:

(1) The invasion of *I. glandulifera* reduces the species richness and abundance of Collembola species in leaf litter and top soil.
(2) The species compositions of Collembola in the leaf litter and top soil are differently affected by the presence of the invasive plant.
(3) The invasive plant *I. glandulifera* reduces the abundance of Acari and causes shifts in the proportion of different Acari groups in leaf litter and top soil.

Materials and methods

Study sites and field experiment

The experiment was carried out in a mixed deciduous forest dominated by *Fagus sylvatica* 15 km south of Basel, northern Switzerland (47°26′ N, 7°33′ E). In this region the annual temperature averages 9.6 °C and the annual precipitation is 1021 mm. We selected study plots in three areas (each measuring 50 m × 180 m), which were differently affected by the windstorm Lothar in 1999. We estimated the disturbance intensity of the storm by assessing the canopy closure of the remaining forest trees in the three areas 8 years after the event using a spherical crown densitometer (Forest suppliers Inc., US). We defined the first area with a canopy closure of 80% as slightly disturbed, the second with a canopy cover of 50% as moderately disturbed, and the third with a canopy closure of 2.5% as heavily disturbed (Table 1). The three areas were situated within 1 km^2. *I. glandulifera* started to invade the forest shortly after the storm.

In spring 2008, we selected five homogeneous patches of *I. glandulifera* in each area. The patches were situated 5–10 m apart from each other. We installed two 5 m × 5 m plots with similar *I. glandulifera* cover in each patch adjacent to each other. In one of the two plots we removed all *I. glandulifera* individuals by hand (hereafter referred to as removed) every spring in the years 2008–2012. The other plot was left invaded by *I. glandulifera* (hereafter referred to as invaded). As an additional control, we selected five 5 m × 5 m control plots that were not yet invaded by *I. glandulifera* in close proximity (7–20 m) to the experimental plots in each area (referred to as uninvaded). To prevent uninvaded plots from the colonization of *I. glandulifera*, we removed all individuals occurring close to these plots in each spring from 2009 to 2012. In our experiment, the uninvaded plots allowed to examine the potential effect of manual removal of *I. glandulifera*. Furthermore, the uninvaded plots allowed an assessment of soil data in disturbed, but not yet invaded forest areas. Thus, the experimental set-up consisted of 45 plots (15 invaded, 15 removed and 15 uninvaded) equally distributed over the three areas, which were differently disturbed by the storm.