Invasive Canadian goldenrod (*Solidago canadensis* L.) as a preferred foraging habitat for spiders

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Abstract Invasions of alien species are a great threat to biodiversity and native species communities. There are many examples in the literature on how the invasive plants affect the natural environment. Beside reports on negative effects of these invasions, there are also several studies indicating a positive impact of the invaders. Canadian goldenrod (*Solidago canadensis*) is one of the most invasive plant species all over Europe. Earlier studies showed that the goldenrod affects natural plant communities and has a negative impact on many animals, both vertebrates and arthropods. However, all the studies were conducted during goldenrod flowering. In contrast, this study has tested the novel hypothesis that Canadian goldenrod has a positive effect on native spider hunting success and increases spider abundance in farmland outside the growing season. Observations were made during spring on 13 meadows: 7 invaded and 6 non-invaded by goldenrod. All tall plants from experimental plots (1 m² each) were examined for the presence of spiders, their nets and prey. Prey items were counted only in spider webs. The results support the hypothesis that *S. canadensis* is a favourable foraging habitat for spiders: 14.6 spiders/m² on invaded plots versus 2.2 on non-invaded ones. Many spiders of the families Theridiidae and Araneidae were found on

goldenrod plants, but on native plants only the Araneidae were found. Moreover, on invaded plots, much more prey items/m² were present in spiders webs than on non-invaded plots (155.3 vs. 13.8). The study is a rare example of a positive influence of invasive plants on the native arthropod community. This is also a novel approach that shows the importance of dry goldenrod stems in invaded ecosystems.

Keywords Invasive ecology · Alien species · Ecosystem services · Agriculture · Biological pest control · Biodiversity

Introduction

Invasions of alien plants are causes of serious problems, which affect biodiversity and native species communities (Fenesi et al. 2015a; Hejda et al. 2009; Schirmel et al. 2015, 2011; Skórka et al. 2010). Recent studies have shown that a majority of interactions between invasive plants and native animal species are unfavourable for the animals (56 % are negative and 44 % neutral), especially for birds and insects (Schirmel et al. 2015). However, there are a small number of studies showing the positive effects of alien invasive plants on animals, mostly on arthropods. For example, nitrophilous grass *Elymus athericus* modifies natural habitats and increases the survival of spiders during flood (Pétillon et al. 2005, 2010), whereas *Impatiens glandulifera* provides services for pollinators (Chittka and Schürkens 2001). Nevertheless, the positive influence of invaders is in most cases limited to only single species or groups of organisms, while the overall impact on ecosystems remains negative (Bartomeus et al. 2008; De Groot et al. 2007; Fenesi et al. 2015b). Moreover, the influence of

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invasive plants on ecosystems may change during the growing season, e.g. the invaders may have a neutral influence on native plants in 1 month and be competitive in the next one (De Groot et al. 2007; Fenesi et al. 2015b).

Canadian goldenrod (*Solidago canadensis* L.) is one of the most successful and widespread invasive plant species all over Europe (Weber 1998). This species is able to modify the ecosystem strongly, e.g. the soil characteristics (Zhang et al. 2009). In addition, it has allelopathic effects on other plant species, i.e. it releases substances that decrease the growth and survival of other plants (Abhilasha et al. 2008). The goldenrod can also limit the access of other organisms to light and water because of its height (up to 2 m) and high densities (Chapuis-Lardy et al. 2006). The goldenrod cover in invaded areas reaches 90–100 %, so this species can produce a large amount of biomass (Morón et al. 2009). Observations have shown that on invaded plots the diversity of native plants dramatically decreases, by almost 60 % (De Groot et al. 2007). Studies of the impact of the goldenrod on the native fauna have shown mostly its negative influence: a decrease in farmland bird species richness (Skórka et al. 2010), the diversity and/or abundance of butterflies, hoverflies, bumblebees, honeybees and carabid beetles (De Groot et al. 2007; Fenesi et al. 2015b; Morón et al. 2009). However, De Groot et al. (2007) showed that in some months of the year, the influence of goldenrod on hoverflies might be positive. Therefore, it is important not to overgeneralize the impact of goldenrod on different taxa, as it depends also on time in the growing season.

Spiders are important predators among arthropods in farmland. They are generalists and limit the abundance of many insect species (a lot of which are pests), thus they are reported as providers of ecosystem services (Zhang et al. 2007). The relationship between spiders and Canadian goldenrod is well known from the literature (Cangialosi 1989; Miller 1966; Morse 1995). Spiders prefer the goldenrod as feeding habitats because of the large surface of the plants to build webs (Cangialosi 1989), resulting in increased hunting success and body weight gain (Morse 1995). Spiders from the families Araneidae, Salticidae and Clubionidae are known to use galls on the goldenrod as a moulting place (Miller 1966). However, all the studies were made in North America, in the natural range of this species. In Europe, the situation may differ, because of the different spider species, their prey species and communities, as e.g. a study on carabid beetles conducted in Europe has shown a decrease in the abundance of these predators, because of the lack of prey insects (De Groot et al. 2007). Another important issue is that all the studies were conducted during summer or autumn, i.e. the season when goldenrods flower (Werner et al. 1980). Flowers are attractive for many insect species and might influence

spider abundance. There is no study on the influence of *S. canadensis* on ecosystems in spring, when last-year stems are dry, but still provide potential habitats for arthropods. In this study, we show the relationship between goldenrod dry stems and spider community in farmland. We tested the hypothesis that last-year, dry stems of *S. canadensis* are better habitats for spiders than native plants (tall grasses), because of an increase in hunting success. It might be a rare example of a positive influence of invasive species on the native fauna and ecosystem services. To our best knowledge, it is also the first study that shows the impact of an invasive plant outside the growing season.

Materials and methods

Study area

The study was carried out in May 2015 in the Barycz Valley (SW Poland). The study area is an extensive farmland with a mosaic of arable fields, meadows, small woodlots and scattered trees and shrubs of various ages, dominated by white willow (*Salix fragilis* L.), silver birch (*Betula pendula* Roth), black poplar (*Populus nigra* L.) and pine (*Pinus sylvestris* L.). It includes both dry sandy and moist sites (for details, see Ekner-Grzyb et al., 2013). Observations were made on 13 meadows at two localities, distant about 5 km from each other: Granowiec (51°29'58"N, 17°38'17"E) and Szklarka (51°30'17"N, 17°34'28"E). Out of the 13 sites, seven meadows were covered by Canadian goldenrod (four at Szklarka, three at Granowiec) and six were not (three in both localities). On the sites invaded by *Solidago canadensis*, there were no other tall plants, while on the non-invaded sites, only the native Poaceae (grasses) were growing. The invaded and non-invaded sites were very close and bordered one another in both localities. The size of the patch covered by goldenrod was 1500 m² at Szklarka and 150 m² at Granowiec. Outside these patches, all tall (>50 cm) plants were native grasses.

Study procedures

On each site, a 1-m² square plot was randomly chosen, and entire tall plants (>50 cm) were cut. Next, all the collected tall plants were separately put into plastic bags. After transfer to the laboratory, the collected plants were examined using a stereomicroscope. The presence of spider nets (i.e. any spider threads), spiders and prey items in nets were recorded. The number of prey items and spiders identified to family level was counted. All the found spiders were alive.

Statistical analysis

Statistical analyses were made using SPSS version 21 software. Numbers of spiders, spider nets and prey items on plants were dependent variables, while type of plants (goldenrod vs. grasses) was independent variables. The distribution of data on numbers of plants, spiders and prey items was not normal, so the data were logarithmically transformed. All the tests (Student's *t* test, χ^2 test with Yates' correction, Wald test) were parametric and two-tailed.

Results

During the study, from the 13 sites, 323 plant samples were collected (150 native plants and 173 goldenrod plants). On the invaded meadows, the mean density of *Solidago canadensis* individuals/m² was 24.7 (95 % CL 15.9–33.6), while on meadows without the goldenrod the mean density of tall grasses was 25.0 (95 % CL 2.8–47.2). There was no significant correlation between density of native and invasive plants (*t* test, *t* = -0.491, *df* = 11, *p* = 0.63). Spider webs were much more frequent on the goldenrod than on grasses (25 % on native grasses, 95 % CL 18–32; vs. 94 % on goldenrod, 95 % CL 90–97), and the difference between spider web presence on plants was significant (χ^2 with Yates' correction = 40.33, *p* < 0.0001). Therefore, there was also a higher probability of spider and prey occurrence on the goldenrod (for spiders, logistic regression *B* = 2.251 ± 0.328, Wald = 47.171, *p* < 0.001; for prey, *B* = 3.536 ± 0.316, *p* < 0.001). Moreover, on 17 goldenrod stems, more than one spider was present (2 spiders on 15 stems, 3 on 1, and 4 on 1), which never happened on grasses. Our results show that the total numbers of spiders and prey items per m² were also higher on invaded plots (for spiders, 14.6, 95 % CL 5.3–23.9; for prey, 155.3, 95 % CL 75.4–235.2) than on non-invaded ones (for spiders, 2.2, 95 % CL 0.1–4.4; for prey, 13.8, 95 % CL 4.4–32.1). The differences in numbers of spiders and prey items per m² were significant (for spiders, *t* = -3.320, *df* = 10, *p* < 0.01; for prey, *t* = -5.324, *df* = 11, *p* < 0.001, see Fig. 1). Also numbers of prey items per spider (all families) were higher on invaded plots than on non-invaded ones (invaded, 6.5, 95 % CL 5.4–7.6; non-invaded 1.4, 95 % CL 0.5–2.3; *t* test, *t* = 3.469, *df* = 84, *p* < 0.001). When only the Araneidae were analysed, differences between plots were also statistically significant (*t* test, *t* = 2.233, *df* = 41, *p* < 0.05).

Identification of the collected spiders shows that they belong to four families: the Thomisidae, Salticidae, Araneidae and Theridiidae. On native plants, only the Thomisidae and Araneidae were observed, while on

Canadian goldenrod, the spiders belong to all four families (Table 1). There was a significant difference in number of spider families on the goldenrod versus native plants (χ^2 = 13.56, *df* = 3, *p* < 0.01).

Discussion

Results of this study fully support the hypothesis that last-year, dry stems of *Solidago canadensis* are more preferred habitats for spiders than native plants (tall grasses). On the sites non-invaded by Canadian goldenrod, on average only 2.2 spiders/m² were observed, compared to 14.6 spiders/m² (nearly sevenfold more) on invaded plots. The abundance of spiders is not a result of a higher density of tall plants on plots, as there were no significant differences in their density. On non-invaded plots, on average 25.0 tall plants/m² were found, whereas on invaded plots, on average 24.7 goldenrod plants/m² were noticed. There was also a higher probability of finding a spider or its web on the goldenrod than on grasses. In the literature, the goldenrod is well known as spider habitat, but all the studies were conducted in the native range of *S. canadensis* and during the flowering season (Cangialosi 1989; Miller 1966; Morse 1995). In this study, spiders belonging to four families were noticed: the Thomisidae, Salticidae, Araneidae and Theridiidae. All these spider families were represented on flowering Canadian goldenrod in its native area (Greco and Kevan 1999; Miller 1966; Morse 1992). There were differences between spider communities on invaded and non-invaded plots. On the sites covered by the goldenrod, we found members of all the mentioned spider families. However, the Thomisidae and Salticidae were rare (one and six individuals, respectively). Most of the recorded spiders were members of the Araneidae (48 individuals) and Theridiidae (44 individuals). The spider community on the sites non-invaded by goldenrod was poorer. It is interesting that no theridiidae spiders were observed on native plants, but they were common on nearby plots covered by *S. canadensis*. Spiders of this family are known to build large webs (Benjamin and Zschokke 2003), so it is possible that these spiders avoid thin plants, like grasses, as foraging habitats. The low numbers of the Thomisidae and Salticidae were not surprising, as these spiders are ambush predators and they do not build webs, but they forage on lower plants, near the ground (Jackson and Pollard 1996; Morse 1984).

Our results suggest also a higher probability of prey occurrence in webs on goldenrod plants than on native vegetation. On invaded plots, we recorded 155.3 prey items/m² versus 13.8 prey items/m² on non-invaded plots. This difference in prey abundance per plot is higher than the difference in spider abundance. The reason of this

Fig. 1 Number of spiders (a) and prey items in webs (b) per m² on plots invaded and non-invaded by *Solidago canadensis* (significance of differences: $p < 0.01$ for a and $p < 0.001$ for b)

Table 1 Numbers of spiders of four families found on *Solidago canadensis* and native grasses

Family	<i>S. canadensis</i>	Native grasses
Thomisidae	1	1
Salticidae	6	0
Araneidae	48	12

There are significant differences in number spiders families on these plants ($\chi^2 = 13.56$, $df = 3$, $p < 0.01$)

phenomenon is probably the larger surface to build the web on *S. canadensis* than on grasses (Cangialosi 1989). The study was conducted in spring on non-flowering plants, and thanks to that there is no effect of flowers as attractants for insects (Fiedler and Landis 2007). Thus, we suppose that the main reason for the higher hunting success and hence spider abundance is the structure of the plants. It is known that at least one of the other arthropod predators—the bug *Phymata americana*—uses goldenrod plants as foraging area, but the bug is an ambush predator and probably gains from goldenrod attractiveness for prey insects (Greco and Kevan 1995). The goldenrod invasion in farmland increases spider abundance and it might be a positive aspect for ecosystem services (Zhang et al. 2007). Spiders are effective pest predators and are proposed as a solution in biological pest control (Marc and Canard 1997; Riechert and Lockley 1984; Sunderland and Samu 2000).

In conclusion, the presented study has shown that *S. canadensis* invasion on natural meadows provides a favourable habitat for two spider families. The most probable reason for this phenomenon is the larger surface for web building on goldenrod than on native plants. To our knowledge, this is the first report that the invasive Canadian goldenrod can affect animal communities during spring,

when its stems are dry. This finding is also a rare example of positive impact of an invasive plant on a native species community. However, there is also a probability that the areas invaded by goldenrod are ecological traps for spiders. The presented study cannot answer this question because of the lack of data about spider fitness, survival and reproduction. Further studies in this field are needed to determine the influence of goldenrod on the condition of spider populations.

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Compliance with ethical standards

Conflict of interest We declare that there is no conflict of interest. All of the authors agree to submission of this paper. The manuscript has not been previously published in any language anywhere and it is not under simultaneous consideration or in press by another journal.

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