The role of spatial scale and soil for local adaptation in *Inula hirta*

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Abstract

Many plant populations are adapted to their local environment. Reciprocal transplant experiments in the field and in the experimental garden allow for studying different aspects of local adaptation. However, usually only one of these approaches is used. We applied both experimental approaches to study the role of spatial scale and soil conditions for local adaptation in the perennial herb *Inula hirta*. We reciprocally sowed seeds and transplanted juvenile plants among six field sites from two regions and, in the garden, among pots with soil from each field site. We recorded germination percentage, survival percentage, number of stems and plant height in all experiments. We also recorded above- and below-ground biomass, flowering percentage and the number of flower heads in the garden. No population-specific local adaptation was detected in germination, survival, flowering percentages or in the number of flower heads. At the regional scale in the field, however, the performance of local transplants was higher than the performance of foreign transplants by 10% and 7% in the two regions, respectively. Similarly, when grown in the garden in soil from the more basic and nutrient-poorer region, plant height and aboveground biomass of local transplants were higher than the corresponding values for foreign transplants by 31% and 112%, respectively. Congruent evidence for local adaptation from the juvenile-transplant experiments in field and garden suggests that soil conditions represent an important factor of local adaptation in *I. hirta*. Overall, our results show that both spatial scale and soil conditions play an important role for local adaptation in *I. hirta*. Moreover, we underline the importance of combining field and garden experiments to reveal factors affecting local adaptation in plants.

Zusammenfassung


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**Keywords:** Dry grasslands; Fitness components; Genotype by environment; Habitat fragmentation; Home-site advantage; Natural selection; Plant traits; Reciprocal transplant

### Introduction

Depending on levels of genetic variation within populations and gene flow between populations, different selective forces at different sites may result in adaptation to local conditions (Hereford 2009). Plant populations may generally be adapted to their local environment, because plants are sessile and their propagules have limited dispersal (Galloway & Fenster 2000). However, although local adaptation is indeed rather common among plants, it is not ubiquitous and plants of some populations even perform better at foreign than at native sites (Leimu & Fischer 2008).

It is generally assumed that the scale of local adaptation reflects the scale of environmental heterogeneity (Galloway & Fenster 2000). However, a meta-analysis showed that environmental divergence explained only a small part of the variation in the magnitude of local adaptation (Hereford 2009). Therefore, it is often difficult to estimate the spatial scale at which plants are locally adapted (Vander Mijnsbrugge, Bischoff, & Smith 2010). At small spatial scale, soil conditions can represent an important factor of local adaptation (e.g., Hufford, Mazer, & Camara 2008). Nevertheless, local adaptation to soil conditions is not universal (e.g., Göransson, Andersson, & Falkengren-Gerup 2009) and may differ among plant species (Macel et al. 2007).

Local adaptation is usually studied with reciprocal transplant experiments (Kawecki & Ebert 2004; Leimu & Fischer 2008; Hereford 2009). Plants are considered locally adapted when local plants exhibit higher fitness than foreign plants, ideally at each site, or when the relative success of transplanted plants decreases as the distance to the population of origin increases (Kawecki & Ebert 2004). Reciprocal transplants are mainly carried out in the field, but in some cases, they are conducted in experimental environments.

According to theory, field and garden transplant experiments are expected to yield different results in terms of plant fitness, except for specific sets of conditions (Nuismer & Gandon 2008). However, very few empirical studies involved both experimental approaches (but see Buggs & Pannell 2007; Laine 2007). A major drawback of the garden approach is that plants are grown without naturally interacting organisms such as herbivores, and thus local adaptation to such factors of the natural habitats cannot be detected (Antonovics & Primack 1982). In contrast, while reciprocal transplants in the field involve all relevant factors they do not allow for identifying which factors actually lead to local adaptation. Hence, only a combination of field and garden experiments allows for both testing for local adaptation and revealing underlying factors.

We tested whether geographically isolated populations of the rare perennial herb *Inula hirta* are locally adapted, and whether soil conditions represent an important factor for local adaptation. To answer these questions we conducted a series of field and garden transplant experiments among six populations. We hypothesized that soil conditions are important for local adaptation because *I. hirta* occurs on shallow soils in habitats with sparse vegetation. A strong effect of soil substrate on adaptation may be more likely in such an environment than in environments with strong plant–plant competition (Jiang et al. 2008). To assess the spatial scale of local adaptation, we used populations in two different regions. To involve both early and late life-history stages, we performed sowing and juvenile-transplant experiments. In the experimental garden, we assessed reproductive fitness conservatively as the number of flower heads because seed-related parameters may be affected by uncontrolled crosses between plants from different populations (Raabová, Münzbergová, & Fischer 2009).

### Materials and methods

#### Study species

*I. hirta* L. (Asteraceae) is a perennial herb of dry calcareous grasslands with a sub-continental distribution (Hrouda 2005). Habitats of the species include rocky steppes and sun-exposed slopes with sparse vegetation. It occurs on shallow, calcium-rich soils on marl, limestone or basalt bedrock (Hrouda 2005). Due to habitat fragmentation, the species is restricted to small populations and is declining in many parts of Europe (e.g., Holub & Procházka 2000). Adult plants...
are 15–65 cm high with hairy stems, terminating in a single flower head with yellow florets (Hrouda 2005). One average flower head produces 310 seeds (1.8–2.5 mm long). The species reproduces both sexually and clonally and is primarily pollinated by bees (Raabová, personal observation). Clonal growth is restricted to short distances <1 m (Raabová, personal observation). Apomixis is quite common in the Asteraceae, but has never been reported for *I. hirta*. The flowering period lasts from May to July (Hrouda 2005). Pollinator exclusion prevented the production of viable seeds, suggesting that the species is not self-pollinating (Raabová, unpublished).

**Study sites and plant and soil material**

We carried out this study in the Czech Republic, using three populations in each of two regions, which are separated by 70 km (Fig. 1). Within each region, the distance between populations ranged from 9 to 34 km. The sizes of the populations, estimated from the number of flowering ramets in 2005, ranged from 300 to 900; region Czech Karst: K1 (Koda) = 800; K2 (Karlík) = 200; K3 (Lochkov) = 900; region České středohoří: S1 (Malíř) = 300; S2 (Brřehoryje) = 400; S3 (Třtěno) = 500. We collected bulk samples of seeds from at least 30 ramets separated by at least 1 m and distributed evenly over the populations in July 2003 and 2004. The seeds were stored at room temperature and no stratification was performed. The garden experiments were conducted in an experimental garden in Pruhonice, with similar climate to the field sites and with a maximum distance of 70 km from the studied populations (Fig. 1).

To obtain soil for the garden experiments, we excavated three soil blocks at least 5 m apart from each other at each field site in November 2003. We removed top soil litter and took the soil from the horizon still reached by the plant roots (maximally 40 cm deep). We also removed stones and large roots from the soil. We homogenised the soil within each site and stored it in plastic bags in an unheated greenhouse until April 2004.

To characterise soil properties of each site, we subsequently collected five samples of the upper soil layer from each field site in the summer of 2004 (about 10 cm deep after removing the top soil litter). We transferred the samples to the laboratory, air-dried them, sieved them through 2 mm mesh and homogenised them. We measured actual pH (H$_2$O), concentrations of Ca$^{2+}$, Mg$^{2+}$ and K$^+$, contents of total N, total C and carbonates following the procedure of Raabová, Münzbergová, and Fischer (2007).

**Reciprocal sowing and juvenile-transplant experiments in the field**

We sowed seeds into the field sites in October 2004. We established five 1 m $\times$ 1 m plots divided into nine grid cells in each site and placed a bulk sample of 100 seeds from each population in the centre of six randomly selected grid cells in each plot (6 sites $\times$ 6 populations $\times$ 100 seeds $\times$ 5 replicates = 18,000 seeds). The three remaining grid cells in each plot served as controls for natural seed rain. We counted the number of juveniles in the summers of 2005 and 2006. Due to seedling mortality, the number of juveniles was slightly lower in 2006 than in 2005 (mean $\pm$ SE: 2005, 2.2 $\pm$ 0.3%; 2006, 1.9 $\pm$ 0.3%) but otherwise these two records were not qualitatively different.

To pre-grow juvenile plants for transplanting, we sowed seeds from each population in plastic trays containing garden soil in February 2004. To facilitate root-ball development, we individually transplanted seedlings into multi-pot trays with pots 3 cm $\times$ 3 cm in April 2004. We transferred the multi-pot trays to the garden in June 2004 and transplanted the plants into the field in October 2004. We planted five individuals from each population in each of five rows at each site (6 sites $\times$ 6 populations $\times$ 5 individuals $\times$ 5 rows = 900 plants). Each plant was assigned to a random position 10 cm from the nearest plant. We did not disturb the established vegetation surrounding the transplanted plants. We watered the plants immediately after planting and measured the number of stems and stem height. We recorded plant survival, number of stems and stem height in September 2005 and 2006.
Reciprocal sowing and juvenile-transplant experiments in the garden

In April 2005, we sowed a bulk sample of 100 seeds from each population into pots measuring 11 cm in diameter. These pots were filled with soil with five replicates per site (6 sites × 6 populations × 100 seeds × 5 replicates = 18,000 seeds). We placed the pots in a randomised design in the greenhouse and watered them daily. We recorded germination weekly. Most of the germination occurred after four weeks.

For the garden transplant of juvenile plants, we used the same source plants as for the field transplants. In June 2004, we individually planted 20 juveniles per population into 11-cm pots filled with soil from each site (6 sites × 6 populations × 20 individuals = 720 plants). We recorded plant survival, number of stems, stem height and number of flower heads in October 2005 and August 2006. In August 2006, we harvested both above- and below-ground biomass, and weighed them after drying to constant weight at 70 °C.

Data analysis

To test for differences between sites in soil properties, we used hierarchical analysis of variance (ANOVA) with population nested within region. To analyse plant performance in the transplant experiments, we used analysis of variance (ANOVA) for normally distributed variables (number of stems, plant height, biomass and number of flower heads) and analysis of deviance (logistic regression) for binomial variables (germination, survival and flowering). We distinguished target (where the plants were planted experimentally) and origin (where the plants had come from) of the transplanted plants. Local adaptation at the regional scale becomes apparent as significant region of origin-by-target region interaction, with local plants generally performing better than foreign plants. In case of a significant population of origin-by-target population interaction, we included a local versus foreign population contrast and tested it against this interaction. For significance tests in analysis of deviance we used quasi-$F$ values that we calculated as ratio of the mean deviance of the factor to the mean deviance of the appropriate error term (Tables 2 and 3). To correct for maternal effects, we measured initial plant height at the time of planting and used this value as a covariate. Because stem height of plants transplanted to the pots in the garden was zero, the length of the longest leaf was used as actual plant height. Due to the complicated statistical design, we tested plant performance for 2005 and 2006 separately. However, because the results of the two separate analyses were not qualitatively different, we only present data from the end of the experiments in 2006 in this paper. We performed all the analyses with S-plus 6.2 (Insightful Corp., Seattle, Washington, U.S.A.).

### Table 1. Mean chemical soil properties (±SE) of the six studied sites of *Inula hirta* and $F$-values of analysis of variance for the effects of region and site (nested within regions) on these soil properties. Region K is Czech Karst and region S is Ceske stredohori. DF = 1, 4 for the effects of region and 4, 24 for the effects of site. Different superscript letters indicate significant differences between sites at $P < 0.05$ (Tukey’s post hoc comparison).

<table>
<thead>
<tr>
<th>Site</th>
<th>Region</th>
<th>pH(H$_2$O)</th>
<th>Ca$^{2+}$ (mg/g)</th>
<th>Mg$^{2+}$ (mg/g)</th>
<th>K$^+$ (μg/g)</th>
<th>Total N (%)</th>
<th>Carboxylates (%)</th>
<th>Total C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>K</td>
<td>6.4 ± 0.0</td>
<td>8.0 ± 0.0</td>
<td>8.0 ± 0.0</td>
<td>8.0 ± 0.0</td>
<td>8.0 ± 0.0</td>
<td>8.0 ± 0.0</td>
<td>8.0 ± 0.0</td>
</tr>
<tr>
<td>K2</td>
<td>K</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
</tr>
<tr>
<td>K3</td>
<td>K</td>
<td>7.5 ± 0.0</td>
<td>7.5 ± 0.0</td>
<td>7.5 ± 0.0</td>
<td>7.5 ± 0.0</td>
<td>7.5 ± 0.0</td>
<td>7.5 ± 0.0</td>
<td>7.5 ± 0.0</td>
</tr>
<tr>
<td>S1</td>
<td>S</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
</tr>
<tr>
<td>S2</td>
<td>S</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
<td>7.0 ± 0.0</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>6.7 ± 0.0</td>
<td>6.7 ± 0.0</td>
<td>6.7 ± 0.0</td>
<td>6.7 ± 0.0</td>
<td>6.7 ± 0.0</td>
<td>6.7 ± 0.0</td>
<td>6.7 ± 0.0</td>
</tr>
</tbody>
</table>

Region 4.51 ns 0.01ns 0.09ns 3.39ns 60.69** 10.75* 0.21ns

* $P < 0.05$  ** $P < 0.01$  *** $P < 0.001$  = Not significant.
Results

Soil properties

Soils from the Czech Karst region had higher contents of total N but a lower content of carbonates than soils of the Ceske stredohori region. Sites within each region differed significantly from each others in all soil properties (Table 1). Soil carbonate content was strongly positively correlated with pH and negatively correlated with total N content (see Appendix A: Table 3).

Plant performance in the sowing and juvenile-transplant experiments in the field

In the field-sowing experiment the establishment from seeds was very low after two years (mean = 1.9%). Mean germination percentage was significantly higher in the Ceske stredohori (3.41) than in the Czech Karst (0.29; Table 2). Germination percentage also differed significantly among target populations within regions and blocks within target populations (Table 2). There was a significant population of origin-by-target population interaction in germination (Table 2), but seeds from the local populations did not germinate better than seeds from the foreign populations (quasi-$F_{1,24} = 2.68$, $P > 0.1$).

After two years, the survival percentage of adult plants in the field transplant experiment with juvenile plants was 64.8%. The average plant had two stems and was 7.1 cm tall. Plants growing in the Czech Karst were significantly taller than plants in the Ceske stredohori (mean = 8.92 cm versus 5.18 cm; Table 2). Both survival percentage and plant height differed significantly among target populations (Table 2). Plants originating from the Ceske stredohori had significantly higher survival percentage and more stems than plants from the Czech Karst (mean survival = 68% versus 62% and mean number of stems = 2.14 versus 1.93; Table 2). Plant height also differed significantly among populations of origin within regions (Table 2). There was a significant region of origin-by-target region interaction in plant height (Table 2), indicating local adaptation at the regional scale as local plants were taller than foreign plants by 10% in the Czech Karst and by 7% in Ceske stredohori (Fig. 2A) Summed over both regions, plants from local regions were taller than plants from foreign regions by 9% (mean = 7.35 cm versus 6.76 cm).

Plant performance in the sowing and juvenile-transplant experiments in the garden

Germination percentage, survival percentage, number of stems and plant height were much higher in the garden than in the field (see Appendix A: Tables 1 and 2). Mean germination percentage in the sowing experiment in the garden was 15.3%. Germination percentage differed significantly among target populations and populations of origin, but the...
population of origin-by-target population interaction was not significant (Table 3). Mean germination percentage in each population pair in the garden was not significantly related to the one in the field (P > 0.1).

After two years, survival percentage of adult plants in the juvenile-transplant experiment in the garden was 74.2%. The average plant had 6.2 stems and was 23.7 cm tall. Mean aboveground biomass was higher than belowground biomass (4.5 g versus 3.3 g). Mean flowering percentage was 75.5%, aboveground biomass was higher than belowground biomass = 5.18 g versus 3.45 g and mean number of flower heads = 5.43 versus 4.04; (Table 3). The number of stems differed among populations of origin within regions (Table 3). There was a significant population of origin-by-target population interaction for survival percentage and plant height (Table 3), but plants from local populations did not perform better than plants from foreign populations (survival, quasi-F_{1,24} = 3.1, P > 0.09; plant height, F_{1,24} = 0.75, P > 0.1).

At the regional scale, there was a significant target-by-origin interaction in plant height and aboveground biomass, indicating local adaptation (Table 3). Summed over both regions, plants from local regions were taller with more aboveground biomass than plants from foreign regions by 13% and 19%, respectively (mean plant height = 24.33 cm versus 21.45 cm and mean aboveground biomass = 4.69 g versus 3.94 g). However, local plants outperformed foreign plants only in the Ceske stredohori region. In this region, plant height and aboveground biomass of the local plants were higher than the corresponding values for foreign plants by 31% and 112%, respectively (mean plant height = 24.33 cm versus 13% and 19%, respectively (mean plant height = 24.33 cm versus 21.45 cm and mean aboveground biomass = 4.69 g versus 3.94 g). However, local plants outperformed foreign plants only in the Ceske stredohori region. In this region, plant height and aboveground biomass of the local plants were higher than the corresponding values for foreign plants by 31% and 112%, respectively (Fig. 2B and C; plant height, F_{1,16} = 4.08, P = 0.06; aboveground biomass, F_{1,16} = 4.6, P = 0.04).

**Discussion**

**Evidence for local adaptation and congruence of field and garden experiments**

Both the field and the garden transplant experiments with juvenile plants demonstrated that plants grown in their local regions were larger than plants grown in foreign regions. In the field, the differences in plant height between plants from local and foreign regions were relatively small, but nevertheless significant, in both studied regions. In the garden, the differences between plants from local and foreign regions were larger, but statistically significant only in the more basic and nutrient-poor region. The small differences in plant height in the field may be explained by the overall small height after two years (mean = 7 cm) while normally *I. hirta* grows 15–65 cm high (Hrouda, 2005). Our results agree with previous studies demonstrating local adaptation in perennial herbs (e.g., Becker, Colling, Dostál, Jakobsson, & Matthies 2006; Raabová et al. 2007). Moreover, a meta-analysis showed that life-history of plants does not affect the strength of local adaptation, indicating that local adaptation
## Table 3. Analyses of variance for number of stems (stems), plant height (height), aboveground biomass (AB), belowground biomass (BB) and number of flower heads (flowers) and deviance for germination (Germ.), survival (Surv.) and flowering (Flow.) in the sowing and juvenile-transplant experiments with *Inula hirta* in the garden. Error indicates the denominator for the individual $F$- and quasi-$F$-tests. Numbers of stems and flower heads were log-transformed. Plant height and biomass were square-root-transformed. Initial plant height (square-root-transformed) was used as a covariate.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Error</th>
<th>Garden sowing</th>
<th>Garden juvenile-transplant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Germ. F</td>
<td>Stems F</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Height</td>
<td>Height</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AB</td>
<td>AB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BB</td>
<td>BB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flowers</td>
<td>Flowers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flowering quas-F</td>
<td>Flowering quas-F</td>
</tr>
<tr>
<td>Initial height</td>
<td>8</td>
<td>84.40***</td>
<td>96.60***</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Target region (Rt)</td>
<td>1</td>
<td>65.40***</td>
<td>77.40***</td>
<td>0.012***</td>
</tr>
<tr>
<td>Target population (Pt)</td>
<td>4</td>
<td>19.78***</td>
<td>18.34***</td>
<td>1.002**</td>
</tr>
<tr>
<td>Population of origin (Ro)</td>
<td>4</td>
<td>64.65***</td>
<td>62.24***</td>
<td>1.508**</td>
</tr>
<tr>
<td>Ro × Pt</td>
<td>1</td>
<td>2.58***</td>
<td>2.29***</td>
<td>0.017***</td>
</tr>
<tr>
<td>Pt × Pt</td>
<td>4</td>
<td>0.03***</td>
<td>0.02***</td>
<td>0.058***</td>
</tr>
<tr>
<td>Residuals</td>
<td>145</td>
<td>144–585</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The range in degrees of freedom is given if df varied depending on the traits studied.

* $P < 0.05$
* * $P < 0.01$
** *** $P < 0.001$

| ns Not significant. |

Generative traits (flowering percentage and number of flower heads) in the garden experiment with juvenile plants did not indicate local adaptation. During the two-year experiment, *I. hirta* plants did not flower in the field, which did not allow us to study evidence for local adaptation for this important generative trait in the field. Nevertheless, the traits in which we detected evidence for local adaptation (plant height and aboveground biomass), were positively correlated with the number of flower heads in the garden. In clonal plants, there can be a trade-off between investment in vegetative and generative reproduction (Reekie & Bazzaz 1987). Despite this theory, however, several studies have shown similar responses to environmental heterogeneity in vegetative and generative traits (Becker et al. 2006; Becker, Dostál, Jorritsma-Wienk, & Matthies 2008). It is possible that evidence for local adaptation in generative traits may become apparent after a longer time in slowly growing perennial plants, such as *I. hirta*. In addition, a meta-analysis showed that the magnitude of local adaptation is often stronger when measured in generative than in vegetative traits (Hereford 2009).

### Role of soil properties

The congruent evidence for local adaptation from the juvenile-transplant experiments in field and garden clearly suggests that soil conditions represent an important factor of local adaptation in *I. hirta*. We found evidence for local adaptation only at the regional scale, which suggests that soil elements which differ between the two regions (i.e. nitrogen content and carbonate content) could be important for local adaptation of *I. hirta*. The data on soil chemistry well describe soil properties both in the field and in garden experiments, because soil storage, such as before the garden experiment, was not found to affect chemical soil properties (Pánková, unpublished). Apart from chemical soil properties, soils of the two regions differ significantly also in physical properties, e.g., with higher water holding capacity in the Ceske stredohori region (Raabová, unpublished). However, soil structure
Scale of local adaptation

We showed that *I. hirta* plants performed poorly in nutrient-poor and basic soil conditions if they originated from nutrient-rich and acidic environments. By combining our field and the garden experiments, we concluded that such local adaptation is caused mainly by the differences in soil conditions between the two regions. We detected local adaptation only at the larger spatial scale (between regions) but not among populations within regions. This is in agreement with the study of Becker et al. (2006) who found evidence of local adaptation at large but not at small spatial scale. It indicates that it is important to cover different spatial scales in reciprocal transplant experiments in order not to miss the relevant one.

Several studies demonstrated decreasing plant fitness with increasing geographic or environmental distance to the population of origin (Becker et al. 2006, 2008; Raabová et al. 2007; Bowman, Perret, Hoehn, Galeuchet, & Fischer, 2008). However, it is difficult to determine which factor is underlying such a distance effect and to say which factor is the main driver of local adaptation (Leimu & Fischer 2008). For example, climatic factors could be correlated with edaphic factors (Becker et al. 2006) and different environmental distances (e.g., dissimilarities in vegetation composition, soil properties or potential direct solar irradiation) could also be correlated with each other (Raabová et al. 2007). This underlines the need for synergistic combination of field transplants under natural conditions and garden transplants with targeted manipulation of the environment, which in combination can reveal factors affecting local adaptation in plants.

Implications for conservation

Since the species was able to grow in all studied sites and to reproduce in all soil types, we propose that transferring plants of *I. hirta* among populations may be useful for conservation purposes. However, habitat conditions and, in particular, soil properties should be taken into account (Hufford et al. 2008) and transplants should be done primarily within the same region of origin.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.baae.2011.01.001.

References


