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Titel | Title

Which factors drive the invasion of two invasive Impatiens species in montane regions of the Alps?
Distribution patterns and driving factors of Impatiens glandulifera and Impatiens parviflora in the Salzach Valley near Werfen and in the Gasteiner Valley

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Abstract

Within the genus *Impatiens*, we find two species, *I. parviflora* and *I. glandulifera*, which are alien species in Central Europe, and one species, *I. noli-tangere*, which is native to the region. While both invasive species are well studied in riparian habitats and forests of Central Europe, their distribution patterns within the montane regions of the alps have not been studied to the same extent. In this study, I investigated the occurrence and abundance of the three *Impatiens* species in two valleys within the alps and tried to discover differences between the distribution patterns within the genus *Impatiens*, the effects of the alien species on the native flora and find the main driving factors behind the distribution of invasive *Impatiens* species in this region. I therefore established 64 plots of 50 m² in both the Gasteiner Valley and the Salzach Valley around Werfen in Salzburg Austria, assessing the cover of every species within the plot and categorizing the plots to different habitat types. Next, I analyzed the data and added ecological factors such as Ellenberg Indicator values and distances to known distribution vectors such as roads and streams, for each plot to create a model to assess the main driving factors of distribution.

The study showed that both *I. parviflora* and *I. glandulifera* are widespread throughout the study regions, but also revealed differences between the habitat choice and distribution of both species. In addition, all three *Impatiens* species have very similar ecological preferences when compared to each other, but the differences between plots inhabited by one *Impatiens* species and those uninhabited by this species were more significant and altered among the three species.

The model created as part of this study shows that two known distribution vectors had no significant impact on the distribution of all three species, and that ecological factors of the habitats are more important for the distribution patterns. The study also revealed that in conclusion ecotones and disturbed habitats are the most prone to invasion by either *I. parviflora* or *I. glandulifera*, whereas dense forests with low disturbance are generally safe from invasion by *I. glandulifera* but still inhabited by the less negative *I. parviflora*.

Key words: *Impatiens glandulifera, Impatiens parviflora, Impatiens noli-tangere*, invasive, alien species, distribution pattern, Ellenberg indicator values, disturbance

Introduction

Alien species are species that have been introduced into regions where they are not native (Richardson & Pyšek 2006). Once introduced, a subset of these species can become detrimental to native species and communities, and are called invasive species (Pyšek & Pyšek, 1995; Sakai et al., 2001; Richardson & Pyšek, 2006; Hejda, 2013; Fried et al., 2014). Invasive alien species are a major threat to biodiversity and ecosystems worldwide (Wilcove, 1998; Pyšek, 2020; IPBES, 2019). They can impact on local species communities and the functioning of invaded ecosystems, as well as potentially change their structure and species composition (Hulme, 2007; Vilà, 2010; IPBES, 2019).

The genus *Impatiens*, one of the most species-rich genera worldwide, is one of the two genera in the family Balsaminaceae. Species of this genus are native to Africa, Eurasia, and North America, with their center of diversity being in the Himalayan region, tropical Africa, Madagascar, South India, and Southeast Asia (Janssens et al., 2009). Some species of this genus have been spread around the world by humans and became invasive alien species, often with strong negative impacts on the local flora (Coakley & Petti, 2021). Species of the genus *Impatiens* are annual herbs that are spread locally via their slingshot-seeds and can additionally be distributed over large distances by rivers or soil adhesion on shoes or tyres (Grey-Wilson, 1980). In Central Europe, only one *Impatiens* species, *Impatiens noli-tangere* L., is native, but some other *Impatiens* species have been introduced. The two main alien species of the genus are *Impatiens glandulifera* ROYLE and *Impatiens parviflora* DC., both established in Central Europe.

Native to India, Nepal, and Pakistan, *I. glandulifera*, is one of the most widespread invasive alien species worldwide, widely established in Europe, North America, Japan, and New Zealand (Cockel & Tanner, 2012). In Europe, the species was introduced in 1839 via botanical gardens from where it escaped, and was first recorded in the wild in 1850 (Pyšek & Prach, 1995; Cockel & Tanner, 2012). Currently, this species is widespread and common throughout Europe, and has been established (Cockel & Tanner, 2012). *I. glandulifera* prefers moist and partially shaded, nutrient-rich sites (Pyšek & Prach, 1995), but is also able to successfully colonize sites with less favourable conditions, such as roadsides (Follak et al., 2018).

Fig. 1: Site with yellow small-flowered *Impatiens parviflora* (left) and *Impatiens glandulifera* (right) with large pink flowers. *(Source: Christof Viehauser)*

Once established, *I. glandulifera* often creates dense stands because of its high number of seeds, efficient short-distance seed dispersal, long period of germination capacity, and rapid growth, reaching heights of up to 2 m, and creating shaded areas where only a few other species are able to germinate (Pyšek & Prach, 1995; Clements & Feenstra, 2007; Tanner & Gange, 2013; Helsen et al., 2018). This species has been listed on the List of invasive alien species of Union concern by the European Union in 2017 (Commission of the European Union, 2017) and is also listed on the Blacklist of invasive Neophytes in Switzerland (SKEW, 2008; Info Flora, 2022). Because of these listings, member states of the European Union are obliged to implement strategies to prevent the introduction and spread of *I. glandulifera*, as well as to create systems for early detection and to eradicate and manage existing populations.

Impatiens glandulifera is a great threat, especially in floodplains and riparian habitats (Coakley & Petti, 2021), where it finds very favourable habitats and can spread faster and to longer distances by distributing its seeds downstream by the flow of water. In addition, other habitats are also susceptible to invasion by *I. glandulifera* (Coakley & Petti, 2021). However, its impact and distribution in mountainous areas in Central Europe, such as the Alpine region, have not been extensively studied.

Impatiens parviflora is a small-flowered, annual *Impatiens* species native to Central Asia that was introduced into temperate regions of Europe and eastern North America. In Europe, the species was introduced into botanical gardens, and was first recorded in 1831 in forests neighbouring the botanical garden in Geneva, and it has become the most common alien species in European forests (Trepl, 1984; Florianová & Münzbergová, 2017).

Other than *I. glandulifera*, *I. parviflora* prefers shaded and moist habitats, but its habitat requirements have a wide range (Coombe, 1956; Godefroid & Koedam, 2010). It is one of he few invasive species that can grow even in near-natural habitats (Trepl, 1984, Godefroid & Koedam, 2010).

However, the degree of invasiveness of *I. parviflora* is still an ongoing debate. It tends to become dominant at favourable sites, making up most of the coverage of the herb layer, similar to other species of this genus (Dostálek, 1997; Florianová & Münzbergová, 2017; Barabasz-Krasny et al., 2018). In contrast, sites where it is very abundant are often those with unfavourable conditions for native species (Schmitz, 1998; Lamprecht, 2008). Therefore, its effect on native plants and local plant communities is of great interest and requires further research.

The aims of this study were i) to characterize the distribution of both *Impatiens* species, ii) to identify whether there are differences between the distribution patterns in two different alpine regions in Austria (Werfen and Gasteiner Tal), and iii) to identify the relevant factors explaining their distribution.

My hypothesis is that differences in the distribution patterns occur between the two study species, due to the differences in their respective ecological niches. I also hypothesize that the main driving factors are associated with human impact on the distribution of seeds. Furthermore, I suspect that disturbed habitats will be more prone to invasion by the study species.

Materials and Methods

Study regions

This study was carried out in two 4 km x 9 km study regions in the federal state of Salzburg, Austria. The first study region was in the Gasteiner Valley between Bad Hofgastein and Bad Gastein and the second study region was in the Salzach Valley near Werfen between Tenneck and Elmauthal (see Figure 2). Each study region followed the course of the main river in the area (Gasteiner Ache in the Gasteiner Valley and Salzach in the Salzach Valley near Werfen).

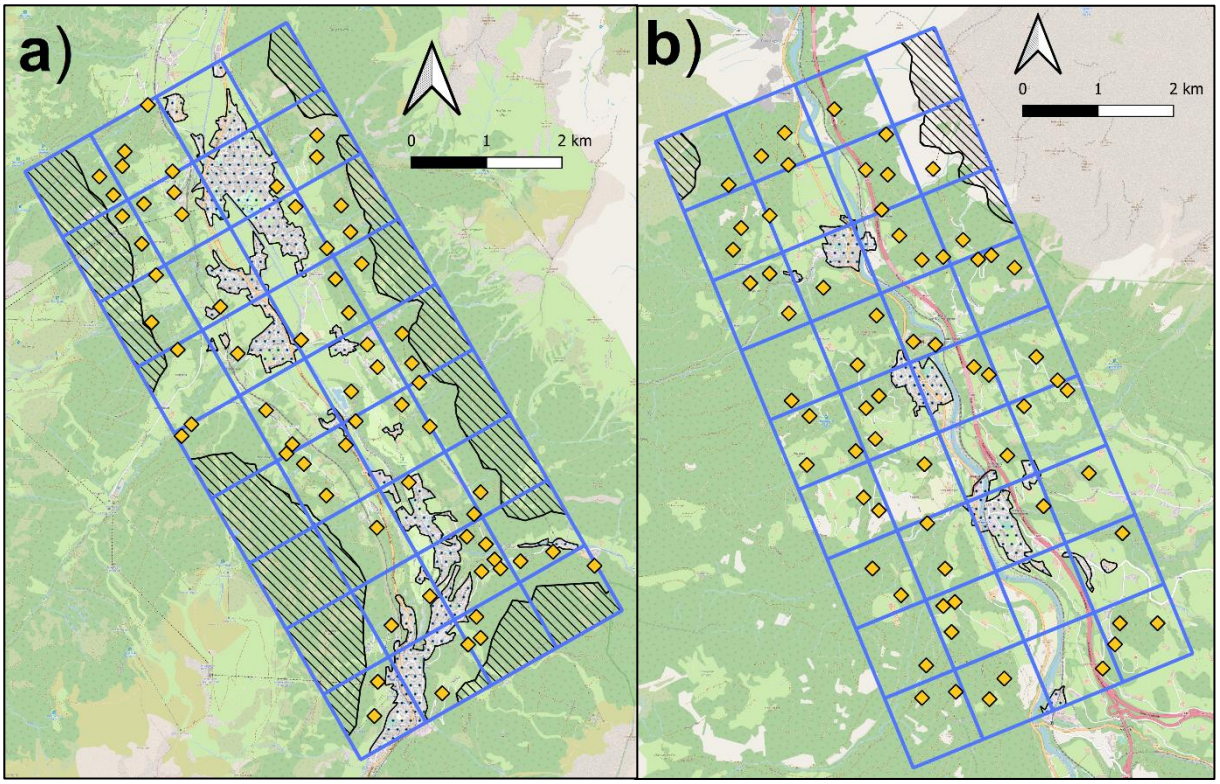

Fig. 2: Study region a) Gasteiner Valley and b) Salzach Valley near Werfen. The yellow diamonds represent sample plots. The blue squares show the 36 1 x 1 km grid cells used to subdivide each region. The black hashed area was excluded from the study due to being above 1300 m asl, while the grey dotted area was excluded as it is occupied by settlements.

The study regions differed in certain respects. The Gasteiner Valley is located in the High Tauern Mountain range, with bedrock of various high-grade metamorphic rocks such as Gneiss and Granite. On the other hand, the Salzach Valley around Werfen is located within the Northern Limestone Alps. In most parts, the Gasteiner Valley is a wide U-shaped Valley with a broad and flat valley bottom, moderately steep slopes, and few side valleys, whereas the Salzach Valley around Werfen has a narrow valley bottom around the Salzach River, steeper slopes, and more side valleys created by streams. Additionally, the valley floor of Gasteiner Valley at Bad Hofgastein is located at c. 850 m asl, whereas the Salzach Valley at Werfen is located at c. 500 m asl.

This translates to different altitudes of the plots in both regions (Gasteiner Valley: 1073 m asl, Salzach valley 774 m asl). Finally, the human impact on the landscape and land use differed between both regions. In the Salzach Valley, larger settlements are confined to flat, low-lying areas near the river, while many small settlements and single houses are scattered in the side valleys. In contrast, in the Gasteiner Valley settlements are located only in the valley bottom and are more concentrated. Although both regions have one large road along the river from north to south, the road network is much more branched in the Salzach Valley region owing to scattered settlements.

Site selection

For this study 64 plots with a size of 5 m x 10 m were sampled in each study region in July and August 2021. The plot sites were determined semi-selectively. To provide an unbiased distribution in the study region, each region was divided into 36 1 km x 1 km cells. According to the current literature, *I. glandulifera* reaches its upper altitudinal limit at c. 1000-1200 m asl (Drescher and Prots, 2000; Helmissari, 2010; Vorstenbosch et al., 2020) and *I. parviflora* rarely occurs above 1200 m asl (Becker et al., 2005) in the Austrian Alps. Therefore, all areas higher than 1300 m were excluded.

Settlements and agricultural land such as meadows and fields were excluded from the study as well. Then, aerial photographs (basemap.at) and satellite images (googlemaps.com) were used to determine habitats suitable for both species (forests, forest borders, tall herb vegetation, shrublands, and non-agricultural open areas). Then, I randomly selected plot sites with a fair distribution throughout each square of the study region ranging from 0 to 5 plots within a square with a minimum distance of 100 m between each plot. Due to the excluded areas mentioned above and the inaccessibility (private land, extremely difficult terrain, and official entry bans) of some parts of the study regions, some squares were left without any plots. For the map of the study regions and plots (see Fig. 2) QGIS (QGIS.org, 2022) was used.

For each plot, I measured the aspect, altitude, and slope, together with the geographic coordinates. The cover of the tree, shrub, and herb layers, litter, scree, rock and open ground was determined as well (in %). Furthermore, I identified all vascular plant species in the plot and determined the species cover (in %) in every layer in which they occurred. Specimens of all species that were not identified in the field were sampled and herbarized for later identification. Species were identified at the species level, but some could only be identified at the genus level. I also noted the form of the terrain, land use (if any), and made special remarks.

Finally, I assigned each plot into one of five habitat classes: (1) open areas = open areas with tall perennial communities, (2) successional tall herb vegetation = clear-cut forests with early succession communities, (3) open forests = forests with a tree cover < 75%, (4) dense forests = forests with a tree cover > 75%), and (5) ecotones (i.e., forest edges).

Collecting data

QGIS (QGIS.org, 2022) was used to determine the distance between each plot and the nearest road, as well as to the nearest watercourse. The roads and watercourses were located using aerial photographs (basemap.at) and satellite images (googlemaps.com). Furthermore, climatic data for the time period 1971-2000 (Hiebl et al., 2011) - mean annual temperature, mean temperature in July, mean annual precipitation, mean number of days with snow cover, and mean number of days with less than 0°C were assigned to each plot. In addition, I calculated the Shannon Index, evenness, and species richness for each plot using JUICE 7.1 (Tichý, 2002).

To characterize the ecological preferences of the plot vegetation, I used the adjusted Ellenberg-values Light, Temperature, Moisture, Soil-Reaction and Nutrients for Central Europe (Glaser et al., 2024) as ecological indicators. With these, I calculated the mean value in all five Ellenberg categories for each plot.

Statistical Analyses

Data were analysed using R 4.1.3 with RStudio 1.1.383 (R Core Team, 2022) and the following R packages: dplyr (Wickham et al., 2022), forcats (Wickham, 2022a), ggplot2 (Wickham, 2016), ggpubr (Kassambara, 2022), ggstatsplot (Patil, 2021), gridExtra (Baptiste, 2017), janitor (Firke, 2021), lme4 (Bates et al., 2015), lmerTest (Kuznetsova, 2017), purrr (Wickham and Henry, 2023), readr (Wickham et al., 2022b), rstantools (Gabry et al., 2022), sjPlots (Lüdecke, 2022), stringr (Wickham, 2019), tibble (Müller and Wickham, 2021), tidyr (Wickham and Girlich, 2022), tidyverse (Wickham et al., 2019), viridis (Garnier et al., 2021) and viridisLite (Garnier et al., 2021).

First, I subdivided the plots into four groups according to the presence of *I. glandulifera*, *I. parviflora*, and *I. noli-tangere*; the final group consisted of plots without any *Impatiens* species. The mean cover of each vegetation layer was calculated for all plots, for each group of plots, and for each habitat in each region.

Second, I identified the top ten accompanying species in the herb layer of every group where one of the Impatiens species was present, and compiled them into one list containing 20 species in total, as some species were most common in more than one group. Additionally, I compiled another list of all species of the genus Impatiens and those that occurred in at least 25 plots (20% of all plots or more). For every species on that list, the mean percentage of cover in each group and for all plots was calculated.

Furthermore, I created boxplots and violine plots of the mean Ellenberg Indicator values for temperature, light, moisture, soil reaction, and nutrition of the sample site for the three groups of plots where Impatiens species were present. To determine significant differences between them, I ran a pairwise Kruskal-Wallis-Test for every indicator value. This process was repeated with species richness instead of Ellenberg-Indicator Values.

I then compared the mean Ellenberg-Indicator values and species richness of the plots with *I. glandulifera*, *I. parviflora*, or *I. noli-tangere* present with those plots where that species was absent, by creating boxplots and violine plots as well as conducting pairwise Kruskal-Wallis tests.

Finally, I created two mixed models for the occurrence and abundance of each *Impatiens* species in the study, in which the occurrence and cover in the herb-layer of the *Impatiens* species as the response variable, the distance to the next running water, the distance to the next street, the tree cover, and the mean Temperature-Ellenberg Indicator and Nutrient-Ellenberg Indicator of the plot were used as fixed effects and the Habitat Types as random effects.

Results

Species composition and richness of invaded vegetation

In the 128 plots a total of 326 species were recorded (see Table S2). The mean number of species in each plot was 31.3 (SE ±9,1) with a minimum of 8 species and a maximum of 55 species. A total of 88 (69 %) plots contained at least one *Impatiens* species, with *I. parviflora* being the most abundant species with an occurrence in 57 (45 %) plots, followed by *I. noli-tangere* in 39 (30 %) plots. *I. glandulifera* was detected in 23 plots (18 %).

Vegetation density and habitats colonized

The comparison of the average cover of vegetation layers showed that the differences between plots with and without *Impatiens* species were stronger than the differences between the *Impatiens* species themselves (Fig. 3).

This effect seems to be strongest in the tree layer with plots in which *Impatiens* species did not occur had, on average, higher tree cover and *I. glandulifera* had substantially lower tree cover values than both other species. The differences of the other two layers (shrub and herb layer) among the study species were much smaller.

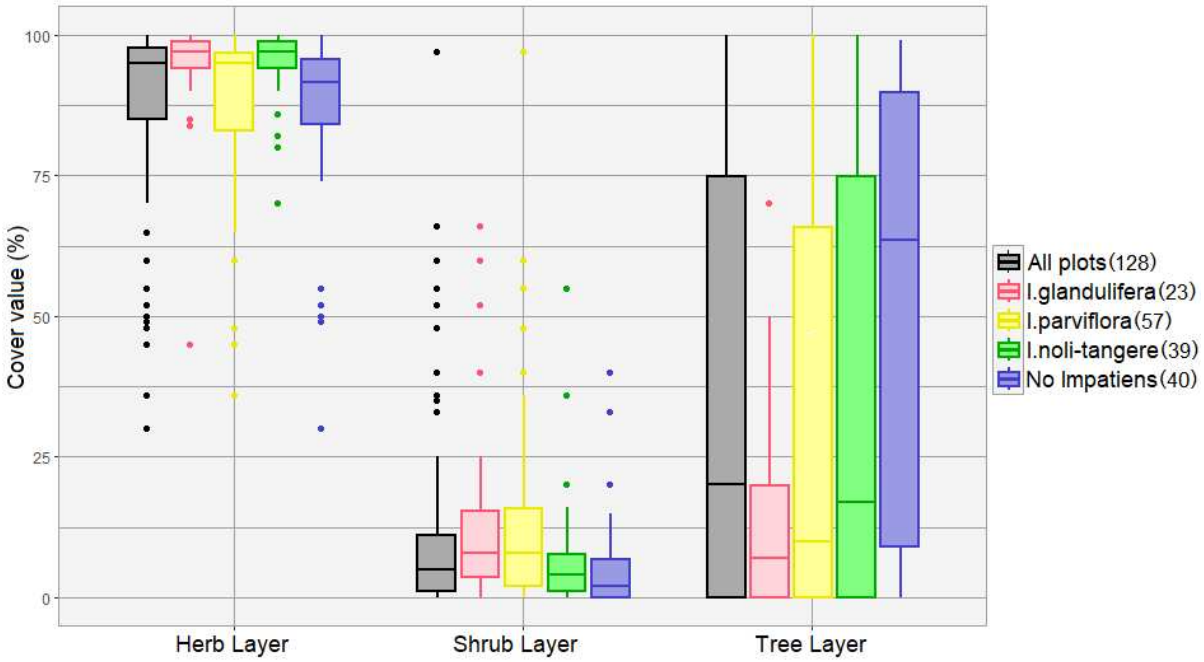

Figure 3: Boxplots of the vegetation layers (herb, shrub, tree) of the plots grouped by the occurrence or absence of *Impatiens*-species.

Differences in the distribution of colonized habitat types between the two study regions were rather small (Fig. S1). While the number of plots in dense forests and open areas with tall perennial communities is nearly equal, the difference between the two regions is best shown by the distribution of ecotone plots and open forests (Fig. S1). In Gasteiner Tal, ecotone habitats were the largest group of plots with 27% of all plots, whereas this percentage was only 19% in Salzachtal. Open forests, on the other hand, make up 19% of all plots in Salzachtal, but only about half as much as 11% in Gasteiner Tal.

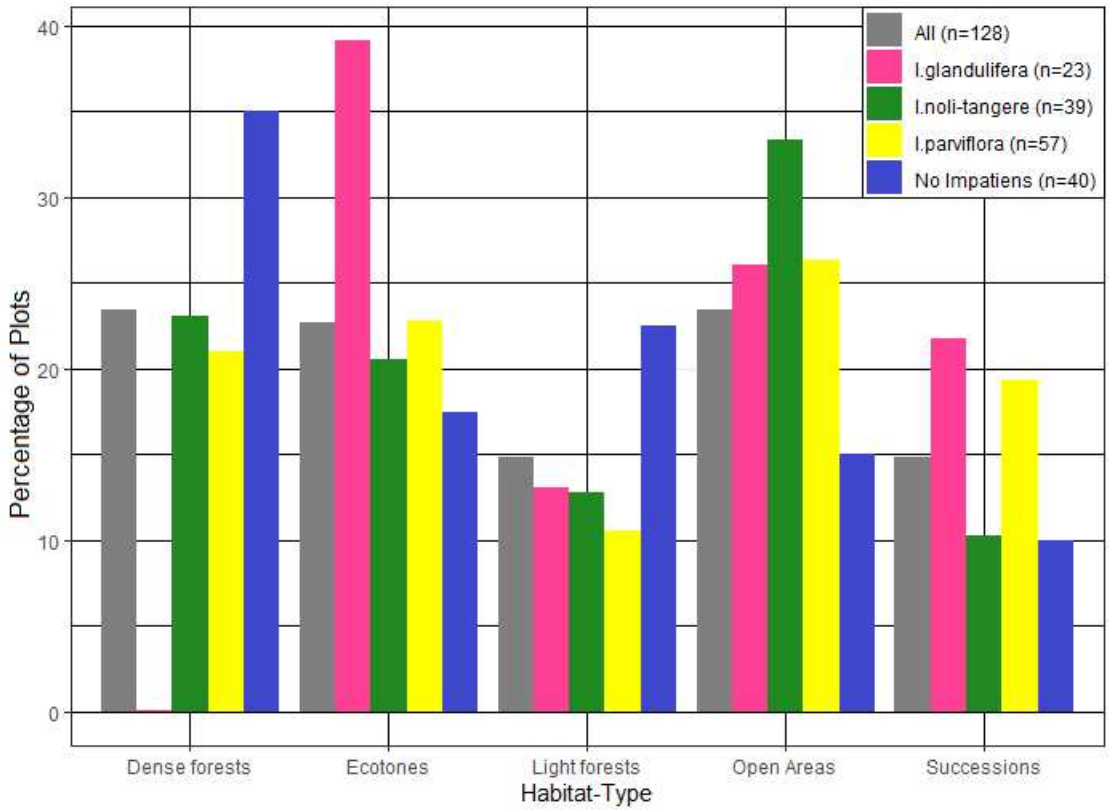

Fig. 4: Distribution of plots within different habitat types in percent and additionally grouped for the presence of each *Impatiens* species as well as for plots without *Impatiens* species.

Comparing the distribution of plots among the five different habitat categories, we observed strong differences according to the presence of *Impatiens* species (Fig. 4). As shown, plots without *Impatiens* species are predominantly located in forests, while clear cuts with early succession communities and open areas with megaphorb communities play a minor role. In contrast, plots with *I. glandulifera* were completely missing in the dense forests. Although the percentage of plots with this species in light forests and open areas is nearly equal to the total percentage of this habitat, it is substantially more often found in ecotones and succession areas. The percentage of plots with *I. parviflora* for dense forests, ecotones, and open areas was nearly equal to the overall percentage of that habitat, which was lower in light forests and higher in succession areas. However, *I. parviflora* was evenly distributed throughout all habitat types. *I. noli-tangere* is quite similar to its congener *I. parviflora*, but its distribution is less even throughout all habitat types. It was less often found in succession areas, but was more often found in open areas.

Accompanying species in invaded vegetation

Of the 326 species that occurred in at least one plot within this study, 20 were ranked among the top ten species in the herb layer of plots where at least one *Impatiens* species occurred (Table 1). Most of these species were very common in all plots and had similar frequencies within plots where different *Impatiens* species occurred.

Table 1: Percentage of presence of the most common species within the herb layer in plots colonized by *Impatiens* species. Red values highlight the top ten accompanying species in each of the groups (11 in *I. noli-tangere* due to ties in percentage cover). Total = all plots.

Accompanying Species	**Total [%]**	***I. parviflora [%]***	***I. glandulifera* [%]**	***I. noli-tangere* [%]**
Rubus idaeus	75%	**77%**	**83%**	**90%**
Oxalis acetosella	61%	**53%**	30%	**59%**
Urtica dioica	61%	**84%**	**78%**	**85%**
Senecio ovatus	59%	**44%**	**39%**	**67%**
Fragaria vesca	52%	**44%**	30%	44%
Acer pseudoplatanus	51%	**44%**	13%	39%
Impatiens parviflora	45%	100%	**44%**	**49%**
Angelica sylvestris	44%	42%	**48%**	**79%**
Athyrium filix-femina	44%	40%	30%	**62%**
Geranium robertianum	44%	**54%**	30%	46%
Galeopsis tetrahit	43%	**54%**	35%	36%
Rubus fruticosus agg.	42%	**46%**	**44%**	**49%**
Petasites albus	39%	39%	17%	**49%**
Epilobium montanum	38%	**47%**	26%	41%
Ranunculus repens	38%	39%	30%	**62%**
Dactylis glomerata	36%	40%	**52%**	31%
Dryopteris filix-mas	35%	30%	30%	**51%**
Galium sylvaticum	33%	39%	**48%**	23%
Poa trivialis	28%	32%	**39%**	26%
Mentha longifolia	22%	32%	**44%**	21%

Common species

Of the 326 species that occurred in the plots, only 38 occurred in at least 25 plots (see Table S1 in the Appendix). The most common species was *Rubus idaeus*, which occurred in 96 plots (75%). Many common species had low cover values of < 1% in all plots (see Table S1 in the Appendix). Only seven species reached an average cover of over 5%, with the highest average cover being 12,5% by *Oxalis acetosella*.

Investigating the differences at the species level, most species that occurred in > 20% of all plots had low cover values, between 0.1 % and 1 % (see Table S1 in the Appendix). Focusing on the Impatiens species, it is evident that *I. glandulifera* has higher cover values than *I. parviflora* or *Impatiens noli-tangere*, with an average cover of 50% in the plots, compared to only 15% in the other two species. Additionally, in plots where *I. glandulifera* was present, the other *Impatiens* species only covered 2.4 % or 1.2% and only a few nitrophilous species, such as *Urtica dioica*, *Rubus idaeus*, and *Rubus fruticosus agg.* reached cover values of at least 5%. *I. parviflora* and *I. noli-tangere* had very similar cover values when only considering the cover of the three *Impatiens* species, but *I. parviflora* seems to be able to have a higher cover in plots where *I. noli-tangere* was present than vice-versa. Overall, the three species of the genus Impatiens were among the species with the highest cover percentages (see Table S1 in the Appendix).

Of the other species that were very common (occurrence in 50 or more plots), some, such as *Rubus idaeus*, *Fragaria vesca*, and *Angelica sylvestris* had similar cover values in all groups of plots (see Table S1), while others differed in cover values among plots with different *Impatiens* species. One such pattern can be observed in *Oxalis acetosella*, *Senecio ovatus*, *Petasites albus*, and *Athyrium filix-femina*. These species had higher cover values in the herb layer in plots with the native *I. noli-tangere* or where no *Impatiens* species were present at all, whereas it was low in plots where one of the two invasive *Impatiens* species occurred. A different pattern was observed in the cover percentages of *Galeopsis tetrahit*, *Geranium robertianum*, and *Rubus fruticosus agg*. These species had high cover when *I. parviflora* and *I. noli-tangere* were present, and low cover values when *I. glandulifera* occurred in the plot, but also when all *Impatiens* species were absent.

Nevertheless, cover values of all species were below the percentages in all plots, most of the time the lowest of all groups was best seen in *Acer pseudoplatanus*, where cover was extremely low in plots where *I. glandulifera* was present and nearly equal cover in those plots where *I. glandulifera* was absent.

The only outlier of this general pattern was *Urtica dioica*, which had its highest cover in plots with *I. glandulifera*, with very high coverage in plots with other *Impatiens* species and very low cover where no *Impatiens* species was present (see Table S1).

Comparison of Ellenberg Indicator Values

The Ellenberg indicator values of plots colonized by different Impatiens species revealed few differences (Fig. 5). In total, there were only two significant differences. One was found between *I. glandulifera* and *I. noli-tangere*, and was lower in the latter. The other difference was found in Temperature between *I. parviflora* and *I. noli-tangere*, which was again lower in *I. noli-tangere*.

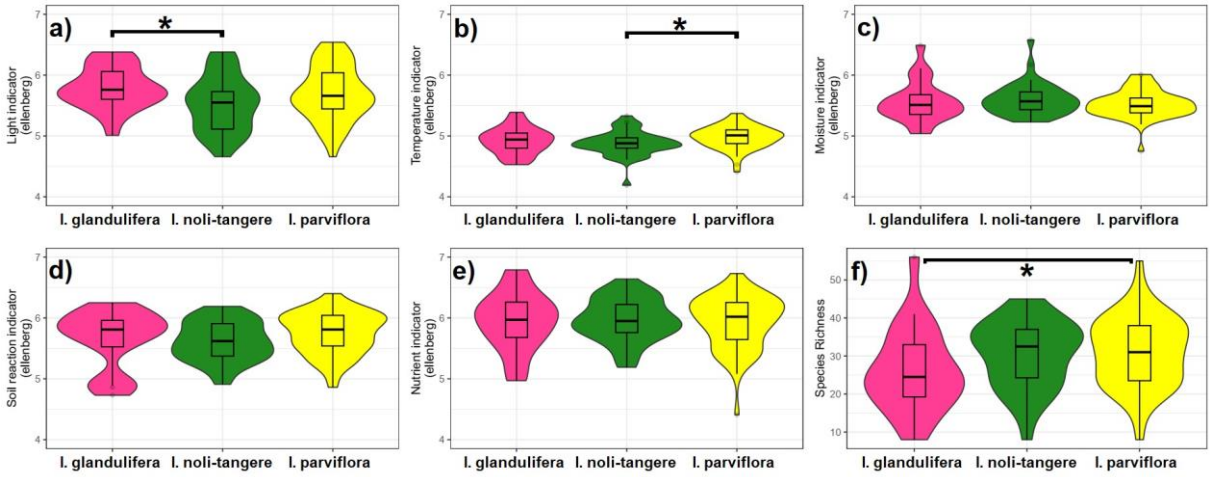

Fig. 5: Differences between the average Ellenberg Indicator values for a) Light, b) Temperature, c) Moisture, d) Soil Reaction, e) Nutrient and f) species richness of plots according to presence of the studied Impatiens species shown as violin plots and boxplots. Kruskal-Wallis-Test Significance levels: * 0.05, ** 0.01, *** 0.001

The species richness of plots did not differ between *I. parviflora* and *I. noli-tangere* (Fig. 5f), whereas plots without *I. glandulifera* had a significantly higher species richness than plots where it occurred.

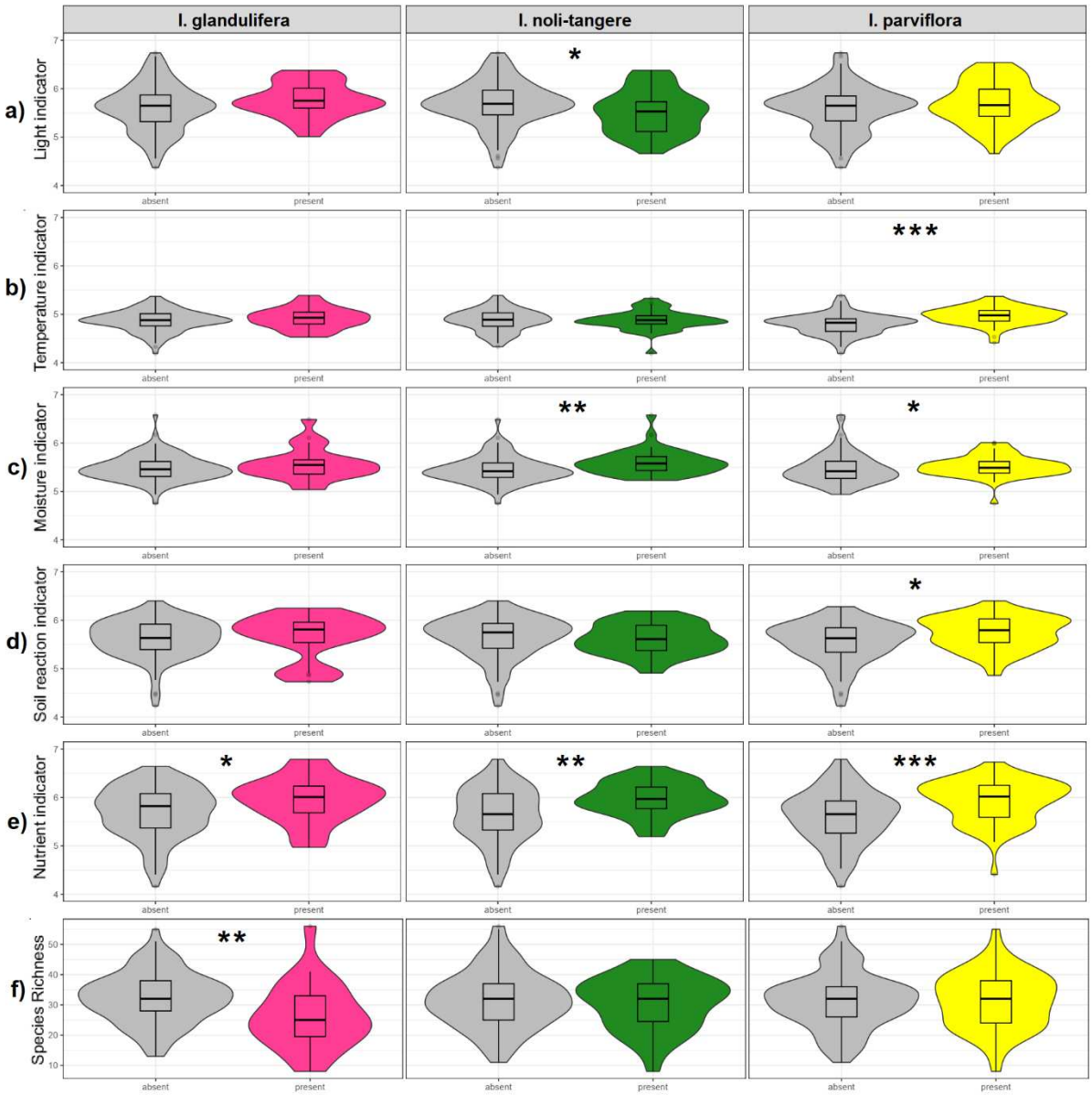

Fig. 6: Comparison of the average Ellenberg Indicator values for a) Light, b) Temperature, c) Moisture, d) Soil Reaction, and e) Nutrient of plots according to presence (in colour) or absence (grey) of the studied Impatiens species shown as violin plots and boxplots. Kruskal-Wallis-Test Significance levels: * 0.05, ** 0.01, *** 0.001

Comparing plots with and without a study species revealed a number of differences in Ellenberg Indicator values (Fig. 6). For Light, the plots with native *I. noli-tangere* had a lower Light-Ellenberg indicator than those without *I. noli-tangere* (Fig. 6). Another highly significant difference was found between plots with *I. parviflora*, which had a higher Temperature-Ellenberg indicator than the plots where *I. parviflora* was absent. More differences were found for Moisture as plots without *I. noli-tangere* and without *I. parviflora* had a lower Moisture-Ellenberg indicator value than plots where these species were present. This difference was stronger in *I. noli-tangere* than in *I. parviflora*.

However, the largest differences occurred for the Nutrient-Ellenberg indicator values, as all plots with the presence of *Impatiens* species had higher values than plots without any of them. This effect was the weakest for *I. glandulifera* and the strongest for *I. parviflora*. Interestingly, the least significant differences were found between the plots where *I. glandulifera* was present and those where this alien species was absent.

Regarding average species richness, I found that it was lower when *I. glandulifera* was present compared with plots where *I. parviflora* and *I. noli-tangere* occurred (Fig. 6f). This difference was significant between *I. glandulifera* and *I. parviflora*, and nearly significant (p = 0.0661) between *I. glandulifera* and *I. noli-tangere*. For *I. parviflora* and *I. noli-tangere*, the species richness was very similar.

Analysis of environmental factors explaining study species occurrence

To test which environmental factors influenced the occurrence of the study species in the plots, I used a linear mixed model that included these predictor variables: distance to next street (DNS), distance to next running water (DNW), mean Ellenberg Indicator Values of the plant species in the plots for Temperature and Nutrients and the Cover of the Tree Layer of the plot, with the habitat as a random variable (Table 3).

Table 2: Coefficients (Coef.), standard Errors (SE) of the coefficients, associated t-values (*t*) and p-values (p) for predictor variables and random effect estimates as variance (Var.) and Standard Deviation (SD) in the linear mixed model of the occurrence of *Impatiens* species (*I. glandulifera*, *I. parviflora*, *I. noli-tangere*) in 128 plots within the study region. Significance levels: * 0.05, ** 0.01, *** 0.001

	I. glandulifera				***I. parviflora***				***I. noli-tangere***			
Fixed Effect	**Coef.**	**SE**	**t**	**P**	**Coef.**	**SE**	**T**	**p**	**Coef.**	**SE**	**T**	**p**
Distance to next Street (DNS)	-0.000	0.000	-0.252	0.802	-0.000	0.528	-0.115	0.909	-0.000	0.000	-0.570	0.567
Distance to next running Water (DNW)	-0.000	0.000	-1.045	0.298	-0.000	0.000	-1.295	0.198	-0.000	0.000	-0.773	0.441
Mean Temperature Ellenberg-Indicator	0.315	0.009	3.472	<0.001***	0.459	0.000	3.843	<0.001***	-0.251	0.116	-2.169	0.032*
Cover Tree Layer	-0.002	0.000	-2.016	0.067	-0.000	0.000	-0.503	0.616	-0.000	0.001	-0.360	0.719
Mean Nutrient Ellenberg-Indicator	0.038	0.006	0.613	0.541	0.066	0.082	0.806	0.422	0.346	0.080	4.343	<0.001***

The model predicted that only two of the five variables had a significant impact on the occurrence of *Impatiens* species. These are the Ellenberg Indicators for temperature and nutrients. In *I. glandulifera* and *I. parviflora*, temperature had a positive effect on occurrence, whereas in *I. noli-tangere*, this effect was negative. The amount of nutrients was only significantly relevant to *I. noli-tangere* and had a positive effect on the presence of this species.

I then repeated the same procedure for the abundance of each *Impatiens* species (Table 3). The results showed that the distances to the next street (DNS) and to the next running water (DNW) cannot be used to explain the abundance of these species. The Ellenberg indicator for nutrients was the only significant predictor variable for *I. noli-tangere*; the higher the nutrient indicator, the higher the coverage of *I. noli-tangere* in the herb layer. This effect was also rather strong, with an increase of 6% for a step of one in the nutrient indicator value. Another similarly strong effect was observed with the Ellenberg indicator for temperature, although this effect was negative and just not significant. For both other species, the Nutrient indicator was not significant, whereas the Temperature indicator value was. Both *I. glandulifera* and *I. parviflora* were significantly more likely to have increased abundance in a plot if the temperature indicator was higher. For *I. glandulifera*, this effect was extremely strong, with an increase of 18% in cover for per unit step in the indicator value. In *I. parviflora*, this increase was less strong, with an approximately 7% increase in the herb cover. Furthermore, the cover of the tree layer had a significant negative impact on the abundance of *I. glandulifera* in the model, although it was very weak in comparison to temperature, as the cover of *I. glandulifera* only decreased by 0.1% for every 1% increase in tree cover.

Table 3: Coefficients (Coef.), standard Errors (SE) of the coefficients, associated t-values (*t*) and p-values (p) for predictor variables and random effect estimates as variance (Var.) and Standard Deviation (SD) in the linear mixed model of the abundance of *Impatiens* species (*I. glandulifera*, *I. parviflora*, *I. noli-tangere*) in 128 plots within the study region. Significance levels: * 0.05, ** 0.01, *** 0.001

	I. glandulifera				***I. parviflora***				***I. noli-tangere***			
Predictor Variable	**Coef.**	**SE**	**t**	**P**	**Coef.**	**SE**	**T**	**p**	**Coef.**	**SE**	**T**	**p**
Distance to next Street (DNS)	0.008	0.034	0.245	0.807	-0.022	0.020	-1.091	0.277	-0.014	0.019	-0.719	0.474
Distance to next running Water (DNW)	-0.001	0.011	-0.114	0.909	-0.012	0.006	-1.926	0.056	-0.007	0.006	-1.170	0.244
Mean Temperature Ellenberg-Indicator	18.346	5.546	3.308	0.001**	6.833	3.347	2.042	0.043*	-5.698	3.273	-1.741	0.084
Cover Tree Layer	-0.123	0.051	-2.407	0.018*	0.051	0.031	1.656	0.100	0.021	0.030	0.680	0.498
Mean Nutrient Ellenberg-Indicator	2.879	3.820	0.754	0.453	3.431	2.305	1.488	0.139	6.273	2.255	2.782	0.006**

Discussion

Colonized habitats of the three study species

When looking at the total number of plots inhabited by the three *Impatiens* species present in the study region, we observe a clear difference in abundance. This shows that *I. glandulifera* is not yet as widespread as *I. parviflora*, which seems to have become more common than the native species *I. noli-tangere* in the study regions.

Between sites inhabited by at least one *Impatiens* species and sites without any *Impatiens* species, we can see a clear difference in the cover of the vegetation layers (Fig. 3). This corresponds with the difference between the habitat types (Fig. 4), in which areas uninhabited by *Impatiens* were more often found in forests and less in succession and open areas. This avoidance of forest areas was strongest in *I. glandulifera*, which, in contrast to *I. parviflora* and *I. noli-tangere,* mostly occurred when the tree layer cover was below 50% (Fig. 3) and was never found in dense forest habitats (Fig.4). All three species are known to prefer shaded habitats, but it seems that *I. glandulifera* is not able to grow in dense forest areas, whereas *I. parviflora* and *I. noli-tangere* do.

This is despite the fact that the difference in the mean Ellenberg light indicator between inhabited and uninhabited plots of this species is insignificant (Fig.7a). Čuda et al. (2014) found in their study in a non-alpine area that *I. glandulifera* acts similarly, being less abundant in very shaded areas as well as in very open areas. The latter effect was also observed in this study, with *I. glandulifera* being much more abundant in forest edges and other ecotones where they are neither fully shaded nor unprotected from the sun because of the nearby forest. In addition, the occurrence of *I. parviflora* is strongly correlated with a denser tree canopy (Čuda et al., 2014; Florianová & Münzbergová, 2018).

The conclusion that in the study area, *Impatiens* species are therefore found more often in open habitats with lower tree layer cover cannot be made, as only *I. glandulifera* acts in this way. *I. glandulifera* is also found only sparsely in forest habitats and is most common at the forest edges in non-alpine regions (Beerling & Perrins, 1993; Kostrakiewicz-Gierałt, 2015; Čuda et al., 2017a). However, Čuda et al. (2017a) also found that it was very abundant in sparse woodlands and rare in open areas such as non-managed grasslands, roadsides, and clearings, distribution patterns in which the study areas strongly differ. *I. parviflora* is also known to inhabit forests in non-alpine regions (Barabasz-Krasny et al., 2018). Therefore, *I. glandulifera* and *I. parviflora* are similar in their habitat choice in both non-alpine and alpine regions.

When examining the inhabited habitat types (Fig.4), it becomes obvious that *I. glandulifera* and *I. parviflora* are much more common in succession areas than the native *I. noli-tangere*, which seems to perform similarly to especially *I. parviflora* in all other habitat types. This phenomenon is especially interesting because of the increasing likelihood of this habitat type to occur due to human activities such as forestry. The reason for this difference is unclear, and multiple factors may play a role. Light and temperature indicator preferences could explain why *I. parviflora* and *I. glandulifera* were more abundant in this type of habitat (Fig. 5). Florianova and Münzbergova (2017) concluded that the most important factor for the establishment of *I. parviflora* in a non-alpine area was the cover of the herb layer at the time of seedling establishment- For both *I. glandulifera* (Beerling and Perrins, 1993) and *I. parviflora* (Godefroid and Koedam, 2010) the germination occurs earlier than in *I. noli-tangere* (Godefroid and Koedam, 2010). This might result in a failure of *I. noli-tangere* to colonize new succession habitats if one of the two other *Impatiens* species has already started to colonize available patches.

Many studies have also shown that both *I. glandulifera* and *I. parviflora* benefit greatly from disturbed soils which are common in succession habitats -especially those created through forestry activities (Čuda et al., 2017a; Čuda et al., 2020; Florianova and Münzbergova, 2018; Obidzinski and Symonides, 2000)

Another interesting difference in the habitat preferences of the three *Impatiens* species was observed in ecotones. In this habitat type, *I. glandulifera* occured nearly twice as often as the other species. Čuda et al. (2015) also noted that *I. glandulifera* is spreading in habitat types categorized as ecotones in this study and Maule et al. (2000) also found that *I. glandulifera* had its highest biomass at forest margins.

The results of this study show that in the alpine region, dense forests with high foliage cover from trees are least likely to be invaded by *I. glandulifera*, whereas *I. parviflora* can occur in every habitat type, but succession habitats, open areas, and ecotones are more prone to invasion by one of these two neophytic species (Fig. 4). If we look at the ecological factors studied, there is a clear difference within these habitat groups, with forests being shadier, drier, cooler, and more nutrient-poor than succession habitats, open areas, and ecotones. Regarding these factors, both invasive *Impatiens* species showed no significant differences in this study (Fig. 5). It is therefore very interesting why *I. parviflora* grows well even in dense forests, while *I. glandulifera* was not found in this habitat type (Fig. 4). Other studies have shown that *I. parviflora* performs better in shaded and dry conditions than its invasive congener (Godefroid and Koedam, 2010), and that it has a wide tolerance for different light conditions (Reczyńska et al., 2015), which is seemingly lacking in *I. glandulifera*, which prefers mild shade (Čuda et al., 2015; Čuda et al., 2020). Čuda et al., (2015) also showed that *I. glandulifera* is doing worse in its earlier stages under canopy shade compared to open conditions. Although small or negligible, the mixed model (Tables 2 and 3) also shows a negative effect of canopy cover on occurrence and abundance, which is not the case for *I. parviflora*.

Another big difference between dense forests and more invasion-prone habitat types is disturbance. Dense forests are more or less undisturbed, whereas habitats prone to invasion by *Impatiens* species are characterized by a high disturbance rate. This might further inhibit the spread of *I. glandulifera* into this habitat.

Species composition and richness of the accompanying vegetation

In this study, all three Impatiens species tended to create large areas predominantly covered by themselves, which can be seen in Table S1, as all three species were among the six species with the highest average cover over all plots. Although this pattern can be explained by seed dispersal mechanisms (Beerling & Perrins, 1993; Chapman & Gray, 2012), high abundance and dense coverage are especially strong for *I. glandulifera*. This is a finding shared by other habitats, such as floodplains and non-alpine areas of the central europe (Beerling & Perrins, 1993; Čuda et al., 2015).

Although *I. glandulifera* was dominant in most plots where it occurred, other species still occurred at these sites but had a strongly reduced abundance compared to sites without *I. glandulifera* (Table S1). This results in rare species or species with generally low abundance vanishing completely, while more common and abundant species remain. These remaining species are most often nitrophilous perennial herbs, whereas species typically associated with forests are negatively affected by the invading species.

That *I. glandulifera* correlates to a very significantly lower species richness in the studied areas (Fig.7f) and lower abundancies of species with the exception of *Urtica dioica* (Table S1) are signs of this species potential to alter the floral composition and community as well as the diversity and communities of other groups substantially as also shown by Tanner et al. (2013) and Gaggini et al., (2018). Contrary to that, Čuda et al. (2017b) and Hejda and Pyšek (2006) reported only minor to negligible effects for *I. glandulifera*. This study suggests otherwise due to a negative correlation between *I. glandulifera* cover and species richness, as well as a lowered abundance of species in the invaded plots. These two traits of invasiveness are lacking in *I. parviflora* in most of its invaded plots, which results in *I. glandulifera* having a greater impact on native fauna than the latter.

This is also reflected in the listing of *I. glandulifera* on the list of invasive alien species of Union concern by the European Union in 2017 (Commission of the European Union, 2017) and in the blacklist of invasive Neophytes in Switzerland (SKEW, 2008; Info Flora, 2022).

Impatiens parviflora, on the other hand, had occurrences (Table S1) very similar to the native *I. noli-tangere*, and the at species richness in the inhabited plots was similar to *I. noli-tangere* and differed significantly from *I. glandulifera* (Fig.6f). This is somewhat contradictory to the findings of Obdinski and Symonides (2000), who reported a negative correlation between species richness and *I. parviflora*.

In most sites, *I. parviflora* does not have such a strong impact on other species as *I. glandulifera* does. The few sites where *I. parviflora* acted more like *I. glandulifera*, outcompeting other species, could all be described as being strongly disturbed by human impact, most often containing additional nitrogen sources, such as deposits for agricultural waste. Therefore, its invasiveness in the study area can be debated, and the results of this study might confirm that *Impatiens parviflora* mostly inhabits niches currently not used by native species (Chmura and Sierka, 2006; Diekman et al., 2016).

Ecological preferences

The comparisons between the indicator values of the three *Impatiens* species (Fig. 5a-e) show that they are very similar in their preferences for ecological conditions with only two minor significant differences. Therefore, to determine distribution patterns based on Ellenberg Indicator values, it is justified to treat them as equal in this regard.

Although the difference between *I. glandulifera* and *I. noli-tangere* in the light indicator – *I. glandulifera* prefers habitats with more light and a lack of occurrence in very shaded habitats - can be used to explain why *I. glandulifera* does not occur within forests in addition to the reasons mentioned previously.

Much more interesting is the comparison between plots where one *Impatiens* species was present versus plots where it was absent, as seen in Figure 7a-e. The species with the greatest differences is *I. parviflora*, which significantly differs from uninhabited plots in four of the five Ellenberg values, especially in temperature and nutrients. This strong difference in ecological preferences between *I. parviflora* and the native flora might be further proof that the theory of *I. parviflora* utilizing niches that are not used by native species is true (Chmura and Sierka, 2006; Diekman et al., 2016). In contrast, *I. glandulifera* differed significantly only in the Ellenberg nutrient indicator (Fig. 6a-e). The similarity in the ecological indicators between plots inhabited by *I. glandulifera* and plots without it suggests that ecological factors play only a minor role in the distribution of this species in alpine habitats.

In the native *I. noli-tangere*, the Ellenberg indicator values (Fig. 6a-e) suggest that it prefers shaded areas more than the other two species, which is interesting as this fact is not clear when only looking at the occurrence within the different habitat types. This can also be seen in Tables 2 and 3, as the model does not show an impact of the tree cover layer on the occurrence and abundance of *I. noli-tangere*.

A potential explanation for this might be that *I. noli-tangere* may perform better in shaded habitats than in open areas, but still occurs as a remnant species in the seedbank of the plot, while both *I. glandulifera* and *I. parviflora* act as colonizers of this habitat.

Another interesting conclusion can be drawn from the moisture Ellenberg indicator value, as shown in Figure 7c. The plots where *I. parviflora* and *I. noli-tangere* were present had significantly higher mean values, whereas no significant difference was found in *I. glandulifera*. This is interesting, as *Impatiens glandulifera* is known to be a very common species especially on riverbanks and floodplains (Pyšek and Prach, 1995; Hulme and Bremner, 2006), but it seems that in the study region moisture and the availability of water aren't a big factor in the distribution of *I. glandulifera*.

Environmental factors explaining occurrence and abundancy of *I. glandulifera* and *I. parviflora*

The results of the mixed model (Table 2) show that, interestingly, the two main methods of seed dispersal for *I. glandulifera* in other areas – through streams (Čuda et al., 2017a; Čuda et al., 2020) and more recently through roads via wheels on roads (Čuda et al., 2020) – seemingly have no significant effect on the distribution of this species within the study area. This finding contradicts the hypothesis of this study that the main factor for the occurrence of invasive *Impatiens* species is human activity and spread through road infrastructure. However, the results also contradict the observations in the field as well as streams and flooding events, the most important means of long-distance seed dispersal for *I. glandulifera* in non-alpine regions (Čuda et al., 2017a), as most important factor. Instead, temperature seems to be the main factor driving the occurrence of the two invasive Impatiens species. On the other hand, for *I. noli-tangere*, temperature was a significant factor, but nutrient availability was the main factor for the occurrence of this species.

Looking at abundance (Table 3), the picture is quite similar to that of occurrence. This results in distribution factors such as roads and streams serving as vectors of seed dispersal having no significance over the occurrence and abundance of *Impatiens* species, while factors closely linked to habitat can be used to best explain the distribution of all three species.

These results lead to the conclusion that the original hypothesis of this study is incorrect and that human activities are not the main factor for the distribution of invasive *Impatiens* species. However, this seems contradictory to the observations in the field. There might be some reasons why this study was unable to confirm that factors associated with seed distribution, such as roads and streams, are the main factors for the occurrence of invasive *Impatiens* species.

One reason might be that the distance to the next street is not a sufficient variable to assess human impact, and other factors such as land use or forestry may be better suited variables addressing this factor, as Čuda et al. (2020) already identified forestry and logging activities as important vectors of seed dispersal in non-riparian habitats. In addition, the study design may have to be adapted for smaller plots to yield better results, as I could often observe dense occurrences of invasive *Impatiens* species next to a street which I would not have been able to include in this study as they would not fit into a plot without creating artificial effects. In addition, the influence of human impact might become clearer if areas of very strong human impact, such as areas within villages, are taken into account as well.

Another reason could be that the human impact in the study areas was already too high to be detected with one factor alone. Due to winter tourism, hiking routes, forestry, agriculture, infrastructure projects and other human activities the "background human impact" could already be high enough to have already distributed the seeds of both species into even remote areas where they established populations that act as source populations for further spreading. To rule this out, further comparison of the study region with a protected area would be required.

One reason regarding streams and rivers as a factor might be the difference in geomorphology and soil composition. Within the study area plots reached from flat and muddy habitats around the rivers at the bottom of the valleys to steep slopes in the mountains. It would therefore be interesting to see if the geomorphology of streams and habitats, as well as their soil composition has an impact on the distribution of *Impatiens* species along the stream, and if this impact may explain why distance to the next stream is not an important factor for the occurrence of *Impatiens* species by its own.

Conclusion

To conclude, the study showed that both species are established in the study region, but *I. parviflora* seems to be more abundant and widespread than its congeners. Therefore, I conclude that there are differences in the distribution patterns of *I. parviflora* and *I. glandulifera*. One major difference is that *I. glandulifera* does not seem to be able to inhabit dense forests, which *I. parviflora* is very well able to. Other differences can be seen in the preference for different ecological factors within both species. However, there are also many similarities, such as the preference for open and successional habitats due to higher soil disturbance, temperatures, and light availability compared to closed forest habitats.

This makes it clear that disturbed habitats such as succession areas are the most prone to invasion by both study species, but other habitat types such as ecotones and open areas are also vulnerable to invasion. In particular, ecotones such as forest margins are in danger of invasion by *I. glandulifera*.

On the other side, forests are less likely to be invaded by this invasive species. Therefore, forest management should be of high concern for the management of *I. glandulifera* and the control of its distribution, which is of high interest, as this study shows that *I. glandulifera* is a threat to the species richness and can cause changes in the vegetation composition in the study region. For *I. parviflora*, this is not the case, but some findings of this study suggest that *I. parviflora* might be using free niches not occupied by native species and have less negative impact on the local flora.

The hypothesis that human impact is the main driving factor behind the distribution cannot be verified with the methods used in this study, and habitat and ecological factors are the main drivers behind the distribution pattern of *Impatiens* species. Human impact as a factor therefore needs more investigation and further studies using other proxies for human impact than roads, such as forestry intensity or other land uses.

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AI-Usage

The paperpal language suggestion tool (www.paperpal.com) was used as a refining tool to enhance the writing of and improve the quality of the language used in this study. No other dedicated artificial intelligence programs were used in this study.

Appendix

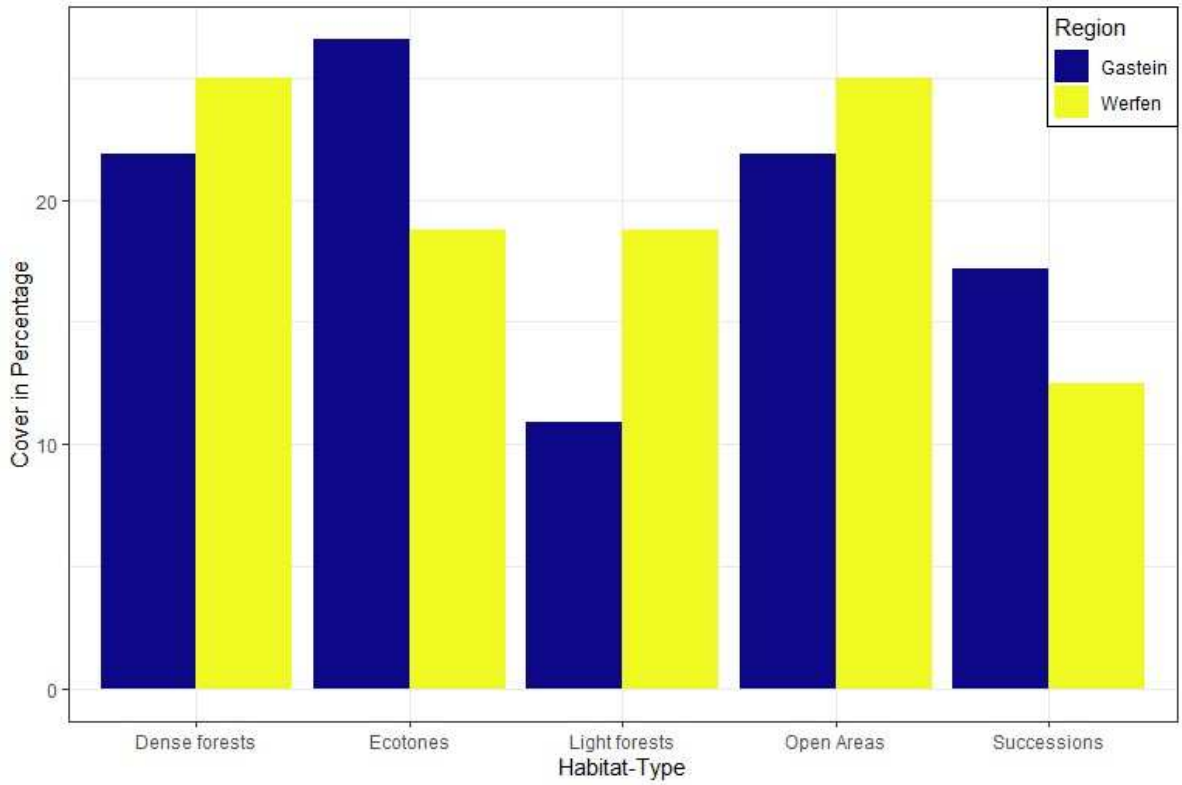

Fig. S1: Distribution of habitats (dense forests, ecotones, light forests, open areas with tall perennial communities, succession communities) as percentages according to each region. In blue are all plots in the Gastein Region and in yellow all plots in the Salzach Valley near Werfen.

Table S1: Average percentages of cover of the three Impatiens species and all species found in the herb layer within 25 or more (20% or more) of all plots according to the absence or presence of Impatiens species within the plot in five groups: *I. parviflora*, *I. glandulifera*, *I. noli-tangere*, No Impatiens and All plots. Percentage values were rounded to one digit. The value in brackets next to the species name indicates the number of plots in which it occurred.

Species (occurrences)	**I. parviflora** (cover in %)	**I. glandulifera** (cover in %)	**I. noli-tangere** (cover in %)	**No Impatiens** (cover in %)	**All plots** (cover in %)
Impatiens parviflora (57)	14.9	2.4	5.6	0.0	6.6
Impatiens noli-tangere (39)	2.4	1.2	14.9	0.0	4.5
Impatiens glandulifera (23)	7.7	50.1	8.2	0.0	9.0
Rubus idaeus (96)	8.0	6.2	6.5	5.6	6.9
Oxalis acetosella (78)	9.8	3.6	17.7	14.1	12.5
Urtica dioica (78)	8.2	9.3	8.1	1.5	5.3
Senecio ovatus (76)	1.9	2.0	3.3	4.7	3.4
Fragaria vesca (67)	0.8	0.3	0.7	1.0	0.8
Acer pseudoplatanus (65)	0.8	0.1	0.6	0.8	0.7
Angelica sylvestris (56)	1.5	1.7	1.0	1.7	1.5
Athyrium filix-femina (56)	1.1	0.7	2.6	1.5	1.6
Geranium robertianum (56)	2.6	0. 5	2.7	0.6	1.8
Galeopsis tetrahit (55)	3.8	1.0	2.8	0.8	2.1
Rubus fruticosus agg. (54)	12.8	11.2	17.3	8.3	11.8
Petasites albus (50)	2.2	1.0	11.2	7.0	5.9
Ranunculus repens (49)	1.0	0.4	1.2	0.6	0.9
Epilobium montanum (48)	0.2	0.1	0.3	0.3	0.2
Dactylis glomerata (46)	1.0	1.1	0.9	0.5	0.8
Dryopteris filix-mas (45)	1.6	1.0	1.8	1.5	1.5
Galium sylvaticum (42)	0.8	0.7	0.3	0.4	0.5
Solidago virgaurea (39)	0.2	0.1	0.1	1.1	0.5
Salvia glutinosa (38)	0.9	0.1	0.2	1.3	0.8
Lactuca muralis (37)	0.4	0.0	0.3	0.9	0.5
Tussilago farfara (37)	2.9	3.4	4.5	1.5	3.1
Poa trivialis (36)	0.8	1.2	0.4	0.5	0.7
Sorbus aucuparia (36)	0.3	0.0	0.2	0.5	0.3
Fraxinus excelsior (35)	0.4	0.1	0.4	0.4	0.4
Chaerophyllum hirsutum (32)	0.3	0.2	2.6	0.2	1.0
Prenanthes purpurea (32)	0.3	0.1	0.5	1.0	0.5
Lysimachia nemorum (31)	1.1	1.0	0.8	0.3	0.7
Brachypodium sylvaticum (30)	0.4	0.1	0.3	1.9	0.8
Hypericum maculatum s.str. (29)	0.3	0.1	0.5	0.8	0.5
Eupatorium cannabinum (28)	1.2	1.5	0.4	2.3	1.3
Glechoma hederacea (28)	2.7	2.1	0.4	0.2	1.4
Mentha longifolia(28)	2.7	1.9	2.5	0.2	1.6
Picea abies (28)	0.1	0.0	0.1	0. 7	0.3
Luzula luzuloides (26)	0.3	0.1	0.2	1.5	0.6
Geum urbanum (25)	0.9	0.2	0.6	0.0	0.4
Poa sp. (25)	0.9	0.1	0.4	1.2	0.9

Zusammenfassung

Innerhalb der Gattung *Impatiens* gibt es in Mitteleuropa zwei gebietsfremde Arten, *I. parviflora* und *I. glandulifera*, und eine in dieser Region natürlich vorkommende Art *I. noli-tangere*. Während beide invasiven Arten in Flusslandschaften und Wäldern in Mitteleuropa gut untersucht sind, wurden ihre Verbreitungsmuster innerhalb der montanen Höhenstufe der Alpen noch nicht in gleichem Ausmaß erforscht. In dieser Arbeit habe ich Auftreten und Abundanz der drei *Impatiens* Arten in zwei Tälern in den Alpen untersucht und versucht die Unterschiede in den Verbreitungsmustern der *Impatiens* Arten, den Effekt der gebietsfremden Arten auf die heimische Flora sowie die wichtigsten Faktoren hinter der Verbreitung von invasiven *Impatiens* Arten in dieser Region herauszufinden. Dafür habe ich 64 Parzellen mit 50 m² sowohl im Gasteinertal und im Salzachtal bei Werfen in Salzburg Österreich etabliert, und in diesen die Deckung aller auftretenden Arten durchgeführt und die Parzellen unterschiedlichen Habitattypen zugeordnet. Danach habe ich die Daten analysiert und ökologische Faktoren wie Ellenberg Indikator Werte und Distanzen zu bekannten Verbreitungsvektoren wie Straßen und Wasserläufe für jede Parzelle eingearbeitet, um ein Modell zu erstellen, mit dem die wichtigsten Faktoren für die Verbreitung einzuschätzen.

Die Stude hat gezeigt, dass sowohl *I. parviflora* als auch *I. glandulifera* in den Untersuchungsregionen weit verbreitet sind, aber auch, dass es zwischen diesen Arten Unterschiede in der Habitatwahl und Verbreitung gibt. Zusätzlich hat sich gezeigt, dass alle drei *Impatiens* Arten untereinander verglichen sehr ähnliche ökologische Präferenzen haben, aber die Unterschiede zwischen Parzellen, die von *Impatiens* Arten besiedelt werden, und jenen ohne *Impatiens* Arten signifikanter waren und sich zwischen den drei Arten unterscheiden.

Das im Zuge dieser Arbeit erstellte Modell zeigte, dass die beiden bekannten Verbreitungsfaktoren keinen signifikanten Einfluss auf die Verteilung der drei Arten haben und das ökologische Faktoren der Habitate wichtiger für die Verbreitungsmuster sind. Die Studie hat abschließend auch gezeigt, dass Ökotone und gestörte Habitate am verwundbarsten gegenüber einer Invasion durch *I. parviflora* als auch *I. glandulifera* sind, während dichte Wälder mit wenig Störung generell nicht von Invasionen durch *I. glandulifera* betroffen sind, jedoch vom weniger invasiven *I. parviflora* besiedelt werden.

Schlagwörter: *Impatiens glandulifera, Impatiens parviflora, Impatiens noli-tangere*, invasiv, gebietsfremde Arten, Verteilungsmuster, Ellenberg Indikator Werte, Störungen