It's a marathon, not a sprint: The management of *Impatiens glandulifera* at the upper reaches of the river Blees in the Naturpark Our (Luxembourg)

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Abstract. The Himalayan balsam (*Impatiens glandulifera* Royle) is a globally spreading neophyte, which is frequently found along rivers and streams in Luxembourg. To prevent or to fight mass stands of the species, different national management measures along various watercourses are in progress. One of these projects encompasses a 4 km long section located at the upper reaches of the river Blees and its tributaries. Here different control measures were carried out annually during the flowering period of the neophyte since 2017. To evaluate the success of this invasive species management, two surveys were conducted each year, one before (summer – June/July) and one after (autumn – September/October) the removal. Since manual methods (eradication of *I. glandulifera* by hand) in 2017 were not successful, the management was significantly improved from 2018 onwards using brushcutters for larger and denser populations. In the following years a combination of mechanical and manual measures was used, until mechanical control methods were no longer necessary after 2020. As the number of stands declined, the workload also decreased, to a minimum in 2020 and 2021. This minimal effort was probably insufficient, as there was an obvious increase of *I. glandulifera* in 2021.We recommend an adapted management of *I. glandulifera* with a combination of mechanical and manual measures. Which measure is finally used depends not only on the accessibility or the population density of an area, but also on the sensitivity of the occurring biotopes. To ensure a sustainable success of eradication, the measures must be carried out over a long period of time, whereby a certain amount of work must not be undercut. Furthermore, consequential damage to abiotic factors must also be restored after the complete removal of *I. glandulifera*.

Keywords. *Impatiens glandulifera,* Himalayan balsam, Blees, invasive species, IAS, control measures, management, eradication.

1. Introduction

Invasive non-native plants can cause significant ecological damage to the natural environments they invade. Hence, they are one of the major threats to biodiversity worldwide (Sala et al. 2000). The Himalayan balsam (*Impatiens glandulifera* Royle), native to the Himalayan foothills of India and Pakistan, is such a highly invasive species. In the past years, the species has spread rapidly in Europe, with some models even predicting that the plant will colonize much larger areas in the future due to the extended growing season caused by climate change (Mujuni 2014). The Himalayan balsam can be considered as a so called "*back-*

seat driver of changes" (Bieberich et al. 2021); the plant benefits from previous changes in ecosystems and then leads to further changes as a result of this establishment. The success of *I. glandulifera* as an invasive species can be related to several factors, including the high phenotypic plasticity (Skálová et al. 2012) and the good floating ability of young seeds, which is associated with a high dispersal ability along water bodies (Najberek et al. 2020). In addition, dead plants of the species form a good fertilizer for following generations, while there are no positive effects (Mujini & Graae 2015) or even negative effects by phytotoxicity for native plant species (Baležentienė 2018). Due to these factors and mechanisms, *I. glandulifera* has competitive advantages over native wild plants and can form dense monotypic stands (Beerling & Perrins 1993, Maule et al. 2000). The annual death of the plants may lead to soil erosion through missing roots and to a higher vulnerability of the underlying soil during winter (Greenwood et al. 2018). This suggests that, besides biotic impacts, the plant also causes abiotic problems in the colonized areas. Although this therophyte has the potential to be deployed for phytoremediation (Coakley et al. 2019) and medicinal purposes (Szewczyk & Olech 2017), the collective evidence of the mentioned negative impacts on native plants and ecosystems necessitate its regulation. Therefore *I. glandulifera* has been considered as an "Invasive Alien Species of Union concern" under European law since 2017 (European Union 2017a). The trade and deliberate planting of Himalayan balsam are prohibited; furthermore, new populations should be eradicated quickly, and established populations must be managed (European Union 2017b).

The Himalayan balsam is known as an ornamental plant in Luxembourg for more than a century and the first record in the wild dates from 1958, with an increased tendency to spread from the mid-1980s (Krippel & Proess 2017, Ries & Krippel 2021). The species is mainly found in riparian habitats, and currently nearly 8,000 observations are documented; most populations having been detected along rivers like Our, Blees, Sûre, Attert and Alzette (MNHNL 2000-). In the risk assessment for Luxembourg the species is classified as A3 (3+3+2+3) according to the ISEIA protocol based on Branquart (2009). Hence, *I. glandulifera* is on the Black List (Ries et al. 2013) for invasive species with a high environmental risk. Moreover, the species received an overall risk score of 0.52 in the Harmonia+ protocol assessment (Ries et al. 2020).

To reduce the distribution of *I. glandulifera* in Luxembourg several projects have been launched in the past. For example, the federation of municipalities SIAS started an eradication project along the river Syr in 2016. Another project started one year later (2017) at the small river Blees and its tributaries. The long-term goal is to free the whole 20 km of this river from stands and individuals of *I. glandulifera*. In a first step of this pilot project from the Nature Park Our (in co-operation with the National Museum of Natural History) different eradication methods and their required workloads to control the Himalayan Balsam were tested along a 4 km long section at the upper reaches of the river; at the source area of the river no measures were performed, as no populations of the invasive species occurred here. To evaluate the success of the control methods, two surveys of *I. glandulifera* were performed annually, one before (summer – June/July) and one after the removal during the flowering period of the species. The observations and conclusions of our surveys from 2017 to 2021 at the Blees will be presented in the present article. The results from this study can be used to determine the future management of *I. glandulifera* on other affected rivers in Luxembourg.

2. Material and methods

2.1. Study area

From 2017 to 2021, a pilot project for the management of *I. glandulifera* was executed at the river Blees in the Naturpark Our in the northeast of Luxembourg (Fig. 1a). This river is particularly suitable for such a pilot project, as large numbers of ecologically valuable biotopes occur here; many already affected by invasive species. The study area covers a section of about 4 km at the upper reaches of the Blees and its tributaries; the source area of the Blees itself was not part

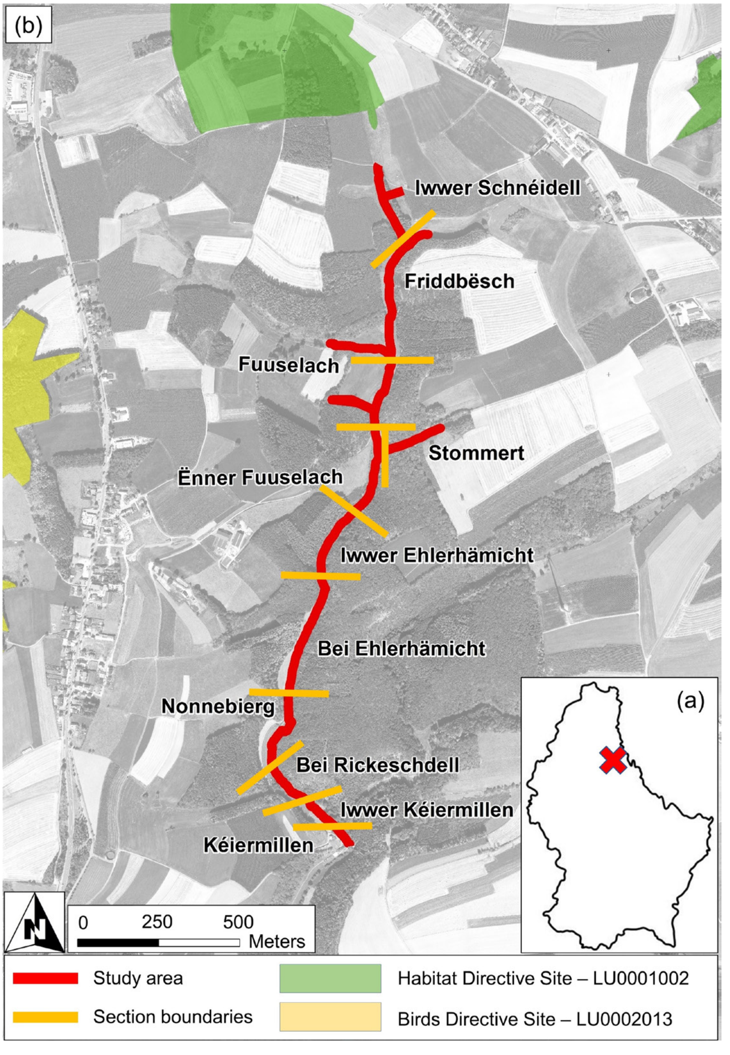

Fig. 1. (a) Location of the study area in the northeast of Luxembourg; (b) Study area of *Impatiens glandulifera* along the upper reaches of the river Blees (red) in the Naturpark Our; the study area was divided into eleven sections (boundaries in orange).

of this study, as no individuals of the invasive species were found here and to avoid a negative impact on these areas with sensitive biotopes. We chose the upper reaches of the Blees for the project, to avoid further downstream invasions in the future. For this project, the study area at the Blees was divided into 11 sections (Fig. 1b).

2.2. Management and estimation of the population size of *Impatiens glandulifera*

In the past five years, different methods were used to eradicate the populations of *I. glandulifera* along the Blees. The management was performed from June to October (depending on the annual weather conditions), during the flowering period of the species. It is essential to start the measures before seed formation of *I. glandulifera*. While in 2017 only manual actions were carried out to fight the stands of the invasive plant (removal per hand), from 2018 onwards mechanical measures (multi-annual mowing with brushcutters) were also used to control *I. glandulifera*. The latter method was implemented where larger, more coherent stands of the Himalayan balsam were found and where the study area was accessible for such equipment. To compare the annual workload of the management, the time spent to control the invasive plant was recorded each year. All control measures were carried out in the flow direction of the river, to prevent a possible transport of seeds to upstream areas.

In each year of the study period the population size of *I. glandulifera* was examined twice a year, once before the start of the management in summer (June / July) and once after the end of the measures in autumn (October). While the first record was used to control the success of the management of the past year and to adapt – if necessary – the annual eradication methods to the current distribution of the *I. glandulifera* stands, the second record was used to show the success of the work carried out during the latest flowering period. On each of the 10 surveys we marked the position of the stands with a GPS device (Garmin GPSmap 64s) and estimated the number of individuals for each stand using a system with four categories: 1 (≤ 10 individuals), 2 (11-100 individuals), 3 (101-1,000 individuals) and 4 (> 1,000 individuals).

So, the total population size for each survey could be calculated for the whole area. Furthermore, a distinction between punctual and linear stands of the invasive species was made. While punctual stands are uniform clusters on certain areas, linear stands are contiguous occurrences alongside the water courses.

To visualize the expansion and density of the individual stands for each of the 10 surveys, heat maps (Kernel Density Estimation) were created with the program QGIS 3.22.3 'Białowieża'.

3. Results

3.1. Development of the population size

In the beginning of the study in summer 2017 the total calculated population size of *Impatiens glandulifera* along the river Blees was 19,680 individuals. Following the removal by hand the population size decreased to 10,275 individuals after the flowering period in autumn of 2017. The highest population size was observed in summer 2018 (23,705 individuals). Thereafter, the population decreased further following another management event during the flowering period in 2018. Since autumn 2018 no linear stand could be observed any longer and the calculated individual numbers stayed at a consistent level, with the lowest numbers in summer 2020 and subsequently a small increase of individuals. Although in both surveys from 2021 the calculated number of individuals were higher than in 2020, the sum of individuals reached only 5 % of the amount observed in summer 2018 (Fig. 2).

The size of the stands developed in a similar way over the years. After a peak in summer 2018, no larger stands (category 3 and 4)

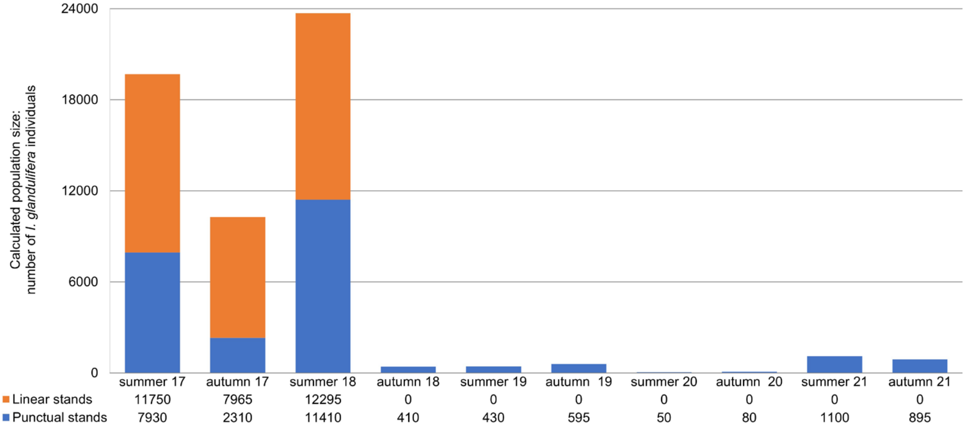

Fig. 2. Calculated number of *Impatiens glandulifera* individuals for each of the ten performed surveys (2017-2021); the stands are divided into linear (orange) and punctual (blue) distributions. Each year two surveys were executed, one before (summer) and one after (autumn) the removal of the plant during its flowering period.

were detected in the following surveys. In summer 2020 only one single stand (category 2) was observed in the whole study area at the section *Stommert*. In summer 2021, two larger stands of category 3 were again found along the upper reaches of the Blees (Tab. 1).

3.2. Workload

The workload spent on management measures over the whole flowering period of *I. glandulifera* increased from 2017 to 2018, reaching a peak of about 250 hours of work for the eradication in the whole study area of 4 km; this is about 62.5 hours of working time per km of the river. In the following years, the management effort decreased from about 55 hours in 2019 to a stable level of 22-24 hours (5.5 to 6 hours per km) in the last two years of the study (Fig. 3).

3.3. Heatmaps

In 2017, larger stands of Himalayan balsam were distributed almost continuously in the entire study area along the Blees. Since summer 2018 the expansion of the species in many parts of the southern study area decreased. In some of these areas the species even disappeared completely. In contrast to this, the population density increased in the central and northern areas. With few exceptions, *I. glandulifera* had almost been entirely relegated to these ranges of the study area since autumn 2018 (remaining stands in the sections *Iwwer Ehlerhämicht*, *Enner Fuuselach*, *Stommert* and *Iwwer Schnéidell*). After

Table 1. Development of the punctual / linear stand sizes from *Impatiens glandulifera* in the study area at the upper reaches of the river Blees (2017-2021) – stand size categories: 1 (≤ 10 individuals), 2 (11-100 individuals), 3 (101-1,000 individuals), 4 (> 1,000 individuals).

Date		2017		2018		2019		2020		2021	
		summer	autumn	summer	autumn	summer	autumn	summer	autumn	summer	autumn
Category (stand sizes)	1	96 / 0	112 / 3	202 / 9	52 / 0	46 / 0	49 / 0	0 / 0	6 / 0	10 / 0	19 / 0
	2	19 / 5	25 / 19	38 / 5	3 / 0	4 / 0	7 / 0	1 / 0	1 / 0	1 / 0	16 / 0
	3	3 / 3	1 / 4	7 / 4	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	2 / 0	0 / 0
	4	1 / 2	0 / 1	1 / 2	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0

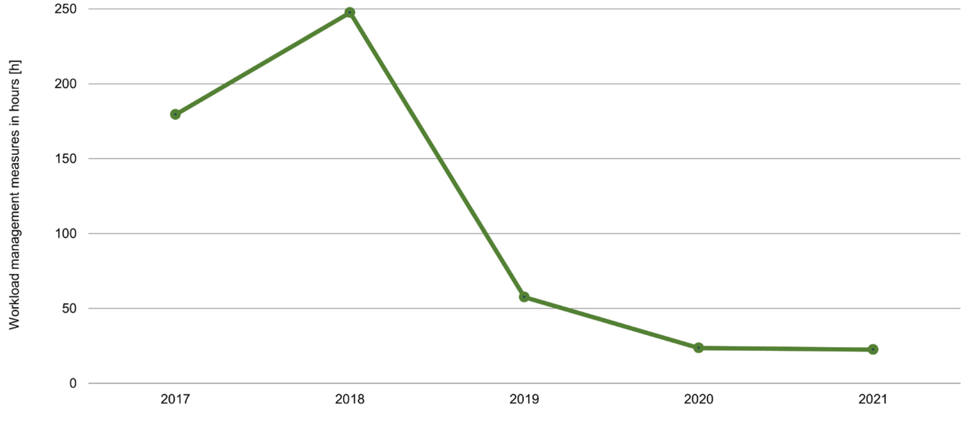

Fig. 3. Development of the workload in hours [h] for the removal of *Impatiens glandulifera* at the upper reaches of the Blees for each year of the study.

only one stand was found in the entire study area in summer 2020 (section *Stommert*), more and larger stands could be observed again in the following surveys in the central and northern parts of the study area (Fig. 4).

4. Discussion

4.1. Development of *Impatiens glandulifera* and the workload during the study

The ten conducted population estimates of *I. glandulifera* show an evident decline of the distribution of the plant within the study area across the assessed period. Although there was a slight expansion of the invasive species at the end of the study in 2021, the number of individuals and stands remained substantially lower compared to the situation at the beginning of the project. This sharp decline after an initial increase in population density (from 2017 to summer 2018) coincides with the onset of mechanical measures to control the species. After an initial removal of the plant by hand in 2017, multi-annual mowing with brushcutters seems to bring the desired effect to control larger stands of *I. glandulifera*. In addition to the decline of all larger stands, the linear stands alongside longer parts of the river had also disappeared after the use of mechanical meas-

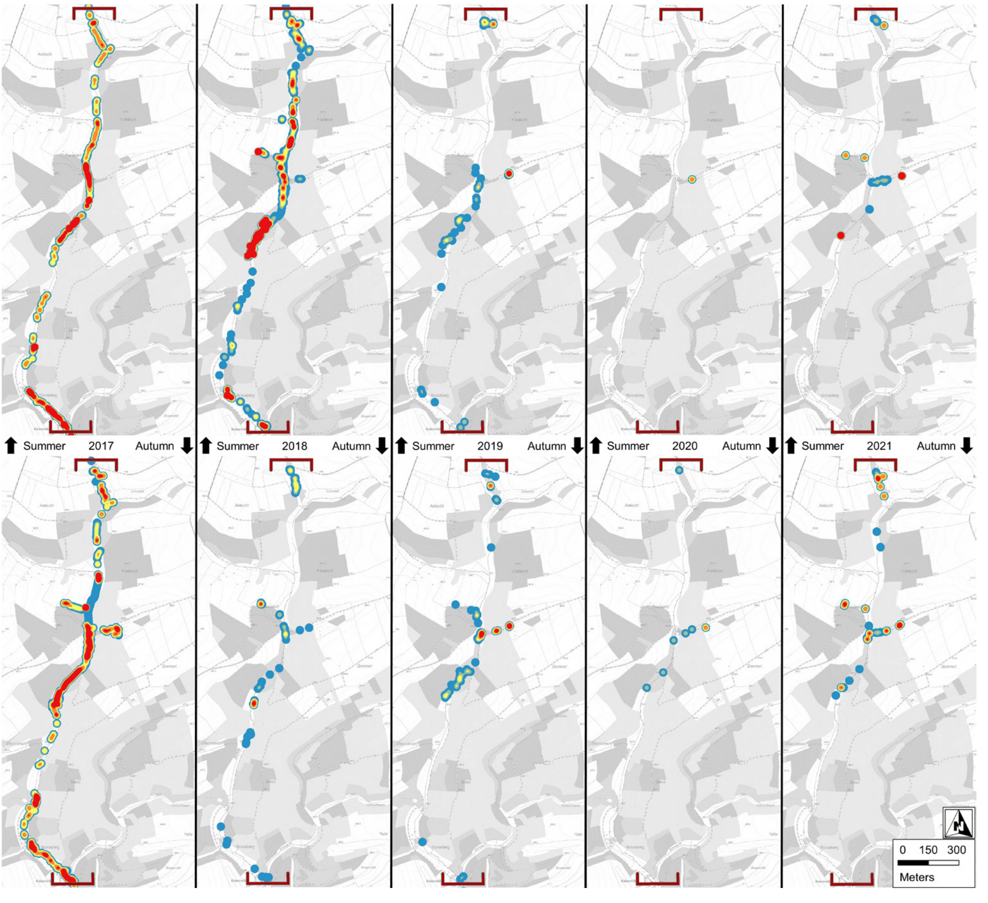

Fig. 4.: Heatmaps showing the distribution and density of the populations of *Impatiens glandulifera* at the upper reaches of the Blees for each year of the study. The colour scale ranges from small (blue) to large (red) densities; in areas without colours, no individuals of the species were found. For each year two surveys were executed, one before (summer) and one after (autumn) the removal of the plant during its flowering period.

ures. Based on our observations, the best method to control dense and larger populations of *I. glandulifera* is a multiple deep mowing (below the first node of the stem) before flowering or between flowering and seed maturity (late July to early October). This approach safeguards to permanently reduce or eradicate the stands and corresponds with previous results from similar studies (Umweltbüro Grabher 2008, Bundesamt für Naturschutz 2015, Arbeitsgruppe invasive Neobiota 2016). Despite the advantages of mechanical methods, they must be used with care. This intensive treatment of whole areas affects not only the individuals of Himalayan balsam, but also all other species that occur here. Due to the collateral damage to the native flora, mechanical measures should only be used where and when they are necessary. This is of great importance for our study area, where sensitive biotopes with high ecological values like *Molinia* meadows or *Nardus* grasslands can be found. Given the risk of creating collateral damage by species-indifferent mowing practices, it must be decided on a case-by-case basis whether the efficiency of a mechanical treatment outweighs time-consuming selective manual removal. The removal by hand would be useful in sections like *Fuusselach* for example. Here well-preserved protected biotopes with rare species such as the bogbean (*Menyanthes trifoliata* L.) can still be found, and the populations of *I. glandulifera* are not dense enough to overgrow the entire area and displace the characteristic species of these protected biotopes (Bieberich et al. 2018, Power & Vilas 2020). However, if stands in protected biotopes are too dense for successful removal by hand, careful mowing with a brushcutter is recommended; subsequently, a manual removal should be used to ensure continuity of results (Gelpke 2012). Generally, we recommend a combination of mechanical measures and subsequent manual removal. This combination of both techniques should be used wherever denser and larger stands of the invader are found in non-sensitive biotopes and where accessibility with the equipment is possible. Every time measures are implemented, it has to be ensured that the uprooted and mowed plants are properly disposed of. If the remains of the plants are left in the riparian area, there is a risk of (additional) eutrophication of the water body or adjacent biotopes and additionally a risk of further dispersal of the seeds through post maturation (Umweltbüro Grabher 2008).

The general rule for interventions is as late, as much, and as accurate as possible (Gelpke 2012). Due to the long germination period of *I. glandulifera*, there is a risk that small plants and seedlings will not be discovered during the first control measures, if the first survey of the species is too early. In addition, observations must be carried out over the entire flowering period, as seeds from the seed bank can still sprout in late summer or early autumn. The same applies if the plants are teared or cut off too high; if the roots remain in the soil, plants can sprout again and form seeds. Measures carried out too late must also be avoided, as seeds can already be present and spread widely upon any physical contact (Umweltbüro Grabher 2008, Gelpke 2012, Naturfreunde Österreich 2016). The primary goal of the management should thus be a time adjusted and complete elimination of all individuals of *I. glandulifera* in a certain area. Even one remaining individual is sufficient to form about 4,000 seeds and to disperse them up to 7 meters via its scattering mechanism (Landratsamt Starnberg 2018). This explosive reproductive capability was also evident during the last years of the study. After only one stand was found in summer 2020, the number and distribution of the species increased again in the subsequent surveys.

This increase was probably due to an insufficient workload applied in the years 2020 and 2021. Regarding the time required for the control measures during one flowering period, a larger decrease in the workload is visible since the greatest extent in 2018. The development of the time needed for control measures corresponds to the data provided by Pirotte (2017) on *I. glandulifera* at the Ourthe (Belgium). In this project, workload and costs were significantly reduced on a river section of 26 km along the eastern Ourthe (*Ourthe orientale*) over a study period of 7 years. At the beginning of the project in 2009, the workload was 500 hours for the survey area, which declined to 40 hours per flowering period after 5 years (Pirotte 2017). The results of our study are similar, where after a maximum of 250 hours in 2018, the amount of time needed for measures per flowering period in 2020 and 2021 was about 90 percent less (22-24 hours). However, judging by the population increase seen in 2021, this decrease of the workload in 2020 and 2021 seems to be too strong for a sustainable control of the species in our study area. So, a certain minimum amount of work remains necessary for an effective management of the species. In our case, this value is presumably in the range of 24 to 55 hours of workload for the entire study area. While the 55 hours of work from 2019 were enough to reduce the stands in the following survey in summer 2020, the workload from 2020 with 24 hours was apparently insufficient to prevent population growth. In the future, all stands along the Blees, regardless of density and distribution, must be eradicated before seed maturation is complete. Even if no more plants are found in the study area, it is highly recommended to continue inspections for at least the next 6-8 years, based on the longevity and the germination capacity of the seeds of *I. glandulifera*. (Koenies & Glavac 1979, Lienenbecker 1998, Landratsamt Starnberg 2018).

4.2. Future tasks in the study area

After the focus has so far been primarily on the open land areas, humid forest areas near the river must also be investigated in the future. Although *I. glandulifera* is less competitive in forest areas than along river and stream banks, and its spread in forests is consequently rather limited (Čuda et al. 2020), an increasing spread of the species in forests and forest edges could be observed in Luxembourg (Krippel et al. 2020, Ries et al. 2022). Due to the increased flexibility to shade or light availability of the Himalayan balsam compared to individuals from native populations, stands of the species can also grow in shadier forest patches (Gruntman et al. 2019). This can have negative impacts on plants and mycorrhizal fungi native to the affected forest (Čuda et al. 2020). As additionally (re)spreading events from the affected forest areas are possible in the future, these shady areas along the Blees should be additionally examined in future surveys.

Short-term measures should be accompanied by longer-term measures in the near future to eliminate the effects of colonization with *I. glandulifera*. As Bieberich et al. (2021) postulated, *I. glandulifera* is a so-called "*back-seat driver*". The plant benefits from disturbances or changes in ecosystems like an increased nutrient input from surrounding arable fields. These disruptions of the natural environment led to the settlement and mass spread of the species. Once the species has spread, not only biotic factors, but also abiotic factors are altered, making the plant a (negative) driver of future changes. Although positive effects of the species have been observed for pollinators due to the plant's huge production of nutritious nectar (Chittka & Schürkens 2001), the negative impacts on the native flora and fauna outweigh the positive effects. In addition to plant diversity (Hulme & Bremner 2006), there are mainly invertebrates (Tanner et al. 2013, Wood et al. 2020) or fungal communities (Ruckli et al. 2016) that are affected. Moreover, abiotic factors such as PH value or even the nutrient content can be changed by the occurrence of *I. glandulifera.* Coakley & Petti (2021) were able to show impacts of the species on soil moisture and temperature, caused by increased shading. It is important to note that the control measures themselves can also have an impact on ecosystems affected by the alien species. It is well known that manual and mechanical measures can lead to impacts on the mycorrhizal network, which is already disturbed by *I. glandulifera,* or to soil erosion in autumn and winter due to the loss of roots in the soil after the removal (Tanner 2017, Coakley & Petti 2021). Hence, after a complete eradication of *I. glandulifera,* further conservation measures are needed to recover these ecologically important factors. Relevant measures can range from reseeding with native species to planting soil-stabilizing plants along streams. If permanent and sustainable control of the species and its consequences is guaranteed in the upper reaches of the Blees, areas further downstream can subsequently be tackled.

4.3. Further measures to improve the control of *I. glandulifera*

Instead of mowing several times a year, grazing could help in areas where the number and density of *I. glandulifera* stands is increasing again. In some regions, good results have been achieved with cattle grazing, e.g. with Heck cattle (Umweltbüro Grabher 2008). According to this publication, the cattle preferentially grazed *I. glandulifera*, while the other vegetation was largely spared. Similar results were observed in our study. In the grazed areas of the sections *Nonnebierg* and *Bei Ehlerhämicht* were either no stands or gnawed plants or fewer individuals than in the adjacent ungrazed areas. Hence, site-specific grazing on the Blees or other rivers could be an appropriate control measure, especially where the terrain is not suitable for work with mechanical equipment, or where the removal of uprooted and mowed plants is difficult.

A modern and time-saving method for further surveys of the expansion of I. *glandulifera* might be the use of drone and satellite data. This could shorten up the surveys, where – traditionally – the whole study area must be walked by foot. Since the Himalayan balsam is a plant species for which the use of remote sensing data is promising, larger areas could be investigated with these techniques (Skowronek et al. 2018).

In contrast, we do not recommend the use of the small phytoparasitic fungus *Puccinia komarovii* var. *glanduliferae* to control the Himalayan balsam. This rust fungus, native to Asia, was identified on *I. glandulifera* during a study from 2006 to 2010. It should aid in the biological control of the Himalayan balsam, which is currently being investigated in the United Kingdom (Tanner et al. 2015a, 2015b). As there are no long-term studies available yet, no definitive statements can be made about the actual success of this control measure or the impact of the fungus on the local ecosystems. Hence, this type of biological control should not be used in Luxembourg, at least not as long as valid data from long-term studies are not available (Currie et al. 2019, Ellison et al. 2020).

5. Conclusion

The aim of the study was to systematically document the development of *I. glandulifera* along the upper reaches of the Blees in the last five years in order to make statements about the success of the different eradication measures and their required workload. After only manual controls of the stands were performed in 2017, the number of individuals in the study area even increased in summer 2018. Consequently, mechanical measures (multiple mowing with brushcutters in the flowering period of the plant) have been implemented in denser and larger stands since 2018. In the years thereafter, a decline of the species in the number and size of the stands was observed. In contrast, a slight increase in the study area was detected again in 2021. As described in the literature, an incomplete control (even with 99 % stand reduction) is almost as ineffective as if no measures had been implemented at all (Wadsworth et al. 2002). Hence, it can be assumed that the workload in 2020 and 2021 was too low for a successful long-term control of the species.

Based on our survey, we recommend a combined control of the species with initial mowing for larger and denser stands without sensitive biotopes or plants. In the following years removal by hand is sufficient in these areas, whereby a minimum workload is required, as the species can spread quickly and increase explosively from a few stands, individuals or even seeds in the soil. In general, removal by hand should be used for sensitive areas or sparse stands. Hence, sufficient human, financial and temporal resources will be needed in the future. This is currently the only alternative to safeguard a sustainable implementation of control measures and ensure a permanent control of *I. glandulifera*. In addition, efforts should be made to restore the abiotic factors that have been affected by the invasive plant. To work more efficiently in the future, other options, such as grazing could be used as a direct control measure for the species while drones could be used to survey the stands. The resources saved by using more efficient methods could then be used to tackle the expansion of *I. glandulifera* in other sections of the river Blees.

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