Research Report:

The presence of *Fallopia japonica* in the Utrechtse Heuvelrug: How its growth is impacted by reduced light exposure by trees

<u>Group 1C Invasive Species:</u>
Amar de Maaker
Irene Beumer
Nicholas van den Berge
Sarah Steuber
Warner Bartlema

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Utrecht University
Faculty of Geosciences

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1. Introduction

The Utrechtse Heuvelrug is one of the largest natural parks of the Netherlands, located in the centre of the country. The park is home to a variety of flora and fauna, making it incredibly diverse (Provincie Utrecht, 2020). Nonetheless, there are various factors, both natural and anthropogenic, which threaten the stability of the park's biodiversity. One of those factors is the presence of invasive species which will be discussed in this report. Within the park, there are different types of invasive alien species, both animals and plants. Invasive alien species are species that are introduced, accidentally or unintentionally, outside of their natural geographic range and become problematic (IUCN, 2020).

The species that this report will focus on is *Fallopia japonica (*Japanese Knotweed), because it is incredibly damaging to its surrounding environment. *Fallopia japonica* is listed as one of the most invasive species globally by the World Conservation Union (Lavallée et al., 2019). It poses problems and reduces surrounding biodiversity, and its roots are notorious for pushing and slitting asphalt (CABI, 2021). Due to this, proper management and control of the plant’s growth and spreading are essential for maintaining ecosystem health. Our research hopes to aid the current management programs of the Utrechtse Heuvelrug.

In order to better understand how the species is distributed in the park, this research paper focuses on one environmental factor that may provide further information about the ideal habitats for the chosen species in the Utrechtse Heuvelrug. Possible environmental variables that could be looked at are light availability, water availability, soil types, and plant species found in close proximity to *Fallopia Japonica*. However, through literature exploration, it was determined that light availability is the main limiting growth factor. Nonetheless, there is a gap in research regarding this topic, especially in European forests. This is further discussed in the literature review.

This research paper aims to provide further details about the light requirements of the plant and build upon the existing information using quantitative data. Our research will be based on the following research question: *To what extent does light exposure influence the growth of Fallopia japonica in the Utrechtse Heuvelrug?* Furthermore, it aims to provide more information about the characteristics of *Fallopia japonica*’s patches in the Utrechtse Heuvelrug in order to determine the success of its growth. The growth will be determined based on: height of the tallest *Fallopia japonica* and the number of individuals in each patch. In addition, we will also be looking at possible trends in patch variation depending on the nearest tree species, as they can provide further information about the spread of *Fallopia japonica.* This lead us to the following sub-questions which will be answered throughout the report:

1. How does proximity to trees impact the quantity of *Fallopia japonica*?
2. How does proximity to trees impact the height of the tallest *Fallopia japonica*?
3. How do different tree species impact the patches' proximity to trees?

These sub-questions will be used in the data analysis and further deliberated in the discussion.

2. Literature review

Species Information

Fallopia japonica was introduced in Europe in 1849. Its native range can be found in Japan, Taiwan, and Korea. Since it has been imported it has become invasive throughout Europe and North America (Shaw, 2013). *Fallopia japonica* is a geophyte, therefore it contains storage organs underground called rhizomes (De Waal, 2001). Rhizome networks of *Fallopia japonica* can be up to 20 meters in length (Van Driesche et al., 2002); they are extremely difficult to eradicate. Although the plant is often eradicated above the soil, resprouting can occur from the rhizomes. Rhizome pieces weighing as little as 8 grams are able to create new plants (Beerling et al. and references therein, 1994). When parts of the rhizomes or stems become detached they can travel and propagate elsewhere (De Lange, 2017).

The abundance of growth of *Fallopia japonica* creates competition for native species that may have slower rates of growth. *Fallopia japonica*'s peak growth season is in summer. During this time it prevents smaller plant species and tree seedlings from thriving because of its dense foliage which reduces light availability. Once foliage dies in the winter there is an increase in plant waste surrounding its stems, preventing other plants from growing (Beerling et al., 1994). In addition to light competition, *Fallopia japonica* competes with other plants through allelopathy: the release of toxic chemicals in the soil (Dommanget et al., 2014). Dommanget et al. (2014) conducted an experiment to test if water from soil containing *Fallopia japonica* would impact the growth of willow and cottonwood cuttings. Their results showed that the growth of the willow and cottonwood plants was inhibited by polyphenol compounds released into the soil by *Fallopia japonica*. This information is significant because it may explain patterns in the distances between *Fallopia japonica* individuals and trees.

Light Conditions

Fallopia japonica is able to survive in an extensive range of soil conditions, such as various pH values and salt concentrations. However, it has not been observed to grow in abundance within a forest as it requires relatively large amounts of light, which is inhibited by the canopy of trees (Shaw, 2013). In *Biological Control of Invasive Species in the United States*, it is stated by Shaw and Seiger that, in the United States, *Fallopia japonica* was the most abundant in areas with direct sunlight (Van Driesche et al., 2002). It can be expected that the same trend can be noticed in the Netherlands as well. Consequently, it can be inferred that light is one of the main growth determining factors of *Fallopia japonica* and that there is a gap in research when it comes to the species' presence in and on the periphery of forests.

Reproduction

Despite *Fallopia japonica* being an angiosperm, male plants in Europe have been found to be infertile, therefore it can only reproduce asexually (Tiébré et al., 2007). This can occur through new growth from rhizomes, or materials that have been separated from the rhizomes or plants and transported. Thus, most *Fallopia japonica* specimens are likely to be found in the same area since smaller plants grow from the rhizomes of larger ones. Mowing has been used as a management technique. Nevertheless, pieces of the stems often remain in the mowing devices and are moved elsewhere when another area is mowed, which increases the spread of the invasive species further (Michigan Department of Natural Resources, 2012). Soil contaminated with the plant's rhizomes that is transported elsewhere by humans is also a cause for spreading (Forman and Kesseli, 2003). It is likely that this is the main cause of the presence of the *Fallopia japonica* in the Utrechtse Heuvelrug, because of eradication methods, such as mowing, which are included in the forest management and construction of new paths. However, in recent years, fertilized *Fallopia japonica* seeds have been found in Europe. Nonetheless, after further testing it was deduced that they were a hybrid between the *Fallopia japonica* and the Chinese bridal veil. This hybrid, Fallopia x conollyana, is less potent and does not grow as rapidly (Van Dijk, 2020). Therefore, it will not be included in this research project. Information regarding the reproduction of the *Fallopia japonica* is significant to this research paper because it allows for a better understanding of the plant's patterns of growth and dispersal. It may also provide key information regarding the history of the spread of the species in the Utrechtse Heuvelrug. Understanding the growth patterns of *Fallopia japonica* aided us in choosing the points for data location.

3. Methods

For adequate data collection, fieldwork was conducted in the Utrechtse Heuvelrug. In order to choose points for this research, it was necessary to first locate the areas where *Fallopia japonica* has been sighted. These points were detected by consulting waarneming.nl. In addition, data from Staatsbosbeheer regarding the forest areas was also used. This additional information allowed us to choose relevant data collection spots where *Fallopia japonica* has been found on the periphery or within forests. From the data points given by waarneming.nl, twenty locations closest to the forest areas defined by Staatsbosbeheer were chosen. The exact locations for data collection can be seen in figure 1. By locating the exact areas where *Fallopia japonica* can be found beforehand, the data collection was more time-efficient. During fieldwork, six points outside of the designated areas were collected. This was mainly due to the absence of *Fallopia japonica* at some of the chosen points.

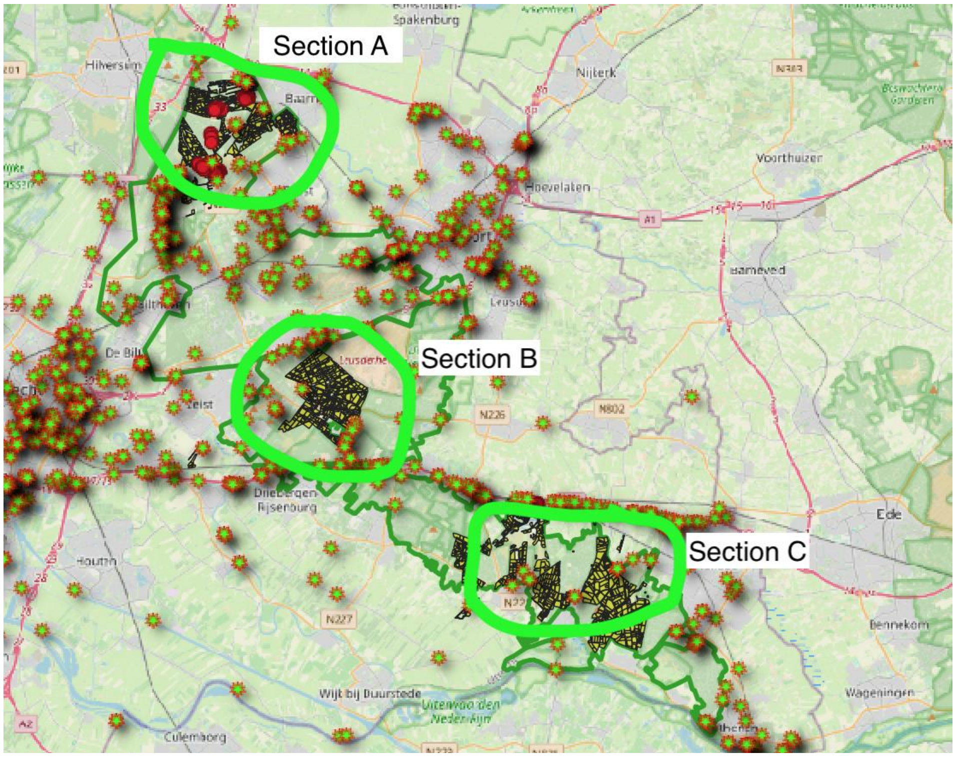


Figure 1: Map of the different sections for data selection. The sections were chosen in relation to the forest section (yellow) given by Staatsbosbeheer. The green outline shows the border of the Utrechtse Heuvelrug Park. Exact locations for the different sections can be seen in the annex.

During the data collection period, information about each patch was collected that would aid in better understanding how much light the patch is receiving. For this research report, a few main variables were identified to indicate the amount of light that reaches the *Fallopia japonica* patches. Firstly, the distance from the plant to the closest tree (within a radius of ten meters around the patch of *Fallopia japonica* plants) was measured. Additionally, the tree closest in distance to the crown of the tallest *Fallopia japonica* plant was identified since variations in the tree canopies may influence the light received close to the ground. An identification sheet was used to identify the leaves of the tree species (Annex; figure 6). The distance to and the leaf area of the tree is used as an indicator for light exposure. It was inferred that a shorter distance between the *Fallopia japonica* and the nearest tree and a larger leaf area, would produce lower levels of light availability. If no tree species was found within the appointed radius of ten meters, it was concluded that there was a high light availability.

Furthermore, different characteristics of the *Fallopia japonica* patches were included in data collection. Firstly, the quantity of the plants in a patch was measured. This was done by counting all individuals. However, for the more dense and large patches an estimation of the number of individuals based on the area of the patch was used. In addition, the height of the tallest *Fallopia japonica* in each patch was measured. Collecting data regarding the quantity and size of the plant was relevant to determine under which light conditions the plant grows the best;

a bigger patch with higher plants means better growth. Lastly, the distance from the *Fallopia japonica* to the nearest path or road was measured, in order to confirm preconceived notions that the construction of paths and roads was the main mode of dispersal.

Summary of Variables

Variables	*Significance*
Proximity to nearest tree (crown of *Fallopia japonica* to trunk of tree)	Light availability/competition
Closest tree species	Interactions, in terms of (light) competition
Height of the tallest *Fallopia japonica* plant	A possible indicator for success of *Fallopia japonica*
Number of individual *Fallopia japonica* (number of crowns)	Abundance of *Fallopia japonica*
Distance to nearest road/path	Most common area where the plant can be found.

The main tool required for data collection was a tape-measure, which was used to measure the distance between the tallest *Fallopia japonica* and the nearest tree. Furthermore, the tool was used to measure the height of the tallest specimen as well. In addition, each researcher used a smartphone with GPS to find the data collection points and take pictures to identify the tree species if necessary. The data collected was saved on Survey123. Link to survey: https://arcg.is/0nmfGv

The fieldwork provided five different variables. The programme SPSS was used to run statistical tests with the aim of identifying certain patterns in the collected data. The Shapiro-Wilk test was performed to test for normality. The Spearman's R Test was used to determine if there is a possible correlation between the different variables. Lastly, to show if there was a difference between two samples the Mann-Whitney U was used.

4. Results

The results from the collected data are organized according to the different sub-questions. In order to select the correct statistical tests a Shapiro-Wilk test was conducted to determine whether the following variables are normally distributed or not: '*Height of Tallest Fallopia japonica', '*Number of *Fallopia japonica',* and 'Proximity to Tree'. 'Height of Tallest *Fallopia japonica'* has a p-value of 0,092 which is larger than 0,01, therefore it is not normally distributed. Secondly, 'Number of *Fallopia japonica*' is normally distributed (p=0,00). Lastly, 'Proximity to tree' is not normally distributed (p=0,071).

Additionally, statistical tests were conducted in order to determine if there is a significant correlation between the variables. To test whether there is a correlation the Spearman's Rank Correlation test was performed. Nevertheless, the test result indicated that there is no significant correlation between the height of the tallest *Fallopia japonica* and the number of specimens. Additionally, they indicated that there is no significant correlation between the height of the tallest *Fallopia japonica* and the proximity to the next tree. For both tests the p-values were higher than 0,01. The last relationship will be discussed in the section of the first sub-question below.

<u>Proximity to trees and quantity of *Fallopia japonica*</u>

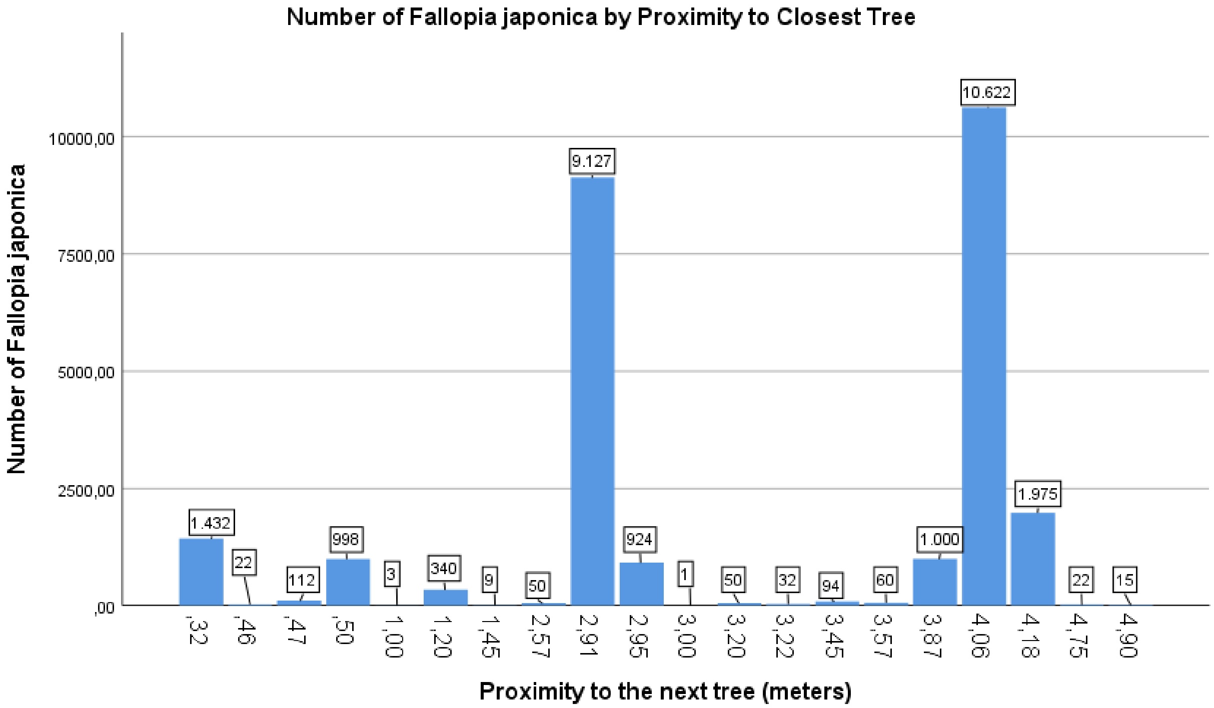


Figure 2: Number of *Fallopia japonica* in relation to proximity to closest tree

Figure 2 shows the relationship between the proximity of the *Fallopia japonica* patch to the closest tree and the number of *Fallopia japonica* individuals. Determining if there is a correlation between the two variables may aid in better understanding *Fallopia japonica* patch characteristics. Since the trees block incoming light, the *Fallopia japonica* patches experience differences in light availability; this is likely to be a factor that causes the number of *Fallopia japonica* to differ amongst the different patches. Figure 2 does not demonstrate a clear correlation. To determine with more certainty, a Spearman's R Test was conducted and a value of 0.902 was obtained which signifies that there is no correlation between the two variables.

Proximity to trees and height of the tallest *Fallopia japonica*

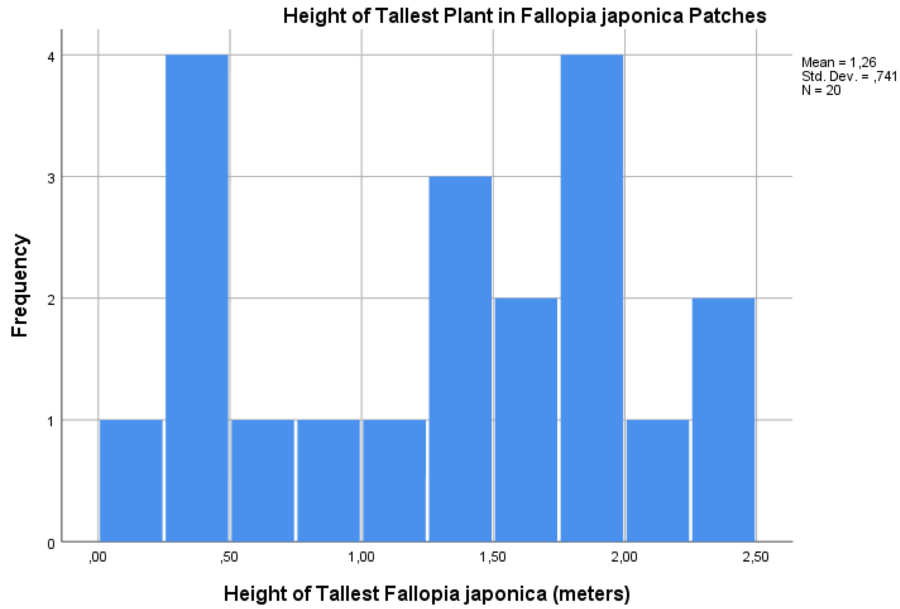


Figure 3: Data distribution graphs for tallest *Fallopia japonica*.

As can be seen in figure 3, the average height from the patches that we surveyed was 1,26 meters. However, it can be seen that the data are not normally distributed. The observed variations can be partially explained by the different tree species present. After conducting a Spearman's R Test for correlation it can be said that there was no correlation between the height of the *Fallopia japonica* and its frequency.

Tree species

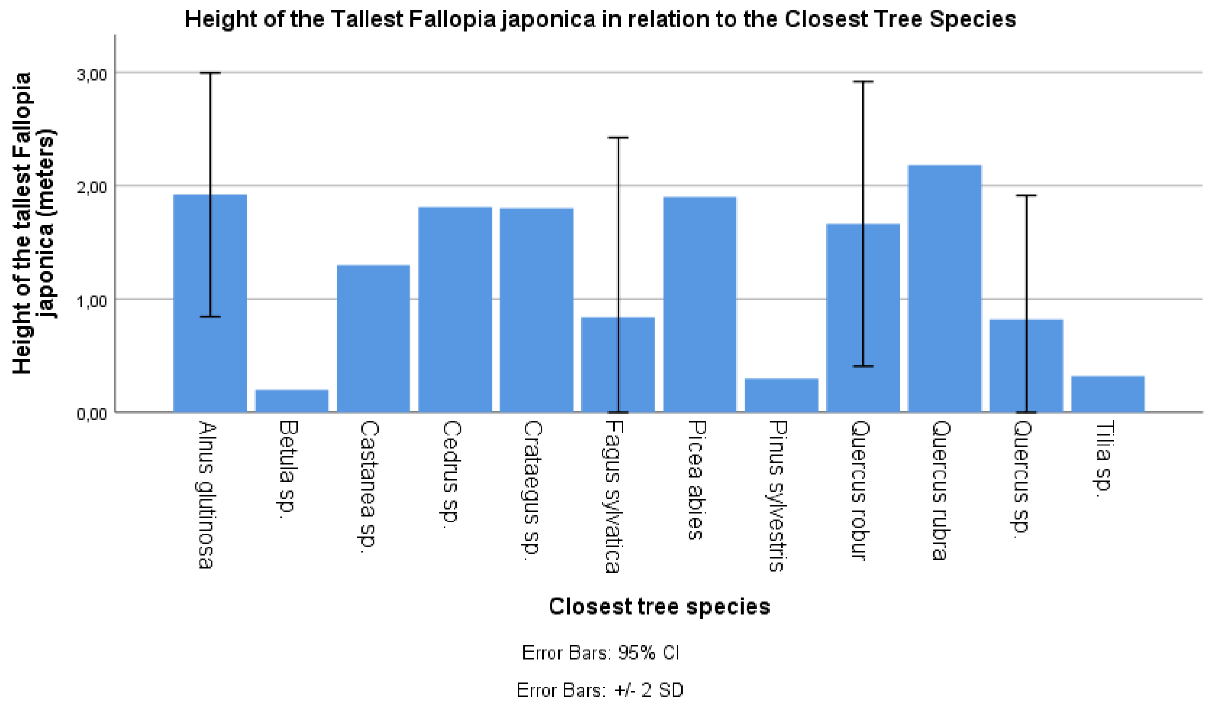


Figure 4: Height of tallest *Fallopia japonica* in relation to closest tree species

Figure 4 displays the differences in height of *Fallopia japonica* in relation to the closest tree species. The error bars represent occasions where more than one Fallopia japonica patch was found to be near the same tree species; for the tree species that were only found in the proximity of one of the surveyed patches, there are no error bars present. In the graph, it can be seen that, from the data collected, *Fallopia japonica* had the largest height in close proximity to *Alnus glutinosa, Picea abies, Quercus robur, and Quercus Rubra.* In order to determine whether there is a significant difference in the height of *Fallopia japonica* in proximity to different tree species a Mann-Whitney U test was performed. This could only be done for tree species that occurred to more than one of the surveyed patches. When comparing *Fagus sylvatica* and *Alnus Glutinosa*, no statistical difference was found (p = 0,121). When comparing *Fagus sylvatica* and *Quercus robur*, no statistical difference was found (p = 0,355). The high p-values may have been a result of the few data points in each group, however, for the samples of this research project it can be said that there is no significant difference.

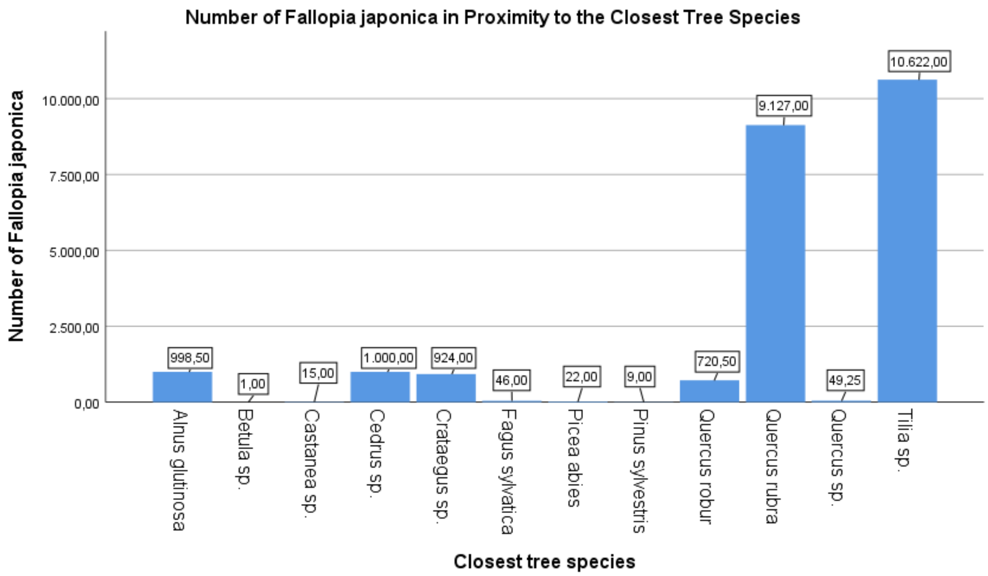


Figure 5: Number of *Fallopia japonica* in relation to closest tree species

From the patches that were included in our data collection, the mean number of *Fallopia japonica* individuals was 1.344. The majority of patches had less than 2.000 individuals. Figure 5 shows the correlation between the total number of *Fallopia japonica* in a patch and the nearest tree species. The range of the data set was 10.621 plants. This is an immense difference, the presence of different tree species and geographical variations in eradication practices may have contributed to this. As for the previous graph, no statistical test can be performed because there was only one sample for the species with the largest number of individuals.

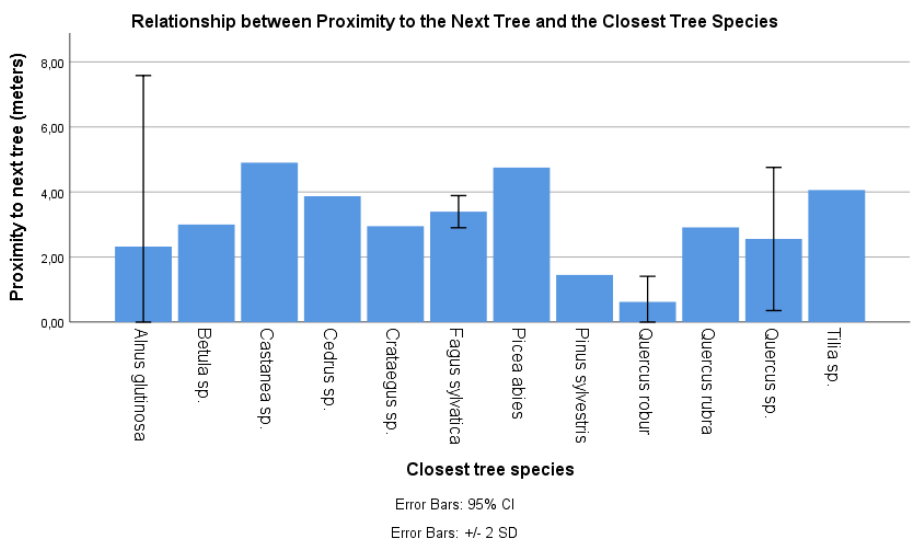


Figure 6*:* The relationship between proximity to the next tree and closest tree species

Furthermore, figure 6 shows the distribution of the tree species over proximity between the crown of *Fallopia japonica* to the closest tree species. For the patches sampled, *Quercus robur* is the tree species that grows closest to the *Fallopia japonica* while *Castanea* grows at the largest distance. For this data set a Mann-Whitney U Test was performed as well, between the tree species with the least and largest proximity to *Fallopia japonica*, again only species that had been sampled more than once can be used. *Quercus robur* and *Fagus sylvatica* were used for the test, resulting in $p>0,05$, thus there is no statistical difference.

5. Discussion

Proximity to trees and quantity of *Fallopia japonica*

As can be seen in figure 2, there are two large peaks regarding the number of individuals: a patch with 9.127 *Fallopia japonica* individuals corresponding to a distance of 2,91 meters to the closest tree and another patch with 10.622 from which the tallest plant was located 4,06 meters from the tree. Geographical variations in eradication practices and the presence of different tree species may have contributed to this. On average the proximity to the next tree from the highest *Fallopia japonica* was 2,74 meters. It is likely that *Fallopia japonica* does not grow in direct proximity to trees because the presence of trees inhibits its growth to a certain extent through light competition. Nevertheless, *Fallopia japonica* also reduces the reproductive success of trees through allelopathy. Leachates from *Fallopia japonica* influence the nitrogen content of the soil and can inhibit the growth of tree seedlings through allelopathy (Dommanget et al., 2014). It can be inferred that tree seedlings growing close to trees are less likely to survive when *Fallopia japonica* is present. This may be one reason for the proximity between *Fallopia japonica* and the observed tree species because new trees are not able to grow. Nevertheless, it is unclear how the presence of adult tree species impacts *Fallopia japonica* since this has not been thoroughly researched. Thus it would be beneficial to conduct further research regarding the interactions between adult trees and *Fallopia japonica* as this may also provide information concerning which tree species may be effective for managing and reducing *Fallopia japonica* patches.

Figure 2 shows that the data are distributed unevenly; with an increase in proximity the number of individuals varies extremely and no clear pattern can be determined. The Spearman's R test provides the same conclusion. Thus, it can be stated that there is no direct correlation between the number of *Fallopia japonica* individuals and the proximity to the closest tree. Nonetheless, as will be mentioned later on this may also be a result of the small sample size.

It must be noted that the method used for this research was not entirely effective. Some of the patches were much larger and consequently more difficult to measure. For the larger patches, a density calculation had to be performed. This was the most efficient method, however, it is still an estimation. As a result, there was a bias in the way the data was collected. The method used was more suited to identify the size of smaller patches of *Fallopia japonica*, however, for the larger patches the data is less accurate.

Proximity to trees and height of the tallest *Fallopia japonica*

As mentioned earlier the Spearman’s Test shows that there is no clear correlation between the variables proximity to tree and height of tallest *Fallopia japonica*. As shown in figure 3, the height of the tallest *Fallopia japonica* varied significantly between patches. A possible explanation for this is the differences in light availability that impacted the growth and phototropism of the plants. Since light is the main growth-limiting factor (as was identified in the literature review) light availability will be one of the main determining factors for patch size and height. Phototropism is the process of plants growing in the direction of the light source (Thimann, 2014). They do this in order to increase the amount of light received by their chloroplasts and therefore the rate of photosynthesis (Fankhauser, 2015). Plants that grow in low-light conditions will grow taller and have thinner stems, in order to quickly grow closer to the light source (*Light, Temperature and Humidity*). Therefore, taller *Fallopia japonica* are likely to be the result of low-light availability in the area of the patch. This contradicts what we previously believed, which was that both quantities of specimens and height of the tallest specimen were the main indicators of growth. From this, it can be said that for the patches surveyed, *Fallopia japonica* receives less light in close proximity to: *Quercus rubra, Picea abies, and Alnus glutinosa*.

The method for measuring height that was used in this research project may not have been accurate in instances where the tallest *Fallopia japonica* specimen was located within the core of a large patch. For further research it would be useful to use another method of measuring height. One cost-effective option would be using an app such as Globe Observer by NASA, which is a mobile app that can be used to measure the height of plants and trees (Ramsayer, 2019).

<u>Tree species and the proximity of patches to trees</u>

From the data regarding the most prevalent tree species in proximity to the *Fallopia japonica* patches, 40% defined trees correspond with the genus *Quercus,* they were either *Quercus robur*, *Quercus rubra* or *Quercus sp.* This may be the result of a correlation between the growth of the *Fallopia japonica* and the presence of the genus *Quercus.* However, it is important to take into account that *Quercus* is a common tree in the Netherlands and in the Utrechtse Heuvelrug (M*inistry of Economic Affairs, 2012)*. Thus, this trend may simply be a coincidence. This can be clearly seen in figure 4, many patches were found in close proximity to the most common tree species. By focusing mainly on the correlation between the presence of the most common tree species and of *Fallopia japonica*, unprecedented research may be conducted.

In figure 6 it can be seen that the distance between *Fallopia japonica* and closest tree was the largest for *Castanea*, which also has the largest leaf size out of the observed tree species (Annex: figure 11). Additionally the recorded distance between *Fallopia japonica* and *Picea abies* was large as well, while the width of *Picea abies* needles is between 1-3 centimeters. However, this is likely to be because gymnosperms have a dense canopy.

The following statements are not specific to one sub-question but the entire method. In this research report proximity to trees is used as an indicator for light availability. The expectation was that the research method would provide the necessary data points to answer the target research question. However, many of the *Fallopia japonica* patches were much larger than expected. For these larger patches the method was not as sufficient as for the smaller patches. For larger patches the closest tree only covered a small part. Thus, the rest of the *Fallopia japonica* plants did not have the same tree coverage and therefore the same light availability. This is likely to have caused variations in the patches, as different sections of the patches received different amounts of light.

As mentioned earlier there were multiple trees in close proximity to the larger *Fallopia japonica* patches, this may have caused inaccuracies in the data collected, since more than one tree species impacted the size and height of each patch. In later research, an option may be to include all trees in a certain radius to make sure this problem does not occur. In addition, it may be interesting to analyze *Fallopia japonica* patches in areas with mainly one tree species present, as this would allow a better and more controlled analysis of the relationships between the different species. This would also be useful in terms of forest management since it would clearly define which tree species are the most endangered by *Fallopia japonica* and which ones may be the best to plant as a preventative measure.

There are additional reasons why the process of data collection chosen for this research project is likely to yield less accurate data. As previously stated, Waarneming.nl was used to locate spots where the *Fallopia japonica* plant has been found. These observations of Fallopia japonica patches were located by people visiting the park in areas close to roads or pathways. The environment is likely to be the most disturbed and managed in areas like these, therefore chosen points may not have been very representative of *Fallopia japonica* patches in less-disturbed and unmanaged areas.

As discussed in the results section, most of the statistical tests for correlation and difference between groups resulted in large p-values and indicated that there were no significant differences/correlation. One reason for this is the small sample sizes. It must be kept in mind that the essence of this research project was to better understand the presence of *Fallopia japonica* patches in the periphery of forests within the Utrechtse Heuvelrug and which tree species it grows closest to. Nonetheless, in order to better understand the nature of *Fallopia japonica* in the park future research projects should aim to collect larger sample sizes as this will provide more significant trends.

Lastly, it is important to acknowledge that there are many other variables that contribute to the growth of *Fallopia japonica*; this is not only dependent on light availability. A few other factors that influence its growth are: water availability, soil type, and weather. This is likely to have caused disturbances in our results. If all other circumstances were optimal for the plant, it could still be very abundant there, even though the light availability is not ideal. However, measuring all of these environmental factors would not have been realistic for the time and resources available for this project.

6. Conclusion

In conclusion, with the method used, little correlation has been found between the variables measured and no statistical difference exists between the different tree species. Nonetheless, some trends were noticed which may be carried forth into future research and provide relevant information. To begin with, the research conducted proved that *Fallopia japonica* exists within forests and on the periphery of forest in the Utrechtse Heuvelrug and that the species can be found in close proximity to a variety of tree species. External resources provided the insight that taller individuals in patches do not indicate successful growth and sufficient light, but instead lower than optimal light conditions. This was used to come to the conclusion that *Fallopia japonica* grows furthest away from *Castanea* and *Picea abies*, which can be explained through their canopy characteristics. This information is useful for the management of the plant in the park. Additionally the information obtained in regards to which tree species *Fallopia japonica* grows closest to (figure 6) can be used to determine the urgency of eradication methods in areas with the tree species that are most overgrown. In regards to the main research question: '*To what extent does light exposure influence the growth of* Fallopia japonica *in the Utrechtse Heuvelrug?'*, the data collected has shown that there are variations in patch characteristics depending on the proximity to trees which can be traced back to differences in light exposure.

In the future, research could be conducted where other environmental conditions than light availability are investigated as this can provide more information about alternative eradication methods. Additionally, more specific data and conclusions could be created if the *Fallopia japonica* patches used were surrounded by simply one tree species. With this research, more relevant data could be created in order to inspire and support management strategies of Nationaal Park Utrechtse Heuvelrug for specific areas. Our research revealed the location of multiple patches in the park and their characteristics, which is relevant data to have when a management strategy is constructed and needs to be applied. The data collected identifies which specific patches need to be managed, using the data shown in figure 12.

Furthermore, since all of the patches that were examined were in close proximity to roads or paths, the main policy recommendation that can be given is to strictly ensure that soil transported into the park and mowing devices are sterile and do not contain fragments of *Fallopia japonica* rhizomes. Lastly, the main limitation of the research conducted is the small sample size. If a large sample size is included in future research, it is likely that the trends will be more significant and the data will be more representative of the species' presence in the Utrechtse Heuvelrug. Nonetheless, this research project provides a base for future research that can provide more information about the *Fallopia japonica* in the national park and prevent further damage to the local biodiversity.

7. Relevance and integration possibilities

Invasive species have become an increasingly large problem, since mankind has increased travel across the globe. This is because foreign species are controlled by other species in their native ecosystems, but when introduced into a foreign system there is no equal competition present. Therefore the traits that allow invasive organisms to survive in their native system can allow it to dominate new ecosystems if left unmanaged.

The information gained from this research project can be useful for the forest management organizations, in the sense that it can allow them to have a better overview of the areas where the *Fallopia japonica* is the most common and which tree species are the most overgrown by *Fallopia japonica* patches. This way, it will become clear where the plant is likely to grow, in terms of light conditions and surrounding tree species. This information can be used to prevent or restrain growth at those locations to ensure that the local biodiversity is maintained and protected. If not, the plant will slowly replace the native vegetation endemic to the Utrechtse Heuvelrug thus decreasing its value as an authentic national park. This means that eradication is beneficial for the visitors of the park as well. Additionally, the quality of the paths will decrease if the plants continue to grow in amount and biomass, penetrating and destroying asphalt.

The research that was conducted and its findings were relevant in the sense that the information obtained is usable for the purpose described above. However, there are still a lot of gaps for further research. Other groups can add value to this research by researching the impact of invasive species on plant biodiversity in the Utrechtse Heuvelrug or the perception of the forest quality by people visiting. There are also developments that complicate our research topic. Groups that are finding ways to increase accessibility, tourism and recreation might worsen the problem, as invasive species are often spread by humans. Lastly, when imagining futures for the Utrechtse Heuvelrug, invasive alien species are important to consider, especially since they are predicted to occur even more in the coming years and greatly undermine the stability of the local biodiversity.

8. Reference list

Beerling, D., Bailey, J., & Conolly, A. (1994). *Fallopia Japonica* (Houtt.) Ronse Decraene. *Journal of Ecology*, 82(4), 959-979. doi:10.2307/2261459

CABI. “Why Is *Fallopia japonica* a Problem?” *Fallopia japonica Alliance*, 2021, www.cabi.org/japaneseknotweedalliance/why-is-it-a-problem/#:%7E:text=Why%20is%20Japanese%20knotweed%20such,UK%20without%20its%20natural%20enemies.&text=Biodiversity%20%E2%80%93%20Knotweed%20affects%20ecosystems%20by,plant%20and%20animal%20species%20diversity.

De Waal. (2001). A viability study of *Fallopia japonica* stem tissue. *Weed Research*, 41 (5), 447-460. https://doi-org.proxy.library.uu.nl/10.1046/j.1365-3180.2001.00249.x

De Lange. (2017, July, 31). *River areas overrun by invasive plants*. Utrecht University. https://www.uu.nl/en/news/river-areas-overrun-by-invasive-plants

Dommanget, F., Evette, A., Spiegelberger, T., Gallet, C., Pacé, M., Imbert, M., Navas, M.L.(2014). Differential allelopathic effects of *Fallopia japonica* on willow and cottonwood cuttings used in riverbank restoration techniques. *Journal of Environmental Management, 132*, 71-78. https://doi.org/10.1016/j.jenvman.2013.10.024

Forman, & Kesseli. Sexual reproduction in the invasive species *Fallopia japonica* (Polygonaceae). *American Journal of Botany*, 90 (4), 586-592. https://doi.org/10.3732/ajb.90.4.586

Fankhauser, C., Christie, J. M. (2015) Plant Phototropic Growth. *Current Biology, 25 (9),* R384-R389. https://doi.org/10.1016/j.cub.2015.03.020

ICUN. “Invasive Alien Species.” *IUCN*, 15 June 2020, www.iucn.org/regions/europe/our-work/biodiversity-conservation/invasive-alien-species.

Lavallée, F., Smadi, C., Alvarez, I., Reineking, B., Martin, F.M., Dommanget, F., Martin, S. (2019). A stochastic individual-based model for the growth of a stand of Japanese Knotweed including mowing as a management technique. *Ecological Modelling, 413*. https://doi.org/10.1016/j.ecolmodel.2019.108828

Light, Temperature and Humidity. Texas A&M. https://aggie-horticulture.tamu.edu/ornamental/a-reference-guide-to-plant-care-handling-and-merchandising/light-temperature-and-humidity/

Michigan Department of Natural Resources. (February, 2012).*Japanese knotweed*. Invasive Species—Best Control Practices. https://mnfi.anr.msu.edu/invasive-species/JapaneseKnotweedBCP.pdf

Ministerie van Algemene Zaken. “Controlling Invasive Alien Species.” *Nature and Biodiversity | Government.Nl*, 4 Oct. 2017, www.government.nl/topics/nature-and-biodiversity/controlling-invasive-alien-species.

Ministry of Economic Affairs The Hague (November 2012). *First National Report on Forest Genetic Resources for Food and Agriculture The Netherlands.* http://www.fao.org/3/i3825e/i3825e48.pdf

Project Love for Bees. (n.d.). *Van welke boom is dat blad?* [Table]. https://projectloveforbees.wordpress.com/determineren-zoekkaarten-links/#jp-carousel-4296

Provincie Utrecht. “Monitoring flora en fauna.” *Provincie Utrecht, 2020*, www.provincie-utrecht.nl/onderwerpen/natuur/monitoring-flora-en-fauna. Accessed 21 May 2021.

Ramsayer, S. (2019, March, 27). *Help NASA Measure Trees with Your Smartphone.* NASA. https://www.nasa.gov/feature/goddard/2019/help-nasa-measure-trees-with-new-app/

Shaw, D. (2013). *Fallopia japonica* (Japanese Knotweed). *Invasive Species Compendium*. Wallingford, UK: CABI. DOI:10.1079/ISC.23875.20203373912

Tiébré, M., Vanderhoeven, S., Saad, L., Mahy, G. (2007). Hybridization and Sexual Reproduction in the Invasive Alien Fallopia (Polygonaceae) Complex in Belgium. *Annals of Botany*, 99 (1), 193–203. https://doi-org.proxy.library.uu.nl/10.1093/aob/mcl242

Thimann, K.V. (2014) Chapter I - Phototropism. *Comprehensive Biochemistry, 27 (1967),* 1-29. https://doi.org/10.1016/B978-1-4831-9716-6.50009-4

Van Dijk. (2020, June, 17). *Does Japanese knotweed also spread via seeds?* Wageningen University and Research. https://www.wur.nl/nl/Landingspagina-redacteuren/nl/Onderzoek-Resultaten/Onderzoeksinstituten/plant-research/show-wpr/Verspreidt-Japanse-duizendknoop-zich-ook-via-zaden.htm

Van Driesche, R., Blossey, B., Hoddle, M., Lyon, S., Reardon, R. (2002). *Biological Control of Invasive Plants in the Eastern United States.* Forest Health Technology Enterprise Team. https://www.fs.fed.us/foresthealth/technology/pdfs/BiocontrolsOfInvasivePlants02_04.pdf

Waarneming.nl

Sources for Table 12

Cedrus atlantica. (n.d.). North Carolina State Extension. https://plants.ces.ncsu.edu/plants/cedrus-atlantica/

Goudzwaard, L. *Temperate Species - Tree Database*. Wageningen University & Research. https://www.wur.nl/en/Research-Results/Chair-groups/Environmental-Sciences/Forest-Ecology-and-Forest-Management-Group/Education/Tree-database/Temperate-Species.htm

9. Annex

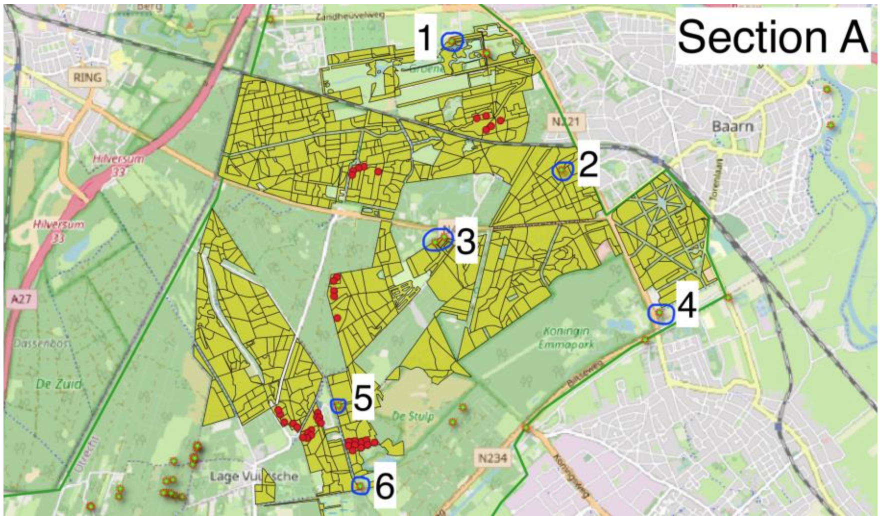


Figure 7: Locations for data collection in Section A, for day 1. Blue circles show the recorded presence of *Fallopia japonica* (green stars) from http://waarneming.nl/ which were chosen because of their close proximity to forest areas (yellow). Data collection points are marked.

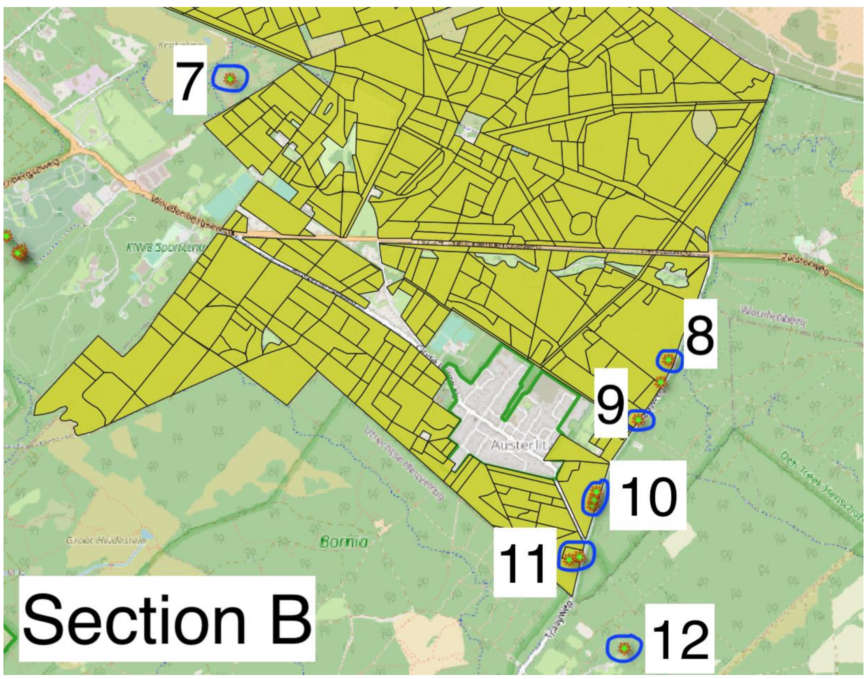


Figure 8: Locations for data collection in Section B, for day 2 (same method used for choosing locations as was mentioned in figure 3).

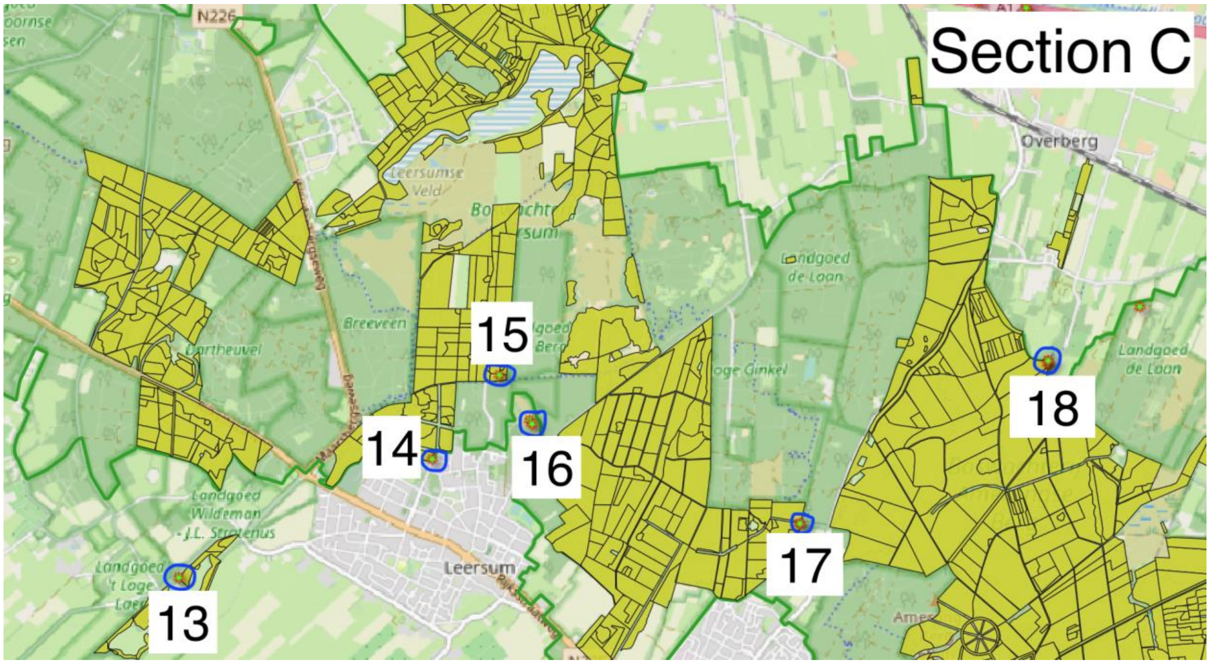


Figure 9: Locations for data collection in Section C, for day 3 (same method used for choosing locations as was mentioned in figure 3).

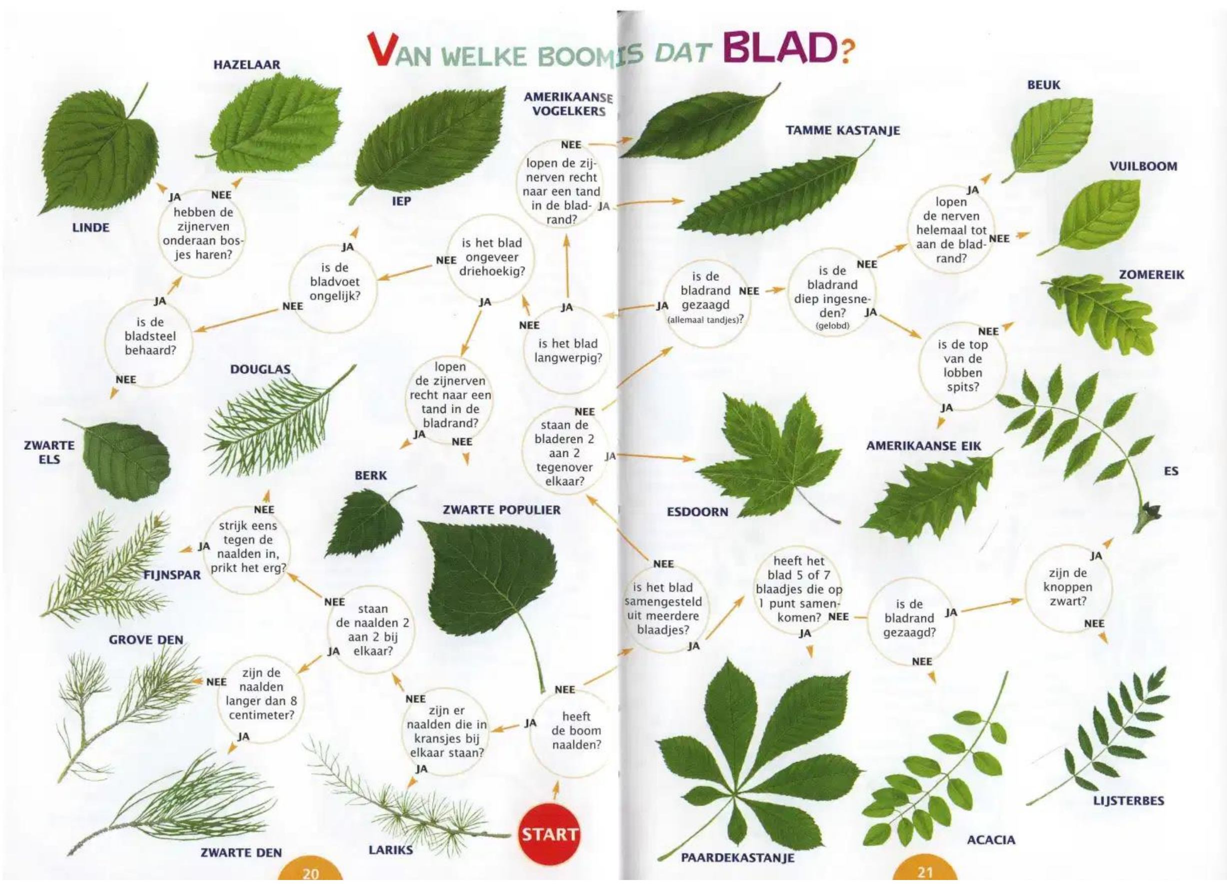
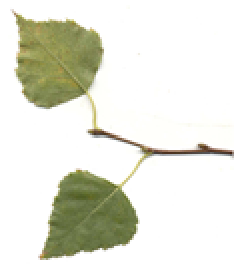


Figure 10: Identification sheet for trees nearest to *Fallopia Japonica* (Project Love for Bees, n.d.).

Species	Leaf size information (length in cm)	Leaf picture
Alnus glutinosa	5-9 cm	
Betula sp.	3-6	
Castanea sp.	10-27	
Cedrus sp.	2-4 cm	

Crataegus sp.	2-6 cm	
Fagus sylvatica	7-12 cm	
Picea abies	1-3	
Pinus Sylvestris	3-9	
Quercus Rubra	15-21 cm	

Quercus Robur	8-11 cm	
Tilia sp.	6-12 cm	

Figure 11: Information regarding the different leaf characteristics of the tree species found in close proximity to *Fallopia japonica* (Goudzwaard, n.d.). Photographer: Leo Goudzwaard.
For *Cedrus sp;* Photographer: Kathleen Moore (Cedrus Atlantica, n.d.)

Proximity to next tree (in meters)	Tree Species	Height of tallest Japanese knotweed (in meters)	Number of Japanese Knotweed	Distance to road (in meters)	x	y
0.46	Alnus glutinosa	1.54	22	6.82	5.251617434	52.21888208
1,20	Quercus robur	1	340	4.5	5.265979114	52.20665119
0.32	Quercus robur	2.42	1432	3.7	0	0
4.06	Tilia sp.	0.32	10622	1.5	5.282300085	52.19439405
3.45	Quercus sp.	0.52	94	9.65	5.327650205	52.08198259
2.57	Quercus sp.	1.55	50	1.76	5.325143047	52.07929866
3.22	Fagus sylvatica	1.4	32	1.08	5.32154379	52.07511708
3.87	Cedrus sp.	1.81	1000	11.08	5.32072219	52.07285437
3.57	Fagus sylvatica	0.28	60		5.320924597	52.06831142
4.9	Castanea sp.	1.3	15	3	5.399982183	52.00956006
3.2	Quercus sp.	0.9	50	14	5.428258443	52.01822539
1	Quercus sp.	0.3	3	6	5.43702509	52.01590992
3	Betula sp.	0.2	1	5	5.438617842	52.01267279
4.18	Alnus glutinosa	2.3	1975	0,63	5.248788	52.2004416
2.91	Quercus rubra	2.18	9127	0,15	5.2649342	52.2075463
0.5	Quercus robur	1.9	998	0,15	5.272567	52.205593
0.47	Quercus robur	1.33	112	2,75	5.274999	52.202279
2.95	Crataegus sp.	1.8	924	0	NEAR POINT 4	
4.75	Picea abies	1.9	22	0,80	UNKOWN	

Figure 12: Raw data table