Czech University of Life Sciences Prague

Faculty of Environmental Sciences

Department of Ecology

Bachelor Thesis

How do invasive species affect biodiversity and ecosystem functions of floodplain forests?

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

BACHELOR THESIS ASSIGNMENT

Anastasia Ievleva

Environmental Sciences
Applied Ecology

Thesis title

How do invasion species affect biodiversity and ecosystem functions of floodplain forests?

Objectives of thesis

Main aim of the thesis is to carry out the metaanalysis of scientific studies dealing with the effects of plant invasions on diversity and ecosystem functions of floodplain forests. The results of the study should also consider the regional specificity in the effects of invasions.

Methodology

The database of studies focusing on changes in diversity of various taxonomic groups and ecosystem characteristics (e.g., microbial activity) in dependence on plant invasions should be prepared based on an extensive search of scientific databases Web of Knowledge, SCOPUS and Scholar Google. For each study, it should be evaluated if the presence of invasive species at the locality has negative or positive effect. Finally, it should be expressed whether the effect of invasive species do vary in dependence on regions of different evolutionary history or environmental conditions.

The proposed extent of the thesis

30 stran

Keywords

floodplain forests, invasive species, metaanalysis, plant communities, regional specificity

Recommended information sources

Chytrý, M., Jarošík, V., Pyšek, P., Hájek, O., Knollová, I., Tichý, L., & Danihelka, J. (2008). Separating habitat invasibility by alien plants from the actual level of invasion. Ecology, 89(6), 1541-1553.

Planty-Tabacchi, A. M., Tabacchi, E., Naiman, R. J., Deferrari, C., & Decamps, H. (1996). Invasibility of species-rich communities in riparian zones. Conservation Biology, 10(2), 598-607.

Stromberg, J. C., Lite, S. J., Marler, R., Paradzick, C., Shafroth, P. B., Shorrock, D., ... & White, M. S. (2007). Altered stream-flow regimes and invasive plant species: the Tamarix case. Global Ecology and Biogeography, 16(3), 381-393.

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Declaration

I declare that I have worked on my bachelor thesis titled "How do invasion species affect biodiversity and ecosystem functions of floodplain forests?" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the bachelor thesis, I declare that the thesis does not break copyrights of any their person.

In Prague on ____________________________

Acknowledgement

I would like to thank my university and professors for giving me an opportunity to gain knowledge. I would also like to thank my supervisor, Ing. Jan Douda, Ph.D., for his patience and constructive advices that helped me learn a lot about scientific methods and conducting research. Lastly, I would like to thank my parents for always supporting my dreams and giving me the chance to get the best education I can.

Abstract

Biological invasion is a significant issue that affects various biotopes, including alluvial forests. Despite its prevalent negative effects on biodiversity, a comprehensive evaluation would be beneficial for the broader understanding of the topic. The following thesis aims to review and analyze both negative and positive effects caused by the spread of invasive plant species in alluvial ecosystems. It is divided into two main topics: i) examination of effects of plant invasion on diversity and ecosystem functions of floodplain forests with consideration of different responses by different taxonomic groups; and ii) exploration of anthropogenic and natural factors affecting the invasive plants themselves.

A new database consisting of articles from the year 1994 to the year 2019 was created, analyzed through descriptive statistics and reviewed. The results confirmed that negative effects of invasive flora's presence prevail. Positive effects were mainly focused on abiotic parameters of ecosystem and certain groups of invertebrates: arthropods and detritovores. Invader's responses to different natural and anthropogenic factors varied greatly. Urbanization proved to be beneficial for invaders presence. Removing techniques were majorly unsuccessful unless scarification technique was used. In many cases, impact of plant invasion was highly dependent on invasive species and side factors of studied ecosystems.

Further research on the relationship between invasive plant species and avian, bacteria and mammal communities are highly recommended, as well as the research that would take in consideration invasive species differences and side factors, affecting alluvial ecosystems.

Keywords: alluvial forest, floodplain forest, invasion, biodiversity, species richness, management techniques.

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1. Introduction

Alluvial forests are highly endangered biotopes. Even though humans altered those biotopes all throughout history, during the 20th century the acreage of riparian forests in Europe was lowered more than ever before (*Machar, 1998*).

There are multiple factors notably impacting riparian ecosystems, one of which is exotic species invasion. Due to their environmental conditions, riparian forests are prone to invasion, and the proportion of exotic species is growing (*Medvecka et al., 2018*). Does the invasion play a significant role in alluvial forests destruction?

The paradigm existing in scientific community suggests that impact of invasive plants is substantially negative, with just a few studies acknowledging positive responses (*Mitchell et al., 2011; Ford et al., 2012; Gutierrez-Lopez et al., 2014*). The overall analyses of invasive plant's influence on floodplain forests with consideration of positive effects is still lacking.

The first part of this thesis examines and compares positive and negative effects of exotic plant species invasion on diversity and ecosystem functions of floodplain forests with consideration of different responses by different taxonomic groups. In addition, regional specifics of plant invasion were addressed.

The second part of the thesis explores influence of different management techniques, biotic and abiotic factors on invasive plants themselves. Discussion of different available methods of fighting invasion propagation was included to help navigating specialists and scholars working in the field of nature conservation.

The following premise is helpful for broader understanding of exotic plant's role in riparian biotopes as well as for designing management strategies in the future.

2. Objectives and methodology

2.1 Objectives

The aims of the thesis were:

1. To carry out the metanalysis of scientific studies dealing with the effects of plant invasions on diversity and ecosystem functions of floodplain forests by preparing the database of scientific articles and statistically testing the collected data
2. To evaluate if the presence of invasive species at the locality has negative or positive effect
3. To address whether the effect of invasive species do vary in dependence on regions of different evolutionary history or environmental conditions

In addition, a part on invader's response to different alluvial ecosystem's factors was added for a broader presentation of invaded ecosystem's dynamics.

2.2 Methods

I started with creating a database table for different taxonomic groups consisting of articles from the year 1994 to the year 2019 with studies of Northern hemisphere only. The articles were collected through the Web of Science (WOS) server by using the key words: "invasive/ alien"; "diversity/ richness/ biodiversity"; "alluvial forest/ floodplain forest/ riparian forest". A total of 68 articles were used for the database and 91 sources were used for the thesis overall.

Data from a database were used for review and descriptive meta-analyses. The information is presented in form of 2 main chapters: first part examines and compares positive and negative effects of exotic plant species invasion on diversity and ecosystem functions of floodplain forests with consideration of different responses by different taxonomic groups; the second part explores how anthropogenic and natural factors affect the invasive plants themselves. The subchapters on effects of removing invasive flora and regional specifics are added.

This was achieved by summarizing data in *Fig.1* and *Fig.2* given in appendix and analyzing it through descriptive statistics by comparing the amount of positive and negative effects of invasion/ on invasion and analyzing them, as well as analyzing the frequency of the studied species presence. For a fuller picture, the collected articles were reviewed with the addition of the other literature sources.

3. Introduction to the issue of invasion in alluvial ecosystems

The following thesis focuses on biological invasion particularly in alluvial forests of northern hemisphere, which are defined by *FNAI (2010)* as “Hardwood forests found in river floodplains on low levees, ridges and terraces that are slightly elevated above floodplain swamp and are regularly flooded for a portion of the growing season. The physical environment is greatly influenced by ongoing disturbances created by a fluctuating riverbed which is both eroding and depositing substrates”. *Interpretation manual of European Union habitats* describes alluvial forests as occurring on heavy soils periodically inundated by the annual rise of the river level, but otherwise well-drained and aerated during low water.

EEA report on European forest ecosystems informs that alluvial and riparian forests are in state that varies from inadequate to bad, which is the highest level of danger in a mentioned system. Invasion of alien species is listed as a significant issue in all European ecosystems, particularly in forests.

According to the *Decision VI/23 on Alien Species that threaten ecosystems, habitats and species,* adopted by the European Union, invasive species are defined as “Non-native species whose introduction and spread outside their natural past and present ecological range accidently or deliberately, with serious negative consequences for biodiversity, their new environment and economy.”

Historically, invasive species have spread with human migrations by sticking to the traveler's clothes, growing on the boats and wagons, attaching to the domesticated animals that traveled with people *(Lockwood et. al.,2007).* The 20th century was rich on channel modifications, flow regulations and other alterations that intensified the expansion of alien species in alluvial ecosystems *(Schnitzler et al.,2007).* Other factors that contributed to the spread are the increase of organic pollution, that attracted certain type of exotics with high nutrient demand, and the abandonment of the traditional hay and grazing lands, which allowed the growth of dense stands of exotic clones *(Schnitzler et al., 2007 ex Pyšek et Prach, 1993).*

The reason for why this spread is so destructive is that invasive species create a competition for native species, interbreed with them, spread disease: harm native biodiversity and ecosystem in general *(EEA report on European forest ecosystems).* Besides that, invasive species can affect human health *(Slabějová et al.,2019).*

The issue of biological invasion is recognized though and fought against. Current means of fighting invasion include legislative means: Regulation No 1143/2014 on the prevention and management of the introduction and spread of invasive alien species by EU, The EU biodiversity strategy to 2020, Regulation No 708/2007 of 11 June 2007 concerning use of alien and locally absent species in aquaculture and its changes according to regulation No 304/2011; Negative Invasive Species Act (USA federal law); Executive order 13751.

However, *AOPK ČR* points out that invasive species are in need of more define presence in Czech legislation (*AOPK ČR, ©2020*), though ways of regulation of biological invasion could be found in the laws No 114/1992 and No 326/2004.

Besides legislative means, there are several non-profit organizations (Invasive Species Council of BC, North American Invasive Species Network) dedicated to fighting biological invasion and increasing general public awareness. Databases containing information on invasive species include: Global Invasive Species Database (GISD), CABI Invasive Species Compendium (CABI ISC), ECOLEX, EASIN. There even are scientific periodicals dedicated strictly to the issue of invasion.

Despite the clear recognition of the issue by the government and the seeming wealth of information, some of the aspects of biological invasion in alluvial forests remain unstudied. The following thesis focuses on reviewing available studies about invasive plants in alluvial ecosystems and addresses effects of biological invasion that require more attention from the scientific community. It includes two parts: part 1. On how invasive plants affect different components of riparian forests and part? 2. On how invasive species are influenced by biotic and abiotic factors in a context of alluvial ecosystem?

4. Influence of invasive flora on alluvial ecosystem

4.1 Are there more positive or negative effects to the invasion?

To evaluate, whether the presence of invasive plant has a negative or a positive effect, the created database was analyzed with the help of descriptive statistics: ecological parameters were analyzed and categorized as positive, negative or not significant.

Out of 105 effects reported in studied articles, 59 were negative, 19 had no effect and 27 were positive. That itself doesn't prove that there are more negative effects than positive, just that negative effects are more researched. However, the number of parameters that are influenced negatively or positively might have more significance.

Figures 3,4,5,6,7 illustrate the amount of positive and negative effects of the presence of invasive species on native ecosystems, as well as cases of no registered influence. *Figures 3-6* are dedicated to taxonomic groups: plants, invertebrate, birds and mammals. *Figure 7* displays the effects of biotic invasion on abiotic factors and other factors that are more complex in categorization.

Another important remark is that some of the parameters had positive relationship with invader's presence but were still attributed to the negative effects for their negative influence on the ecosystem (e.g., subdominant invasive species richness, mortality of native taxons, % canopy missing, decomposition rates). Decomposition, as an example, was faster in a presence of invasive species (*Figure 7*), however, that was considered a negative effect as it alters leaf processing continuum of an ecosystem and can lead to reduced leaf litter availability (*McNeish et al., 2011*).

For plants:

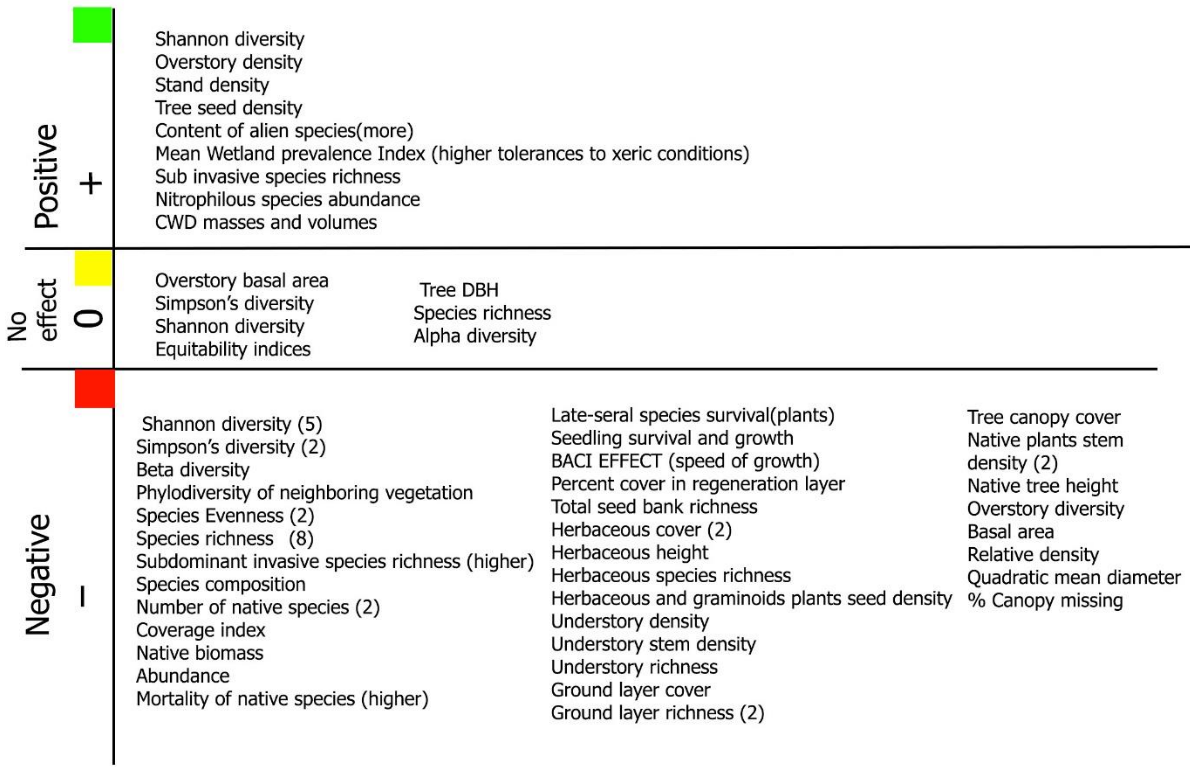

Figure 3. Effects of biological invasion on plants divided into positive, negative effects and the lack of response. The number in brackets (n) represents the number of articles that mention given effect.

As can be seen on the *Figure 3*, invasion tends to influence native flora and rarely has no effect. Few articles display results that are seemingly contradictory. For example, *Dydersky et al., 2015* report a positive relationship between native species richness and invasive species richness, when 5 other articles in the database report that presence of invasive species has a negative effect on native species richness. This could be due to the difference in species of invasive flora. As an example, *Dyakov et al., 2013,* whose study is presented in a second part of database reports that only 4 invasive species out of 20 had positive correlations with species richness, while others had negative correlation or did not correlate at all. *Dydersky* has showed positive effect of *Acer negundo* on native species richness. However, *Bottolier et al., 2012* that also studied *A. negundo* have reported negative results. Perhaps, such difference could be explained by different factors of ecosystem, such as distance to the tourist trail, poaching activities in the area or statistical errors (*Moore et al., 2019*).

Contradictious results could also be found on Shannon's and Simpson's diversity, sub invasive species richness.

Nitrophilous species abundance is likely connected with the raised concentration of N containing compounds (*Figure 7*).

For invertebrate:

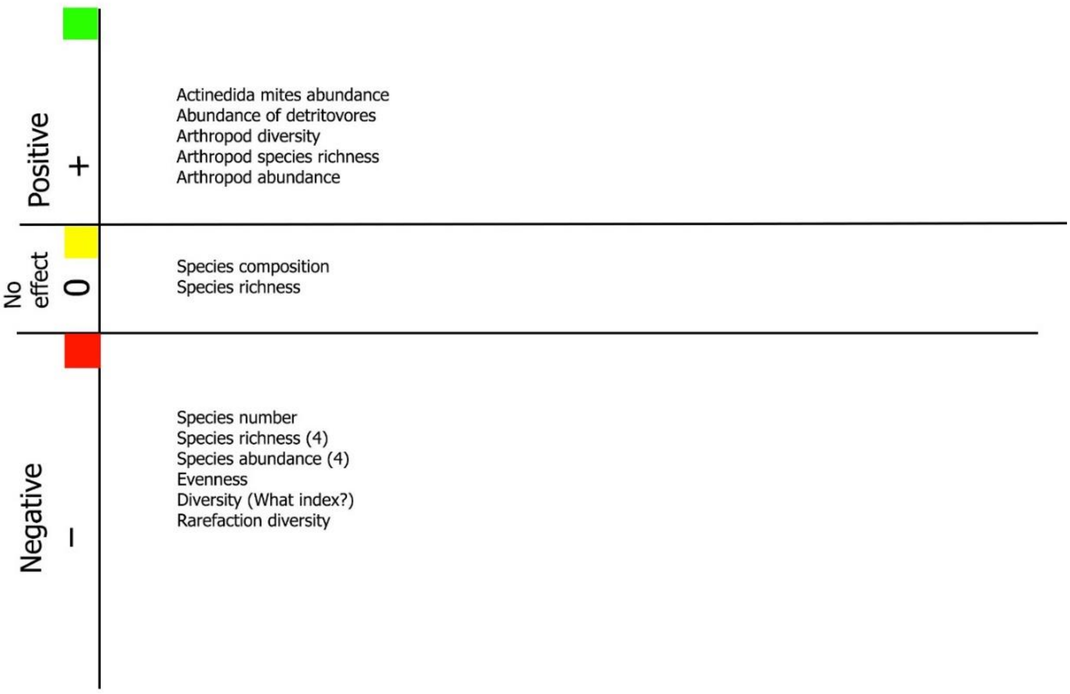

Figure 4. Effects of biological invasion on invertebrates divided into positive, negative effects and the lack of response. The number in brackets (n) represents the number of articles that mention given effect.

Positive relationships with invasion were recorded only for some groups, mainly arthropods (*Ellis et al., 2000*), particularly for *Actinedida mites* (*Gutiérrez-López et al.,2014*), but also detritovore invertebrates (*Topp et al.,2008*). In the study by *Kuebing et al., 2014* (not included in the figure), invasion did not affect arthropod species composition directly, but the dependent variable changed with the block, so the authors suggest invasion might have figured as a secondary factor.

There was generally equal number of articles reporting positive and negative effects of plant invasive species for diversity invertebrates.

For birds:

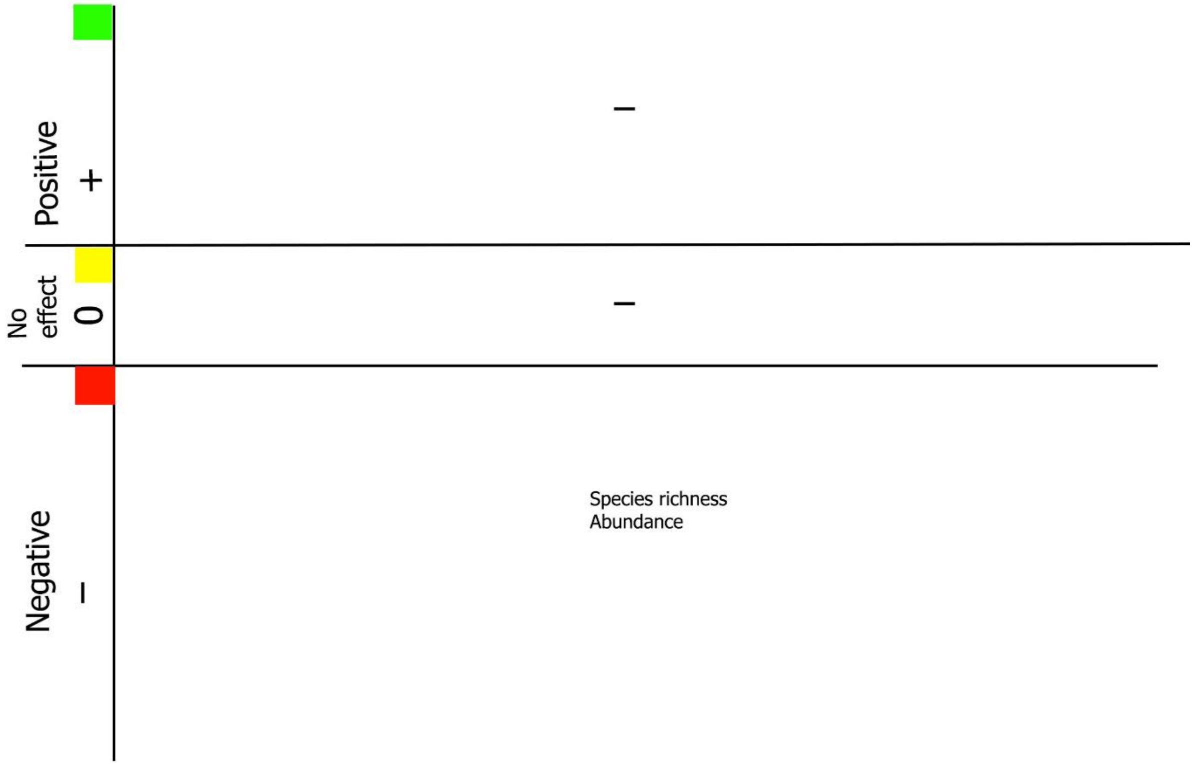

Figure 5. Effects of biological invasion on birds divided into positive, negative effects and the lack of response.

Only 1 research of biotic invasion's effect on birds in alluvial forests was found (*Martin-Garcia et al.,2013*), with 2 parameters studied, both of which had negative relationship with the presence of exotic flora. Further research is highly needed for better understanding of the subject.

For mammals:

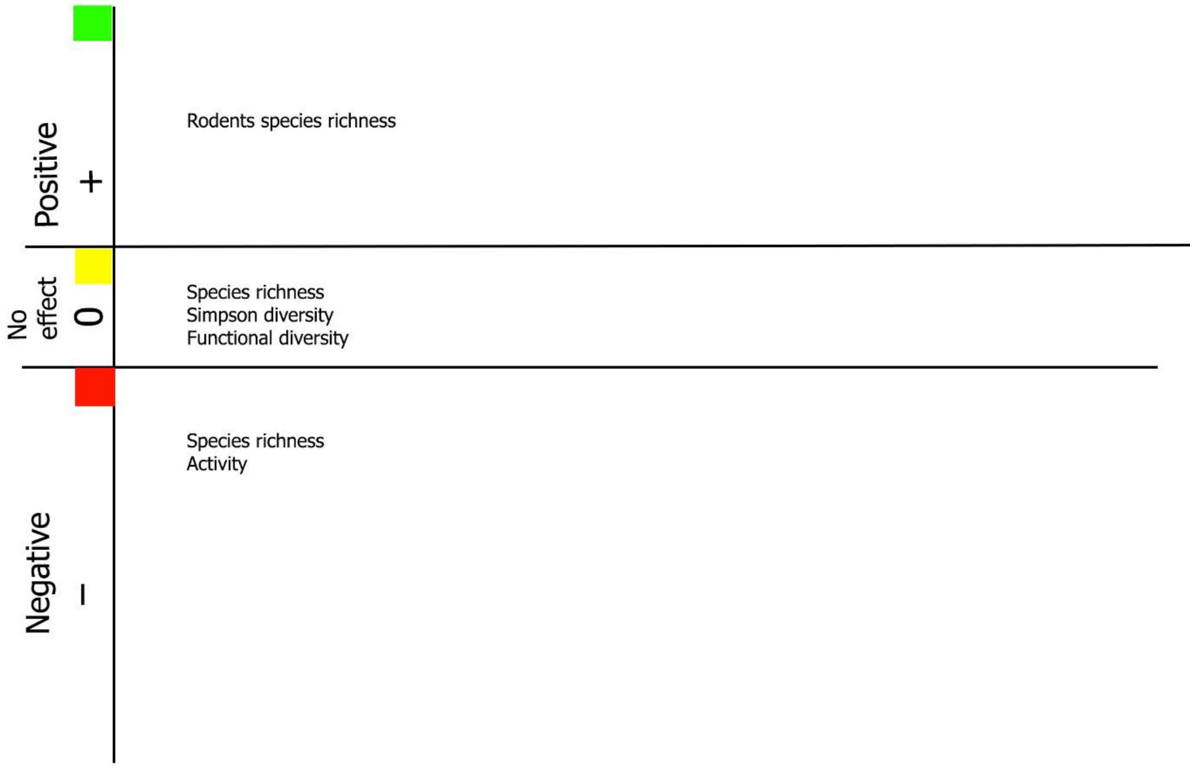

Figure 6. Effects of biological invasion on mammals divided into positive, negative effects and the lack of response.

The results on relationships between mammals and alien flora were quite contradictory, especially concerning species richness with three different outcomes from three different studies (*Ellis et al.,1997; Leavitt,2012; Cruz et al.,2016*). That is, most likely, due to the fact that mammals is very large and various class that requires more research in order to conclude about its interaction with non-native flora. Total of three studies were present in the database.

For abiotic parameters (OTHER):

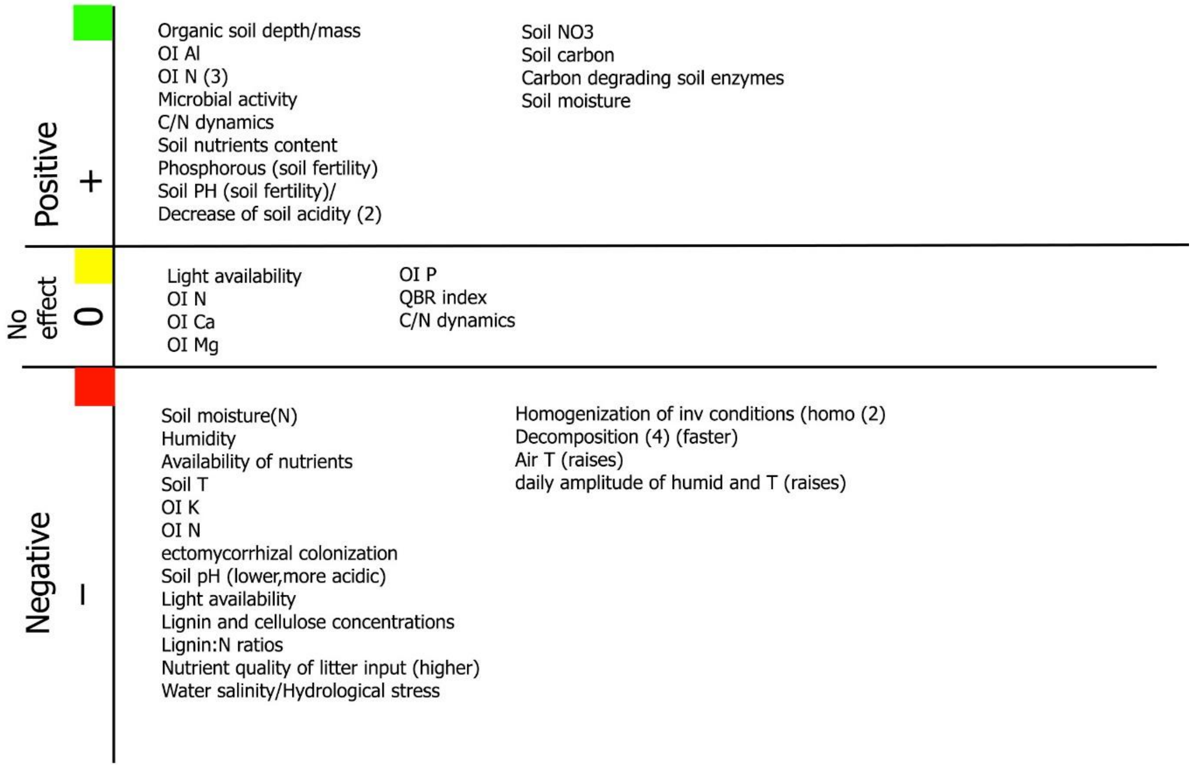

Figure 7. Effects of biological invasion on abiotic and biotic parameters of ecosystem divided into positive, negative effects and the lack of response. The number in brackets (n) represents the number of articles that mention given effect.

According to *the Figure 7,* the relationship between ecological parameters and invader seem to be largely dependable on the invader's specie and secondary factors, as the pure fact of the presence of alien flora seem to lead to differing results in different studies. *Medina-Villar et al., 2016* could be taken as an example: in the study two different invasive species lead to opposite responses from the same variable-concentration of nitrogen containing compounds.

In the study done by *Kuebing et al. ,2014* (not included in the figure), invasion did not affect microbial activity directly, but the dependent variable changed with the block, so the authors suggest invasion might be a secondary factor in that case.

The raising of the temperature and lowering of moisture were attributed to negative column as the change of microclimate does not seem to be a preferable result, however that is up to a debate. The increase in soil acidity was contributed to a negative as it may restrict the reproductive capacity of certain species in alluvial forest, in standing vegetation and potentially reduce the quantity and richness of seed inputs from local seed rain (*Cofer et al.,2018*).

The numbers of positive and negative effects were approximately equal (negative slightly prevailed in numbers), lack of any response was rarely observed.

Alas, no direct studies of influence of invasive plants on bacteria or fish were found.

Overall, there were more negative relationships present in total. However, positive effects were frequently observed in the groups of invertebrates and abiotic factors. Plants, mammals and birds displayed majorly negative relationships, though responses of some taxons are significantly unresearched.

4.2 What invasive species is the most frequently occurring in the studies?

The method from *Schnitzler et al.,2007* was taken in order to assess the frequency of invasive species occurrence: invasive species was considered scare if it was present in less than 5% of records, moderate if it was present in 6-20 % of records and abundant if it was present in more than 20 % of records.

Only first part of database was examined as the second part (influence of factors on invasion itself) was considered more focused of the factors themselves rather than the invader's species those factors affect.

A total 26 of invasive plant species and 2 groups of same genus species were present in a first part of database:

Acer negundo, Adelges tsugae, Ailanthus altissima, Alternanthera philoxeroides, Amorpha fruticosa, Arundo donax, Chaptalia nutans, Cyperus alternifolius, Eucalyptus globulus, Ficus carica, Hedera helix, Impatiens glandulifera, Impatiens parviflora, Ligustrum sinense, Lonicera maackii, Microstegium vimineum, Nicotiana glauca, Populus × euramericana, Reynoutria spp.(+ R. japonica, R. sachalinensis, *R. x bohemica), Rhododendron maximum, Ricinus communis, Robinia pseudoacacia, Rosa multiflora, Rubus caesius, Tamarix spp. (+Tamarix aphylla, Tamarix ramosissima), Typha latifolia, Triadica sebifera, Ulmus pumila.*

Tamarix aphylla and *Tamarix ramossima* are combined into *Tamarix* spp. group to avoid confusion as in *Leavitt,2012* and in *Ellis et al.,2000* studied *Tamarix* species are not specified.

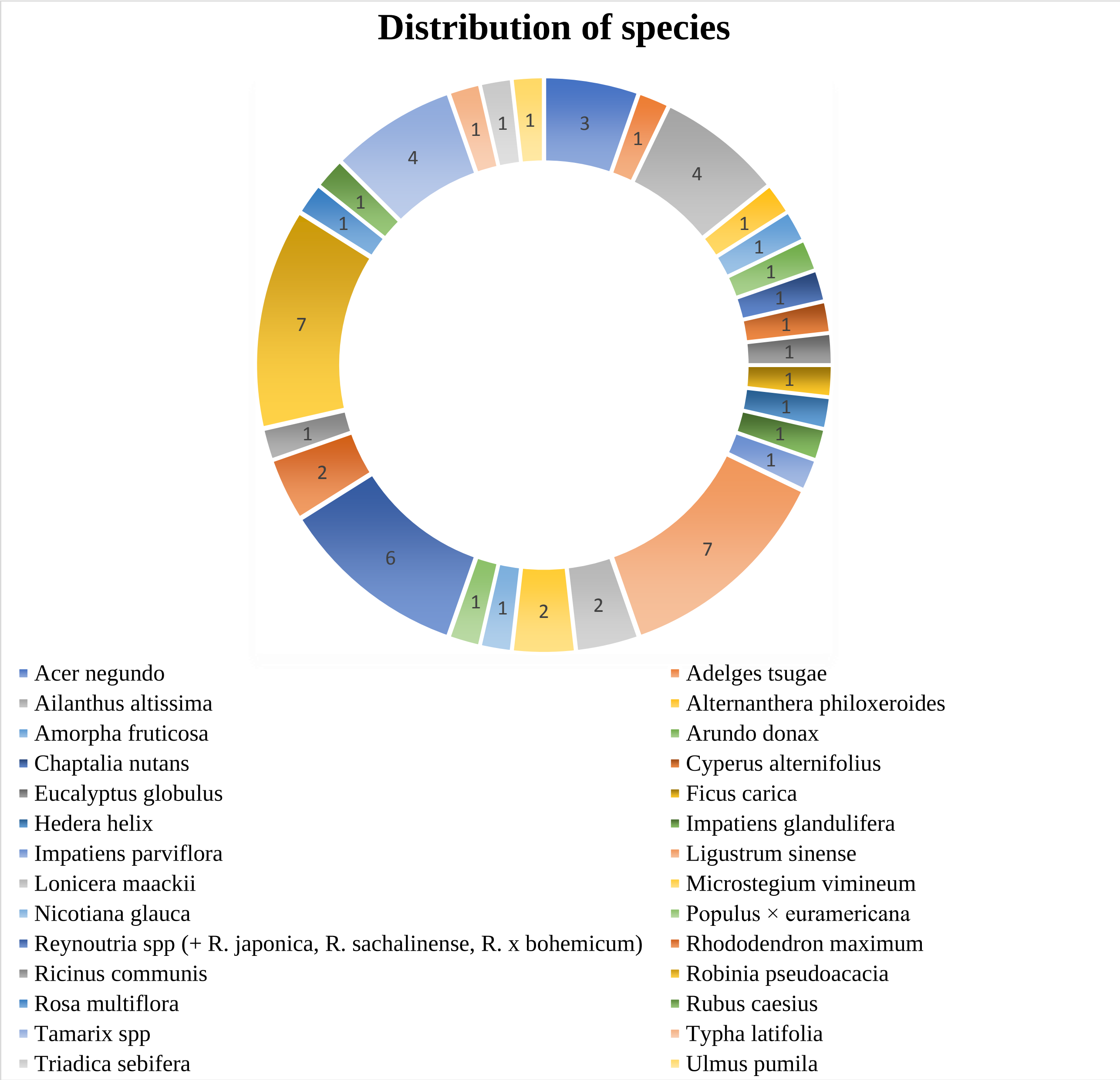

Figure 8. The alien species present in floodplain forests given by the number of appearances in the studies. Each specie is represented by a certain color on the chart.

The most present invasive plants happened to be: *Ligustrum sinense* (n=7), which is native to China and is classified as invader in Europe and Northern America and *Robinia pseudoacacia* (n=7), native to Northern America and invader in Europe.

They were categorized as moderately present, as there were no species that would occur on more than 20 % of the study. Following by numbers were *Reynoutria spp.* (n=6), *Ailanthus altissima* (n= 4), Tamarix *spp*. (n=4) and *Acer negundo* (n=3). The rest of the species were present in 2 studies or less.

"Top 100 of the world's words invasive species list" include mentioned species: *Arundo donax, Reynoutria japonica, Tamarix ramossisima* as top dangerous land plants-invaders (*ISSG,2000*).

The results cannot be an indicator of the frequency of invaders presence in terrain but serve as a representation of current knowledge on invaders, and could be compared with actual invasive species distribution studies in order to analyze whether the researcher's preference plays a role in a prevailing of articles with one species over the others.

4.3 Effects of removing invasive flora

While collecting data through the given methods, 3 studies exploring the effects of removing invasive flora on ecosystem's parameters were found: *Hanula et al.,2009*; *Hundson et al.,2014*; *Ulyshen et al., 2010* (The effects of removing on invader's presence are discussed in a chapter 6). All of the studies inspected the removing of *Ligustrum sinense* and had similar techniques of removing invasive shrub: *Hanula* and *Hundson et al.,2014* used both mechanical mulching and hand-felling with adding the herbicide, while *Ulyshen et al., 2010* used mulching machine and a chainsaw.

No negative effects of removal of *Ligustrum sinense* were discovered, however, some of the cases of treatment didn't give any effect. *Figure 9* contains excerpt from the database, showcasing the effects of removal.

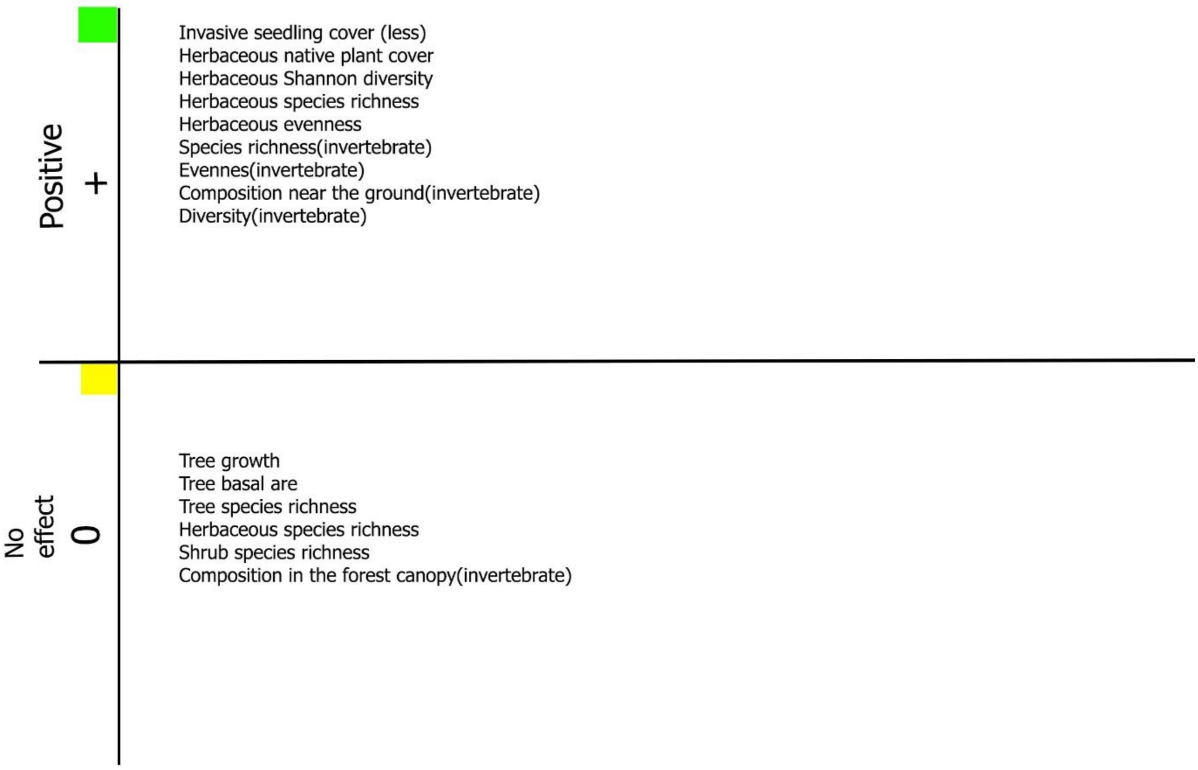

Figure 9. The effects of removal invasive L. sinense on the native ecosystem divided into positive effects and the lack of response.

Overall, removing treatments appear to be effective when it came to the ecosystem's parameters. Different methods of removing gave results similar in their principle, but different in its efficiency. *Ulyshen et al., 2010* reports, that species richness of invertebrate near the ground varied significantly between the mulch and chainsaw plots, even though both treatments gave positive results. Evenness of invertebrate also varied between treatments, however with the removing *Xylosandrus crassiusculus* from the dataset, the differences were removed as well.

Regarding the effects on native flora, *Hanula et al.,2009* reports that both mulching and hand-felling happened to be ineffective in removing invasive shrub without following treatment with 2% glyphosate. Mulched plots had significantly more effective results on plant cover compared to hand-felled plots. Evenness was higher in mulched plots than in hand-felled and control plots as well. On the other hand, *Hundson et al.,2014* reports that hand-felled plots have the lowest percent of invasive seedling cover compared to mulched and control plots. Therefore, it is up to a debate, which removing technique is more effective. It is also important to note, that

Hundson et al.,2014 and *Hanula et al.,2009* had different reports of removal's influence on herbaceous species richness.

Though some of the aspects of removal are covered, the given figure and data is just a glimpse at an issue, so a separate database concerning the effects of removal biotic invaders could be a substantial addition to the scientific knowledge.

5. Regional specifics of invasion

Invasion is a widespread issue, spanning all over the world. To properly choose treatments for each case of invasion, but also to understand general trends and predict possible scenarios for the less invaded parts of the world, it is important to note the regional specifics of invasion in a context of alluvial forests.

Figure 10 is a map illustrating the origins and further invasive distribution of species included in thesis. Distribution to the areas where given species are not considered as invasive is not depicted. However, a conclusion on a character of distribution cannot be made based on the map, as it only includes species mentioned in a thesis, which is a based on the sources from Northern hemisphere only.

Figure 11 is a subpart of a *Figure 10'*s legend, representing the species that are considered highly expansive in their native regions.

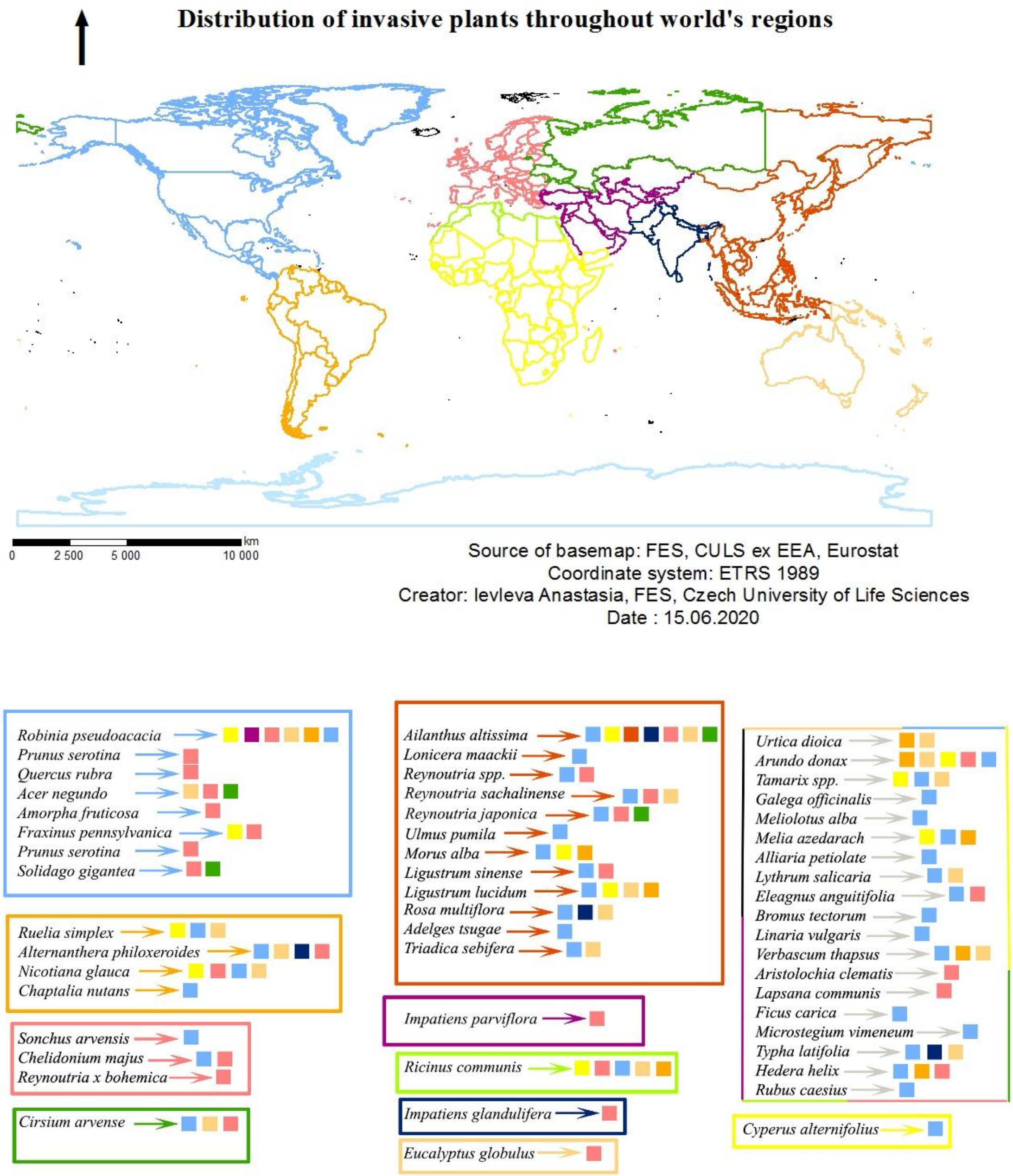

Figure 10. A map illustrating the origins and distribution of invasive species throughout various world's regions. The color of the frame and arrow represents the region of species origins followed by squares representing the countries to which the species were distributed and are now considered invasive. The character of each region`s shape is based on the tendencies of plant invasion rather than on geopolitical features. Light blue- Northern America; Orange- South America; Pink- Europe; Green- East Europe+ Western Russia; Red- East and South East Asia + Far East of Russia; Indigo Blue- South Asia; Purple- Central and Western Asia; Lime green- Northern Africa; Yellow- Africa; Beige- Australia and Oceania; Multicolor- multiple native regions. Sources of information on distribution: CABI© 2020; GBIF© 2020; GISD© 2020; Bailey et Wisskirchen, 2006; Gutierrez-Lopez et al., 2014; Lemna et Messersmith, 1990; Schmiedel et al., 2013; Skowronek et al., 2014; Topp et al., 2008; Urgenson et al., 2009.

Plants expansive in their native areas

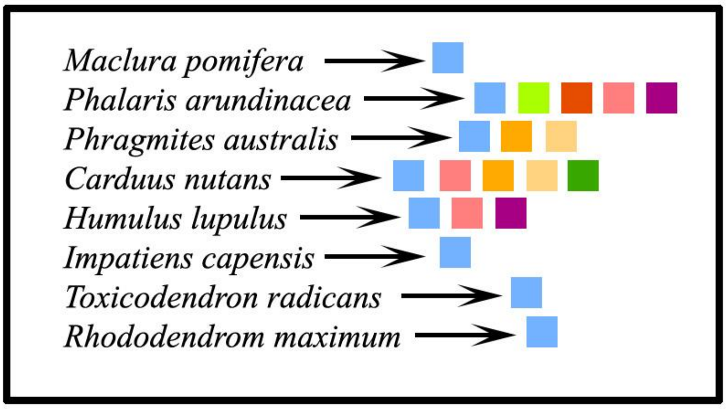

Figure 11. Plants that are considered highly expansive and invasive in their native origin areas. Color coding matches the Fig.8. Sources of information on distribution: CABI© 2020; Baker et Van Lear, 1998; Gowton et al., 2016; Gutierrez-Lopez et al., 2014.

In the thesis' database the character of each response to the invasion was compared between studies in different regions, with recognition of differences between taxonomic groups. No significant differences related to the regions were found as various regions reacted to the invasion the same in terms of most of ecological parameters. The only exclusion seems to be Poland, as few of the studies conducted there seem to differ in qualitative results from the others. *Dydersky et al.,2015* of Poznan reports unusual positive relationship between native and invasive species richness' in a presence of *Acer negundo*. Research done by *Chmura et Sierka* in *2006* in Southern Poland (Jurassic Upland and Silesian Upland) reports a positive influence of *Impatiens parviflora* on plant's Shannon's diversity and species richness.

However, it is not enough to conclude that described contradictions are necessarily connected to the geographical features.

Nonetheless, sources outside of collected database can provide more information on the topic. According to *Schnitzler et al.,2007* distribution of invasive flora in Europe significantly varies. Exotics tend to be less present in areas with longer summer droughts, such as communities along intermittent rivers in the Mediterranean region, and in areas with colder (boreal) climates. Invasive flora is also at the very low level on the eastern edge of the temperate zone: up to the Ob River, east of the Urals, likely in part due to harsh winters (*Schnitzler et al.,2007 ex Taran,1999*). That can be explained by the exotic's need for water and a longer growing seasons, which are less common in the mentioned areas, as many invaders in Europe come from warm-temperate regions (*Schnitzler et al.,2007*).

A significant trend reported by *Schnitzler et al.,2007* is a decrease of exotic species richness with a decreasing latitude, which is also connected with growing seasons, they shorten with an increasing latitude.

It is also important to mention, that according to *Schnitzler et al.,2007* certain topographies are more vulnerable to exotic species, such as communities in flat plains. That is because rivers systems in flat plains tend to be the lower reaches of rivers that support a wide range of species and microhabitats (*Schnitzler et al.,2007 ex Ward et al., 2002*). Since these areas typically represent the largest parts of the river system, the species area relationship does predict higher species richness (as well as exotic species richness) due to their larger area. Larger floodplains will also have more habitats buffered from extreme high-flow and low-flow events of the river and thus provide habitat for exotic species which may not be adapted to the hydrologic regime of the river floodplain (*Schnitzler et al.,2007).*

Another way to look at the regional specifics of biological invasion is to attribute the ongoing factors to the scaling levels. *Fig.12* demonstrates generalized ecological parameters present in thesis' database divided into three levels: Regional level, the level of site and the level of individual organism (only parameters of taxonomic groups, as abiotic factors were excluded). It helps illustrating how the influence of invasive flora on ecosystem is complex and multilayered.

Figure 12. Levels of biotic parameters influenced by biological invasion present in a database.

Most of the factors studied in articles of the database are concentrated on the level of the site. That itself doesn't prove that exotics influence is primarily on a local level, rather that site's level parameters are more frequently studied. It is also important to recognize that most study designs are created around that level.

Invader's effect on organism level were mainly concentrated around native woody flora, presumably not only because this taxonomic group is favored by researches, but also because it provides many different parameters to research.

No influences of regional level were recorded in the database, with the exception of study done by *Chmura et Sierka,2006* concerning beta-diversity. Beta-diversity changes under the influence of both regional and local factors, which in its turn are affected by biological invasion (*Douda et al.,2018).*

6. Influence of anthropogenic, biotic and natural abiotic factors on invasive flora

At the present time the number of invasive species increases in all types of habitats, including alluvial forests (*Lambdon et al., 2008*). For that reason, the techniques and means of fighting biological invasion is a relevant question that requires extensive research and development. To help navigate in a range of management techniques and roots that can produce new techniques, a second part of the database was executed. It provides a review of studies investigating the influence of various environmental factors and management tools on invasive flora in alluvial forests.

6.1 The influence of anthropogenic factors

The effects of natural cause were more frequently studied then anthropogenic factors. *The Table (1)* though depicts that as is widely believed, urbanization and most of related factors positively influence the presence of invasive flora.

6.1.1 Urbanization

Sung et al., 2011 reports how a watershed urbanization positively affects invasive cover and richness by causing hydrological drought, particularly in hot and semi-arid regions. *Rubino et al., 2002* studied how electric and petroleum utility corridors influenced riparian vegetation in Allegheny High Plateau in Pennsylvania and discovered that it positively affected the cover and species richness of alien flora (those variables correlated particularly with open soil, floodplain width and active channel width, which all are associated with corridors). Majority of invasive species found in corridors were shade intolerant and not present in floodplain forest, from which *Rubino* concluded that open utility corridors served as habitat refugia for alien plants in riparian forests. Another study of phenomena associated with urbanization was done by *Pennington et al.,2010*. The effects of building area, presence of railroads and distance to the nearest road were studied. It was found out, that highly urbanized riparian forests tended to have a canopy, that consisted of native early-successional species and alien species with the understory of majorly invasive shrubs. On the other hand, less urbanized forests had more diverse composition. Interestingly, grass cover was also positively associated with exotic canopy basal area, exotic species richness and stem density. *Pennington* suggests, that percentage grass cover might reflects transition areas between grass and forest edge.

6.1.2 Management techniques

Other effects in *Table (1)* include mainly management techniques: propagule limitation, site scarification with late fall; mechanical removing, herbicide without revegetation/herbicide +revegetation, forest logging and lack of management leading to light gaps formation. To help figuring out, which treatment is the most useful in invader's presence reduction, a closer look at the studies is given.

Lack of any management leads to the results that are slightly more complicated than simple "positive-negative" categorization. *Ortman-Akaj et al.,2016* reports that floodplain oak forests with lack of management and presence of gap formation increased its presence of invasive plants through years but only up to 1.4 %. The lack of management in this study had more influence on composition and structure between native species. *Brewer,2011* reports canopy gap fraction is a significant predictor of invasive *Microstegium vimeneum* production. *Warren et al.,2015* reports on the negative correlation with canopy cover as well.

Interestingly, removing invader techniques were mostly ineffective in studies given in database, except for the study of *Thomsen et al.,2012*. In its field experiment invasive was removed during a fall by a mulching machine, followed by further soil scarification with the help of tractor-pulled rotary tiller. Then different combinations of pre-emergent herbicides were applied. Those means delayed invader's emergence the following spring, which gave an opportunity of an early growth of native plants without competition. *Warren et al.,2015* reports positive but non major results in reducing invader's presence as well, however, not by removing a grown plant, but by propagule limitation. As of less effective techniques, *Skowronek et al.,2014* suggests that disturbances should be minimized and mechanical removing of non-native trees in the studied Ticino Park should be stopped. No direct influence on the invaders were studied, but near natural forests and invaded stands were compared in order to investigate, how main canopy tree species and soil properties affect seed bank composition. It was concluded, that invaded stands had only 13 % similarity in a species composition with the near natural forests. *Skowronek* reports that due to this results that the restoration of near native flora from soil seed bank is not feasible in this case and that the mechanical removing should be stopped. However, it is important to note, that this result is very dependable on the context and can't perform as an illustration of a general trend.

Another study, done by *Smith et al. in 2015* researched on how 2 methods (divided in to 5 treatments) of herbicide application influenced recolonization of native species and invader's (*Ruella simplex*) variables in the invaded floodplain forests of Florida. The researchers preformed: 1). Spraying a plot with no-pretreatment herbicide without any planting; 2). Spraying a plot with pretreatment herbicide without any planting; 3). Spraying a plot with pretreatment herbicide with seeding 2 of the most vigorous native species (J. *effusus and S. fisulosa*); 4). Spraying a plot with pretreatment herbicide with seeding native species mix; 5). Spraying a plot with pretreatment herbicide with seeding revegetation with plugs from a native species mix. Alas, none of the treatments resulted in restoring native vegetation or reducing Simplex's stem density, percentage cover or biomass. However, total species richness, including native and exotic species richness, increased in plots planted with a native plug mix compared to control plots. (*Fig. 13*)

Generally, removing techniques displayed results that weren't significantly effective, though it is advised to refer to the broader sources on the topic of management techniques, including sources on other biotopes, as the review of those weren't the focus of thesis's database.

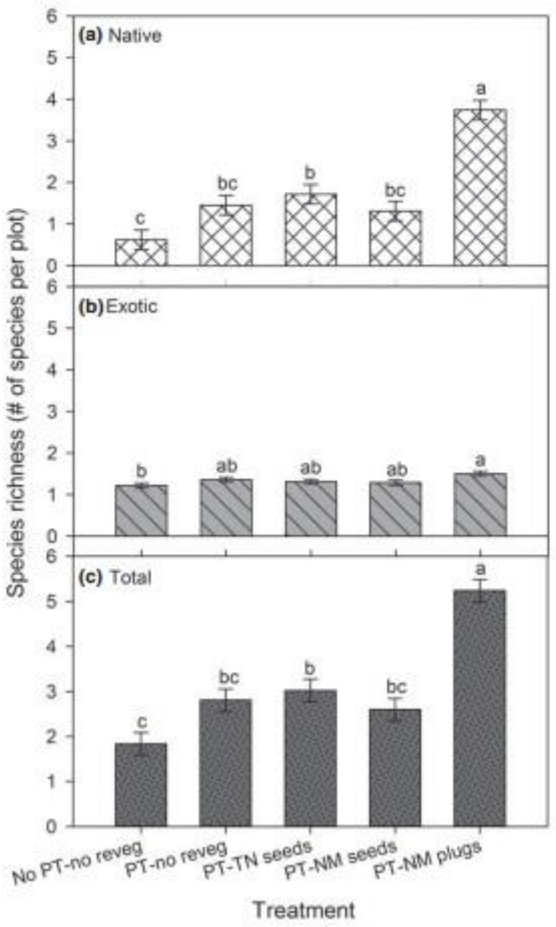

Figure 13. Mean (a) native, (b) exotic and (c) total species richness (number species per plot) Data represent means of seven replicates per treatment SE over time. No PT–no reveg refers to no pretreatment herbicide and no re-vegetation (control). PT–no reveg refers to pretreatment herbicide and no re-vegetation (i.e. unassisted recolonization). PT–TN seeds refers to pretreatment herbicide and seeding with two native species. PT–NM seeds refers to pretreatment herbicide and seeding with a native species mix. PT–NM plugs refers to pretreatment herbicide and revegetation with plugs from a native species mix. Smith, 2015

The last undiscussed anthropogenic factor in a database was forest logging, effects of which were researched by *Dyakov et al.* in *2013*. The study is a notable example illustrating how some of the responses may seem contradictory but can often be explained by the difference in invader's specie, regional specifics or other side factors, affecting the alluvial ecosystem. *Aristolochia clematitis, Chelidonium majus* and *Urtica dioica* were positively correlated with unlogged forest, while *Galega officinalis, Sonchus arvensis* and *Melilotus albus* were positively correlated with logged ones *(Table (1)).* Though the study mainly focuses on the natural factor's influence, which is reviewed in the next subchapter.

6.2 The influence of biological factors

A content of *Table (2)* could be divided into two parts:

- Factors of a native flora: tree/canopy cover, species richness, tree species number/0.1 ha, diversity, grass cover, host tree maturity and diameter, forest age
- Other factors (abiotic, site's or non-floral natural factors): disturbance, riparian extent, wind, distance to the river, fire, beaver's presence, moisture, soil fertility, light, elevation, shade, flooding, non-native habitat

6.2.1 The influence of native flora

In the following subchapter a closer look is taken at how native flora influences an exotic one.

Native plant's species richness and diversity were the most frequently researched parameters in thesis's database, though most of the studies focused of the influence of invasion, not vice versa. Here the effects of given parameters on the invasive flora are presented.

A study done by *Obidzinski et Symonides in 2000* showed that a correlation between the species richness and the frequency, power and density of invasive *Impatiens parviflora* population was negative. However, *Dyakov et al.,2013* research shows once again that the character of relationship between species richness and alien flora is highly dependable on the invader's specie. *Melilotus albus, Sonchus arvensis, Galega officinalis, Lapsana communis* showed positive relationship with species richness, while *Chelidonium majus, Humulus lupulus, Urtica dioica* responded negatively. In this same study, *Aristolochia clematitis, Chelidonium majus, Humulus lupulus Urtica dioica* had positive relationship with species number/ 0.1 ha.

Besides that, *Dyakov* found out that *Amorpha fruticosa* had negative relationship with diversity, while *Meliolotus albus* had a positive one.

Characteristics more oriented on the forest type and structure were also present in database. Multiple studies had been dedicated to examining the influence of tree, or overstory canopy cover on the invader's presence and parameters. According to *Warren et al.,2015* increased tree cover (as a proxi for reduced sunlight and temperature) reduced the presence and community diversity of multiple invasive species *(Table (2))* in riparian sites along Niagara River Greenway (New York, USA). *Lesica et Miles,2001* concluded the same, strengthening the point- study found out that diameter growth rated of invasive *Eleanus anguistifolia* decreased with increasing overstory canopy cover. However, this factor's influence is more complicated, as proved by *Dyakov et al.,2013*, who reports that different alien plants had different strong responses to the increasing tree and shrub cover, but interestingly, none of them responded to the changes in herb cover *(Table (2)).* This once again depicts how most of the factors are multidimensional and how different invaders cause various responses.

Forest age is another characteristic largely defining forest structure, including the structure of riparian forests as well. As of its relationship with invasion *De_Ferrari et Naiman,1994* report positive correlation of forest's age with exotic species richness- the older the forest, the more invasive species there are. A slightly different in its nature, but still notable observation is reported by *Brewer,2010* – an age of stand predicts species composition more than the presence of invasive *Microstegium vimineum.*

The age of individual native organism has a significance as well: *Manescu et al.,2018* reports a positive correlation between a local invader's *Hedera helix* presence and the maturity of the host tree. Interestingly, it was also observed that in case of young host trees *H. helix* preferred to climb onto invasive tree rather than on native. However, independent of tree species*, H. helix'* trunks height was also positively correlated with the host's tree diameter.

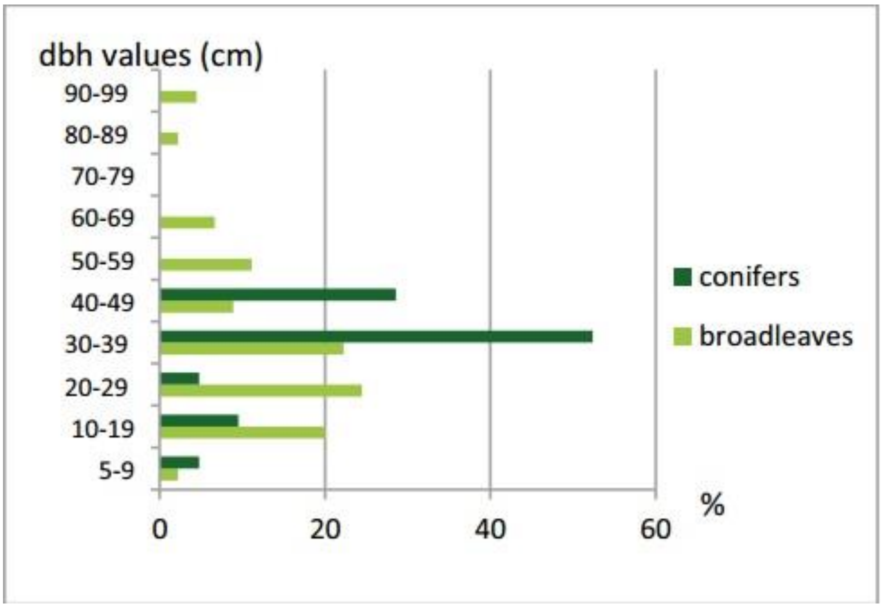

Figure 14. Frequency of H. helix on different dbh of host trees as a depiction of its age and diameter preferences, Manescu,2018

6.2.2 Abiotic and non-floral natural factors

Abiotic factors are strongly connected with the floral ones in its functioning. As tree cover can be depicted as the combination of less light and lower temperature (*Warren et al.,2015),* a closer look at those factors can be taken. *Dyderski et al.,2019* examined whether the alien cover and richness are context dependent (depend on the type of vegetation) and dependence on resource availability, including light. The article reports that light strongly negatively correlated with alien cover. *Brewer,2011* reports that abundance of invasive *Microstegium vimineum* was lower in shady areas of studied sites, however, the per capita negative effect on resident plant community appeared to be the greatest there. *Brewer* suggests that is due to the fact that vulnerable native species were absent in non-shady gaps.

Alas, no study proving invader's response to the temperature in a context of riparian forest were present in database, however it is generally known that invasive species prefer warmer habitats (as an example- *Chytrý et al.,2017*). Instead, an article on fire's consequences is present and is discussed in a subchapter about disturbances that follows.

The responses of invasive flora to the natural disturbances varied between the articles, presumably depending on the type of disturbance. *Gowton et al.,2016* performed an experiment in Susquehanna River, Pennsylvania by planting seeds, and rhizome and stem fragments into riparian forest plots with intact *Reynoutria japonica* subcanopies, and into plots with the invader's subcanopy removed, simulating disturbance. The researchers found out that disturbance didn't have a significant influence on the establishment of rhizomes and stems but significantly affected shoot height and size and timing of shoot death from rhizome and stems fragments. The authors of the article themselves though believe that overall disturbance simulation had minor effect on the recruitment of *R. japonica. Brewer,2011* on the other hand, reports a positive association of invasive *Microstegium vimeneum* with disturbance indicators, moreover, the relationship isn't explained by the presence of species indicative of disturbed area, but by the disturbance variables themselves.

Fornwalt et al.,2010 examined the response of invasive flora (*Table (2)*) to disturbance by fire. The article reports that exotic richness and cover generally increased as fire
severity and time since fire increased, however alluvial forests were not largely affected in case of light burns and didn't become more susceptible to biological invasion. Besides that, invasive species that were present before fire remained post-fire as well, though new exotic species appeared post-fire, including both exotics present in areas surrounding fire and truly new species. Native and exotic richness and cover were either positively or not correlated through all stages of fire.

As of flooding, both *Brewer,2011* and *Warren et al.,2015* report positive influence of invader's production.

Researches investigating less damaging water influence are present in a database as well, more precisely the influence of moisture, riparian extent and distance to the river. According to *Dyakov et al.,2013,* moisture positively correlates with invader's presence, and distance to the nearest river negatively correlates with invasive herbs. That supports the spread point that exotic species prefer moist habitats, however *Lesica et Miles,2001* concluded that moisture levels did not significantly affect invasive ground-layer vegetation. As of riparian extent, *Warren et al.,2015* reports that the likelihood of occurrence of 6 invasive species (*Table (2)*) increased significantly with the riparian extent. The study also reports that the occurrence of invaders decreased with steeper riverbanks.

More relationships with habitat characteristics were recorded: soil fertility, elevation, wind and non-native habitat.

Soil fertility is the most evident environmental factor interacting with plant's life. Fertile soil is a desired matter in human's culture and a factual feature of most alluvial forests. As of interaction with invasive flora, *Dydersky et al.,2019* found out that soil fertility positively affects invasive species richness.

Other habitat characteristics showed the following results: Wind affected seeds dispersal, as the seeds of invasive *Fraxinus pensylvannica* occurred against the direction of prevailing wind (*Schmiedel et al.,2013*). Elevation correlated negatively with the probability of invasion by multiple exotic species (*Table (2)*) in a study done by *Lapin et al.* in *2019*. More general look at the habitat was taken in a study by *Annighofer et al.,2013*, which resulted in a conclusion that biomass production (stem, crown, leaf and total biomass) of invasive *Padus serotina* and *Robinia pseudoacacia* were lower in Ticino, Italy than in their places of origin in North America.

Lastly, an interesting fact concerning biotic, but non-floral influence was recorded. While performing a study in Yellowstone, USA, *Lesica et Miles in 2001* found out that only 18 % of the plots had evidence of beaver's presence, with 78 % of native cottonwood damaged by beavers, but interestingly, not a single invasive *Eleagnus anguistifolia* was damaged. In other words, beaver's presence had no effect on invasive flora, but had negative effect on native.

Overall, according to the database's matherials it can be concluded that effects of non-native habitat on invasive flora are various in nature so that it is unreasonable to simplify and categorize them to either positive or negative influence. Anthropogenic, biotic and natural abiotic factors all had different, but significant relationships with exotic plants. Besides that, invader's specie was a separate factor playing significant role in multiple researches. A more complex analyse that would include reprezentation of ecosystem from a more dynamical point of view is highly suggested.

7. Discussion

7.1 Effects of invasive species on floodplain forest ecosystems

The results of analyzing thesis's database reaffirmed that biological invasion is mostly a negative phenomenon as there were more negative effects present in database consisting of a significant number of articles published on the topic for the last 25 years, in English language. Out of 105 effects total 59 were considered negative. That was expected as invasion has been described as negative phenomena for a long time, with studies documenting its negative impacts on all levels of biological organization. That is including:

- Causing hybridization that leads to reducement of native reproduction by either wasting native gametes in case of sterile younglings or competing with native species in case of fertile younglings; *(Lockwood et al., 2007)*
- Altering the morphology, behavior and demographic rates of native species by creating a competition and introducing new predators. As an example: rodents *Peromyscus polionotus* and *Sigmodon hispidus* both altered their foraging behavior in the presence of invasive ants *Solenopsis invicta*, to the point where rodents preferred taking risks of coming into/being eaten by their avian predators rather than coming into contact with invasive ants. *(Pedersen et al., 2003; Orrock et Danielson,2004)*
- Competition, predation and physical negative impacts on the level of population *(Lockwood et al., 2007)*
- Negative impacts on the community including cases as extreme as mass extinction, which mostly occur in cases of previously evolutionary isolated ecosystem. An example could be an introduction of piscivorous *Lates niloticus* into Lake Victoria, which lays near African Rift Lakes and had been isolated from others for a long time. That was done in the 1950s with the goal of increasing food resources for the local humans. However, this led to the

loss of 200 species of native cichlids due to the competition that invaders provided (*Witte et al. 1992*).

- Changing the flow of materials through ecosystem and other ecosystem processes *(Lockwood et al., 2007)*

Despite the prevalence of negative effects in both thesis's database and outside sources, plenty of positive effects were recognized as well, primarily on the soil's characteristics, but also on certain taxonomic groups, such as arthropods. Those positive effects of invasion should be regarded and implemented in techniques of managing alluvial biotopes.

Unfortunately, the lack of data in some fields made it impossible to perform more rigorous analyses through statistical testing, which is an issue itself. Judging by what areas of research had the least data available, it can be concluded that some taxonomic groups are highly preferred by the researchers, while others are severely under researched. Most of the studies compared invader's relationships with native flora, which makes sense, however mammals and avian groups lacked studies, as there were only 3 studies present on the first and 2 on the last. No studies were found on how fish interacts with invasive flora and very few studies included any water organisms. Bacteria's responses were also under researched and no studies were found on lichens or fungi.

Besides researcher's preferences on the larger scale, some of the patterns of choosing a studied specie were present. As an example, the most frequently studied species through database happened to *be Ligustrum sinense* and *Robinia pseudoacacia,* widely recognized as invasive. However, *Arundo donax* was only present in one article, even though it is considered quite harmful biological invader as it is included in *100 of the world's worst alien species list* (*ISSG,2000*). *Cruz et al.,2016* points out that *Eucalyptus globulus* is not widely recognized as invasive plant and needs strengthening its invasive status, so it's also important to raise the awareness about species that are rarely presented as invasive but are still dangerous to the natives and surroundings overall.

Instances described above can be explained by lack of specialists in the mentioned fields or unpopularity of invasion's topic in those studying fields, or it might be a consequence of an "umbrella species issue". Never mind the reason, those cases illustrate a lack of full and multidimensional presentation on invaded ecosystem, which may lead to lose of significant information, so further researches on given topics are highly suggested.

Many of various responses might have been caused by the difference in invader's species, as there were examples of different invader reacting differently to the same factor or vice versa (*Dyakov et al.,2013*). Certain studies differed from the other in their results, so a closer investigation of side factors that might have influenced it is suggested.

7.2 Regional specificity of effects of species invasions

As of regional specifics, it could be noted that East Asia and North America are the native regions to the significant portion of invasive species in case of Northern Hemisphere. The primary source of invasive plants in Europe is North America and occasionally East Asia, while the main source of invaders for North America is East and South-East Asia (*Fig.10; Fig 11.*). Interestingly, some of the invasive plants were expansive in their native regions or were escaping from cultural plantations (*Fig.10; Fig 11.*). For that reason, cultural plantations requiring proper management and attention is one more side of invasion management.

However, most information on the character of distribution came from the sources outside of thesis`s database. Invaders prefer warmer habitats with higher moisture levels which ties logically with the results of the chapter on factors affecting invaders themselves, where it is proved that invader's presence and productivity positively correlate with riparian extent, moisture and flooding (*Brewer ,2011; Dyakov, 2018; Lesica et Miles, 2001;Warren et al.,2015*). Invaders also often suffered from long droughts and harsh winters (*Schnitzler et al.,2007 ex Taran,1999*).

Most of the articles focused on how invasion affect ecosystem on the level of the site, which could be explained by how study designs in general tend to be formed around that level. *Parker et al.,1999* reports the same dynamic, informing that invasive species impacts are mostly studied on the level of population. For that reason, it's recommended to research more on how invaders affect whole regions, as there were not many studies present on those scales.

7.3 Invader's preferences and mitigation of invasive species in floodplain forests

Like in previous chapters, there were cases of different responses by different invasive species, including interaction with factors as significant as species richness and diversity. Knowing this, it is important to consider each specie's specifics while dealing with invaded stand rather than just acknowledging them as a category.

Some of the articles present in database inform us on unusual and unfavorable responses - such as a study by *Fornwalt et al.,2010*, which reports that severe fires positively affect exotic richness and cover. That is an unlucky news, but an important information that would help specialists to be more prepared in case of emergency. Other articles inform on traditional, but ineffective management techniques – mechanical removing of invaders or herbicide application seemed to be ineffective (*Skowronek et al.,2014; Smith et al.,2015*) unless a soil scarification technique was used (*Thomsen et al.,2012*). Propagule limitation was reported to be a successful removing technique as well.

Natural factors lead to diverse responses, proving invaders preference for the warmer habitats with higher moisture as was mentioned above in *7.2* chapter. According to the results reported by *Warren et al.,2015; Saccone et al., 2013 and Lesica et Miles,2001* invasion suffers from the competition related factors such as native canopy and the presence of intact herb layers, despite the reasonable general believe that invaders are more successful in competition with native plants.

On the other hand, urbanization and all co-existing factors such as the presence of building area, railroads and auto roads, as well as resulting hydrological drought, were reaffirmed to be a positive influence on invaders' presence. As urbanization alters not only invasion rates, but other functions of ecosystem quite severely (*Melliger et al., 2018*), it is another reason to try to minimize its consequences, at least on the alluvial forests.

Overall, tables given in a thesis are recommended as a starting guide for composing management technique that could use both anthropogenic and natural influences on the invader.

8. Conclusion

Invasion is a two-sided phenomenon, complicated in its nature. According to the database affixed to the thesis, negative effects of it prevailed, however certain positive effects are documented and should be recognized more.

Regional specifics of invasion correspond with the invader's preferences for the warmer habitats with higher riparian extents and moisture levels, but a broader research of regional differences would be beneficial.

When it comes to invader's responses to the natural or anthropogenic factors, the picture is complicated, containing both positive and negative responses, so each case of invasion should be taken separately. The exception is urbanization which has a positive relationship with invader's presence in each case, besides causing other major alterations on ecosystem.

There still are plenty areas that need more thorough research to better understand invasion: such as certain taxonomic groups and species or different ecological levels of invasion.

Lastly, the character of relationship between invader and its non-native habitat is often dependent on the invader's specie or side factors, so those should always be taken into consideration.

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10. Appendix

Invader's specie	Effect	Invaders' response	Article
Prunus serotina, Robinia pseudacacia, Microstegium vimeneum	Lack of management=>light gaps formation	Positive on invader's share and production	Ortman,2016; Brewer,2011
Alliaria petiolata, Lythrum salicaria, Phalaris arundinacea, Phragmites australis, Reynoutria japonica, Rosa multiflora	Propagule limitation	Negative	Warren,2015
Phalaris arundinacea	Site scarification with late fall applications of pre-emergent herbicides	N on invader's emergence	Thomsen,2012
Ligustrum lucidum, Ligustrum sinense, Melia azedarach, Triadica sebifera and other	Urbanization	P on alien cover by causing hydrological drought, Positive on exotic species richness	Sung,2011; Rubino,2002
Ailanthus altissima, Maclura pomifera, Morus alba, Lonicera Maackii	Building area	Positive on exotic stem density and species richness	Pennington,2010
Robinia pseudoacacia, Prunus serotina, Quercus rubra	Mechanical removing	No direct effect studied, Soil seed bank studied, suggesting that removal of invaders has no effect	Skowronek,2014
Galega officinalis, Sonchus arvensis, Melilotus alba	Logged forest	Positive	Dyakov,2013
Ailanthus altissima, Maclura pomifera Morus alba, Lonicera Maackii	Railroads presence	Positive on exotic canopy basal area and density	Pennington,2010; Warren 2015
Ailanthus altissima, Maclura pomifera, Morus alba, Lonicera Maackii	Distance to the nearest road	Positive correlation with exotic understory density	Pennington,2010
Ruella simplex	Herbicide without revegetation/Herbicide +revegetation	No effect on stem density, above ground biomass, cover and species richness	Smith,2015

Table 1. The the effects of anthropogenic factors and intentional management techniques on invasive flora organized by the type of effect.

Invader’s specie	Effect	Invaders’ response	Article
Reynoutria japonica, Impatiens capensis, Toxicodendron radicans and others	Disturbance(simulated)	No effect on shoot emergence/establishment of stems and rhizomes, Negative effect on shoot height and timing of shoot death and exotic species richness and cover	Gowton,2016; Dyderski,2019
Alliaria petiolata, Lythrum salicaria, Phalaris arundinacea, Phragmites australis, Reynoutria japonica, Rosa multiflora	Riparian extent	Positive of invader’s occurrence	Warren,2015
Alliaria petiolata, Lythrum salicaria, Phalaris arundinacea, Phragmites australis, Reynoutria japonica, Rosa multiflora	Increasing canopy cover	Negative of invader’s occurrence, community diversity	Warren,2015
Acer negundo	Intact tree and herb layers	Negative on invaders presence due to competition	Saccone,2013
Fraxinus pennsylvanica	Wind	Seeds dispersal: Invader’s seeds occurred against the direction of prevailing wind	Schmiedel,2013
Acer negundo, Morus alba, Amorpha fruticosa, Aristolochia clematitis, Chelidonium majus, Humulus lupulus, Urtica dioica	Larger distance to the river	Negative	Dyakov,2013
Aristolochia clematitis, Chelidonium majus, Urtica dioica	Unlogged forest	Positive	Dyakov,2013
Melilotus albus, Sonchus arvensis, Galega officinalis, Lapsana communis	Species richness	Positive	Dyakov,2013

Chelidonium majus, Humulus lupulus, Urtica dioica; Impatiens parviflora	Species richness	Negative on frequency, cover and density of invader	Dyakov,2013; Obidzinski 2000
Aristolochia clematitis, Chelidonium majus, Humulus lupulus Urtica dioica	Tree species number/0.1 ha	Positive	Dyakov,2013
20 species	Tree/shrub cover	Negative and positive correlation depending on the specie, no correlation with herb cover	Dyakov,2013
Amorpha fruticosa, Meliolotus albus	Diversity	Negative correlation with A. fruticosa and positive with M. albus	Dyakov,2013
Padus serotina, Robinia pseudoacacia	Non-native habitat	Negative on invader's biomass production	Annighofer,2013
Bromus tectorum, Carduus nutans, Cirsium arvens, Linaria vulgari, Verbascum thapsus	Fire	No effect in case of slight burns, Positive on exotic richness and cover with time progression	Fornwalt,2010
Ailanthus altissima, Maclura pomifera, Morus alba, Lonicera Maackii	Grass cover, Cover of the groundlayer	Positive on exotic canopy basal area, exotic species richness and stem density; Negative on the invader's frequency, power and density acc. to Obidzinski	Pennington,2010; Obidzinski, 2000
Elaeagnus angustifolia	Native overstory canopy	Negative on diametr growth of invasive	Lesica,2001
Elaeagnus angustifolia	Beavers	No effect on invasive while negative on native	Lesica,2001
Acer negundo, Amorpha fruticose; Eleagnus anguistifolia	Moisture	Positive on invasive presence, No effect on invasive ground-layer vegetation according to Lesica	Dyakov,2018; Lesica,2001
Hedera helix (local invasion)	Host tree maturity	Positive correlation with invader's presence	Manescu,2018; De_Ferrari,1994
Hedera helix (local invasion)	Host tree's diameter	Positive correlation with invader's height	Manescu,2018
20 species	Soil fertility	Positive on exotic species richness	Dyderski,2019
20 species	Light	Negative on alien species cover	Dyderski,2019
Impatiens parviflora, Robinia pseudoacacia, Solidago gigantea, Impatiens glandulifera, Acer negundo and others	Elevation	Negative correlation with probability of invasion	Lapin,2019

Microstegium vimineum	Shade	Negative on invasive abundance	Brewer,2010
Microstegium vimineum	Flooding	Positive on invader’s production	Brewer,2010; Warren 2015
52 species	Forest age	Positive correlation with exotic species richness	De_Ferrari,1994

Table 2. The effects of natural factors on invasive flora organized by the type of effect.

Alien species	Environmental gradients used: Elevation	Distance from the river	Years after logging	Indexes: Species richness/0.1 ha	Species richness/1 m^2	Diversity (N_2)	Evenness (E')	Cover: Trees	Shrubs	Herbs	Life form: Tree	Shrub	Perennial	Biennial	Annual
Trees															
Acer negundo	-0.39**	**-0.70****	**0.75****	-0.31*	**-0.63****	-0.49**	-0.43**	**0.61****	*ns*	*ns*	**0.61****	0.43**	**-0.65****	-0.36*	-0.41**
Gleditchia triacanthos	*ns*	-0.32*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	-0.46**	*ns*	0.40*	*ns*	*ns*	*ns*	*ns*
Morus alba	*ns*	**-0.63****	**0.68****	*ns*	**-0.61****	-0.32*	-0.34*	**0.63****	-0.37*	*ns*	**0.58****	0.33*	**-0.51****	*ns*	*ns*
Prunus cerasifera	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	0.36*	*ns*	*ns*	*ns*	*ns*
Shrubs															
Amorpha fruticosa	-0.31*	**-0.70****	**0.70****	*ns*	**-0.63****	**-0.51****	-0.45**	**0.58****	*ns*	*ns*	**0.57****	*ns*	**0.62****	*ns*	*ns*
Prunus spinosa	*ns*	*ns*	*ns*	0.34*	*ns*	0.34*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	0.32*	*ns*	*ns*
Herbs															
Arctium lappa	*ns*	*ns*	*ns*	*ns*	*ns*	0.32*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	**0.56****	*ns*
Aristolochia clematitis	*ns*	**-0.56****	**0.51****	*ns*	-0.41**	*ns*	*ns*	0.45**	-0.40**	*ns*	**0.60****	0.36*	-0.30*	*ns*	*ns*
Chelidonium majus	*ns*	**-0.73****	**0.75****	*ns*	**-0.60****	*ns*	*ns*	**0.61****	-0.40**	*ns*	**0.60****	0.39**	-0.48**	*ns*	-0.32*
Cirsium arvense	0.34*	*ns*	0.38*	*ns*	*ns*	*ns*	*ns*	*ns*	0.33*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
Cucubalus baccifer	*ns*	*ns*	*ns*	*ns*	*ns*	0.34*	0.41**	*ns*	-0.49**	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
Fallopia convolvulus	0.34*	*ns*	-0.33*	*ns*	*ns*	*ns*	*ns*	-0.36*	*ns*	*ns*	-0.37*	ns	0.37*	*ns*	0.34*
Galega officinalis	*ns*	0.31*	-0.50**	0.43**	*ns*	*ns*	*ns*	-0.31*	0.46**	*ns*	*ns*	*ns*	0.39*	0.35*	0.42**
Galium apparine	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	0.37*
Humulus lupulus	-0.32*	**-0.63****	0.49**	*ns*	**-0.52****	*ns*	-0.35*	0.48**	-0.42**	*ns*	**0.52****	0.32*	-0.39*	*ns*	*ns*
Lapsana communis	*ns*	0.39*	-0.38*	0.34*	*ns*	0.41**	*ns*	-0.31*	*ns*	*ns*	*ns*	-0.33*	0.38*	0.36*	**0.60****
Melilotus albus	0.35*	*ns*	-0.41**	**0.58****	*ns*	**0.51****	*ns*	-0.35*	0.32*	*ns*	*ns*	*ns*	0.49**	*ns*	**0.64****
Parietaria officinalis	*ns*	-0.43**	0.41**	*ns*	-0.32*	*ns*	*ns*	0.38*	*ns*	*ns*	*ns*	0.46**	*ns*	*ns*	*ns*
Sonchus arvensis	*ns*	*ns*	-0.47**	0.46**	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	0.40**	*ns*	0.34*
Urtica dioica	-0.32*	**-0.65****	**0.83****	-0.45**	-0.48**	0.38*	*ns*	**0.56****	**-0.59****	*ns*	0.43**	*ns*	**-0.60****	-0.37*	**-0.54****

*Table 3. Correlation coefficients (Spearman index, Rs) between the most abundant alien and invasive species, some vegetation variables and used environmental gradients. Correlation coefficients >0.5 are marked with**Bold**. ns = Not significant. *P<0.05; **P<0.01. Dyakov,2013*

Article	Inv species	Effect	Parametr	
invasion_1997_Ellis	tamarix ramosissim	P	Species richness (rodents-mammals)	
invasion_1998_Baker	Rhododendron max	N	Species richness(plants)	
invasion_1998_Baker	Rhododendron max	N	Percent cover in regeneration layer(plants)	
invasion_2000_Ellis	Tamarix spp.	P	Arthropod diversity(invertebrate)	
invasion_2000_Ellis	Tamarix spp.	P	Arthropod species richness (invertebrate)	
invasion_2000_Ellis	Tamarix spp.	P	Arthropod abundance (invertebrate)	
invasion_2006_Chmura	Impatiens parviflor	P	Species richness(plants)	
invasion_2006_Chmura	Impatiens parviflor	P	Shannon Diversity(plants)	
invasion_2006_Chmura	Impatiens parviflor	N	Beta diversity(plants)	
invasion_2006_Chmura	Impatiens parviflor	N	Herbceous species richness(plants)	
invasion_2006_Chmura	Impatiens parviflor	N	Herbaceous cover(plants)	
invasion_2006_Chmura	Impatiens parviflor	NO EFFEC	Alpha diversity(plants)	
invasion_2006_Chmura	Impatiens parviflor	NO EFFEC	Alpha diversity(plants)	
invasion_2006_Vidra	Hedera helix,Micros	N	Species richness(plants)	
invasion_2006_Vidra	Hedera helix,Micros	P	Soil fertility	
invasion_2008_Burton	Ligustrum sinense	N	Shannon diversity (plants)	
invasion_2008_Burton	Ligustrum sinense	N	Species evennes (plants)	
invasion_2008_Topp	Reynoutria spp.	N	Abundance(invertebrate)	
invasion_2008_Topp	Reynoutria spp.	N	Species richness(invertebrate)	
invasion_2008_Topp	Reynoutria spp.	N	Rarefaction diversity(invertebrate)	
invasion_2008_Topp	Reynoutria spp.	P	Abundance of detritovores(invertebrate)	
invasion_2009_Urgenson	Polygonum sachalin	N	Species richness(plants)	
invasion_2009_Urgenson	Polygonum sachalin	N	Abundance(plants)	
invasion_2009_Urgenson	Polygonum sachalin	N	Nutrient quality of litter input	
invasion_2010_Brewer	Microstegium vimin	N (3 sp P)	Species composition(plants)	
invasion_2010_Masse	Rosa multiflora	N	Species richness(invertebrate)	
invasion_2011_Greene	Ligustrum sinense	N	Herbaceous cover(plants)	
invasion_2011_Greene	Ligustrum sinense	N	Herbaceous height(plants)	
invasion_2011_Greene	Ligustrum sinense	N	Species richness(plants)	
invasion_2011_Greene	Ligustrum sinense	N	Seedling survival and growth(plants)	
invasion_2011_Mitchell	Ligustrum sinense	P	Decomposition (plants)	
invasion_2011_Mitchell	Ligustrum sinense	P	C/N dynamics	
invasion_2011_Mitchell	Ligustrum sinense	N	Lignin and cellulose concentartions	
invasion_2011_Mitchell	Ligustrum sinense	P	N concentrations	
invasion_2011_Mitchell	Ligustrum sinense	N	lignin : N ratios	
invasion_2012_Akatov	Robinia pseudoaca	N	Species richness(plants)	
invasion_2012_Bottollier	Acer negundo	N	Species richness(plants)	
invasion_2012_Bottollier	Acer negundo	N	Native biomass(plants)	
invasion_2012_Ford	Adelges tsugae	N	Mortality of native species(plants)	
invasion_2012_Ford	Adelges tsugae	N	Ground layer richness(plants)	
invasion_2012_Ford	Adelges tsugae	P	co-occurring canopy trees	
invasion_2012_Leavitt	Tamarix spp.	NO EFFEC	Species richness(mammals)	
invasion_2012_Leavitt	Tamarix spp.	NO EFFEC	Simpson diversity(mammals)	
invasion_2012_Leavitt	Tamarix spp.	NO EFFEC	functional diversity (mammals)	
invasion_2012_Mcneish	Lonicera maackii	P(faster)	Decomposition (plants)	
invasion_2012_Mcneish	Lonicera maackii	N	Amount of organic matter	
invasion_2012_Urgenson	Polygonum x bohen	N	Light availability	
invasion_2012_Urgenson	Polygonum x bohen	N	Late-seral species survival(plants)	
invasion_2012_Urgenson	Polygonum x bohen	N	ectomycorrhizal colonization	
invasion_2013_Hart	Ligustrum sinense	N	Species richness(plants)	
invasion_2013_Hart	Ligustrum sinense	N	Diversity (plants)	
invasion_2013_Hart	Ligustrum sinense	N	Evennes(plants)	
invasion_2013_Hart	Ligustrum sinense	N	Understory stem density(plants)	
invasion_2013_Hudson	Ligustrum sinense	N	Species number(plants)	
invasion_2013_Hudson	Ligustrum sinense	N	Abundance (invertebrate)	
invasion_2013_Hudson	Ligustrum sinense	N	Species richness (invertebrate)	
invasion_2013_Hudson	Ligustrum sinense	N	Diversity (invertebrate)	
invasion_2013_Hudson	Ligustrum sinense	N	Evennes (invertebrate)	
invasion_2013_Martin-Gar	Populus × eurameri	N	Species richness(birds)	
invasion_2013_Martin-Gar	Populus × eurameri	N	Abundance (birds)	
invasion_2014_Constan_N	Ailanthus altissima	N	phylodiversity of neighboring vegetation	
invasion_2014_Constan_N	Ailanthus altissima	N	Species richness(plants)	
invasion_2014_Constan_N	Ailanthus altissima	N	Shannon diversity (plants)	
invasion_2014_Constan_N	Ailanthus altissima	P	Soil fertility	
invasion_2014_Gutiérrez-I	Ailanthus altissima,	N	Species abundance(invertebrate)	
invasion_2014_Gutiérrez-I	Ailanthus altissima,	P	Actinedida mites abundance(invertebrate)	
invasion_2014_Horackova	Fallopia japonica, Fa	N	Species number(invertebrate)	
invasion_2014_Horackova	Fallopia japonica, Fa	N	Species richness(invertebrate)	
invasion_2014_Horackova	Fallopia japonica, Fa	N	Species abundance(invertebrate)	
invasion_2014_Kuebbing	Lonicera maackii,Lig	P	subinvasive COINVASION (interakce 2 druhu)	
invasion_2014_Kuebbing	Lonicera maackii,Lig	P	Carbon degr COINVASION (interakce 2 druhu)	
invasion_2014_Kuebbing	Lonicera maackii,Lig	N(less)	Soil acidity COINVASION (interakce 2 druhu)	
invasion_2014_Kuebbing	Ligustrum sinense	P	Soil moisture	
invasion_2014_Kuebbing	Ligustrum sinense	?	Arthropod sp composti	VARIED BY BLOCK,NOT BY THE PRESENCE OF INV(secondary factors?)
invasion_2014_Kuebbing	Ligustrum sinense	?	Microbal activity	VARIED BY BLOCK,NOT BY THE PRESENCE OF INV(secondary factors?)
invasion_2014_Staska	Robinia pseudoacac	P	Soil nitrogen	P of R.pseud density and age (the older r.pseudoac is, the more soil NO3 there are)
invasion_2014_Staska	Robinia pseudoacac	P	Soil NO3	
invasion_2014_Staska	Robinia pseudoacac	P	Soil Carbon	
invasion_2014_Staska	Robinia pseudoacac	NO EFFECT	C/N ratio	
invasion_2014_Staska	Robinia pseudoacac	NO EFFEC	Simpson's diversity(plants)	
invasion_2014_Staska	Robinia pseudoacac	P	Nitrophilius species abundance(plants)	
invasion_2015_Camarillo	Triadica sebifera	N	Overstory diversity(plants)	
invasion_2015_Camarillo	Triadica sebifera	N	Stem density(plants)	

invasion_2015_Camarillo	Triadica sebifera	N	Basal area(plants)
invasion_2015_Camarillo	Triadica sebifera	N	Relative density(plants)
invasion_2015_Camarillo	Triadica sebifera	N	quadratic mean diameter(plants)
invasion_2015_Camarillo	Triadica sebifera	P	Stand density (plants)
invasion_2015_Dyderski	Acer negundo	P	Species richness(plants) positive DONE
invasion_2016_Cruz	*Eucalyptus globulus*	N	Mammals species richness
invasion_2016_Cruz	*Eucalyptus globulus*	N	Mammals activity
invasion_2016_Della_Rocc	Robinia pseudoacac	NO EFFECT	Species composition (invertebrate)
invasion_2016_Della_Rocc	Robinia pseudoacac	NO EFFEC	Species richness(invertibrate)
invasion_2016_Foard	Ligustrum sinense	N	% Canopy missing
invasion_2016_Foard	Ligustrum sinense	P(higher)	Mean Wetland prevalence Index(higher tolerances to xeric conditions)
invasion_2016_Foard	Ligustrum sinense	N	Simpson's diversity(plants)
invasion_2016_Foard	Ligustrum sinense	P(more)	CWD masses and volumes
invasion_2016_Foard	Ligustrum sinense	NO EFFEC	Species richness(plants)
invasion_2016_Foard	Ligustrum sinense	NO EFFEC	Tree DBH(plants)
invasion_2016_Foard	Ligustrum sinense	N	Tree height(plants)
invasion_2016_Foard	Ligustrum sinense	N	BACI effect(speed of growth)
invasion_2016_Medina-Vi	Ailanthus altissima,	N	OI N
invasion_2016_Medina-Vi	Robinia pseudoacac	P	OI N
invasion_2017_Radovanov	Amorpha fruticosa,F	N	Number of native species (plants)
invasion_2017_Radovanov	Amorpha fruticosa,F	N	Coverage index(plants)
invasion_2017_Wu	Alternanthera philo	N	Shannon diversity (plants)
invasion_2018_Cofer	Rhododendron ma	N	Herbaceous and graminoids plants seed density(plants)
invasion_2018_Cofer	Rhododendron ma	P	Tree seed density (plants)
invasion_2018_Cofer	Rhododendron ma	N	Total seed bank richness (plants)
invasion_2018_Cofer	Rhododendron ma	NO EFFEC	Overstory basal area
invasion_2018_Cofer	Rhododendron ma	P	Overstory density
invasion_2018_Cofer	Rhododendron ma	N	Understory density
invasion_2018_Cofer	Rhododendron ma	N	Understory richness
invasion_2018_Cofer	Rhododendron ma	N	Ground layer cover
invasion_2018_Cofer	Rhododendron ma	N	Ground layer richness
invasion_2018_Cofer	Rhododendron ma	N	Soil moisture
invasion_2018_Cofer	Rhododendron ma	N	Soil pH
invasion_2018_Cofer	Rhododendron ma	N	Availability of nutrients
invasion_2018_Cofer	Rhododendron ma	P	Organic soil depth/mass
invasion_2018_Cofer	Rhododendron ma	NO EFFEC	Light availability
invasion_2018_Cofer	Rhododendron ma	N	Soil T
invasion_2018_Cofer	Rhododendron ma	N	Soil moisture
invasion_2018_Cofer	Rhododendron ma	NO EFFEC	OI N
invasion_2018_Cofer	Rhododendron ma	N	OI K
invasion_2018_Cofer	Rhododendron ma	NO EFFEC	OI CA
invasion_2018_Cofer	Rhododendron ma	NO EFFEC	OI MG
invasion_2018_Cofer	Rhododendron ma	NO EFFEC	Oi P
invasion_2018_Cofer	Rhododendron ma	P	Oi AL
invasion_2019_Castrolope	Arundo donax,Chap	NO EFFEC	QBR index
invasion_2019_Castrolope	Arundo donax,Chap	N	Raising Water salinity and hydrological stress
invasion_2019_Sibikova	Robinia pseudoacac	N	Homogenisation
invasion_2019_Sibikova	Robinia pseudoacac	N	Soil moisture
invasion_2019_Sibikova	Robinia pseudoacac	P	Soil nutrients content
invasion_2019_Sibikova	Robinia pseudoacac	N	Plant diversity
invasion_2019_Slabejova	Robinia pseudoacac	N	Tree canopy cover(plants)
invasion_2019_Slabejova	Robinia pseudoacac	N	Humidity
invasion_2019_Slabejova	Robinia pseudoacac	P(raises)	Air T
invasion_2019_Slabejova	Robinia pseudoacac	P(raises)	daily amplitude of humid and t
invasion_2019_Slabejova	Robinia pseudoacac	N(homo)	Homogenisation
invasion_2019_Slabejova	Robinia pseudoacac	P	Content of alien species (plants)
invasion_2019_Slabejova	Robinia pseudoacac	NO EFFEC	Shannon diversity (plants)

Figure 1. and Figure 2. Depiction of original database on invasive flora's influence on alluvial ecosystems factors. Green for effects on plants, Brown for effects on abiotic and other parameters, Pink for effects on invertebrate, Light-yellow for effects on avian and Orange for effects on mammals.