UNIVERSITÀ DEGLI STUDI DI PADOVA

Department of Land, Environment Agriculture and Forestry
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A preliminary analysis of data on non-native tree species from a global database: the occurrence of two case species in urban and protected areas.

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Contents

List of Figures

List of Tables

1. ABSTRACT

The introduction and spread of non-native tree species have become a prominent ecological concern in recent years. This study presents a preliminary analysis of data sourced from a comprehensive global database, focusing on the occurrence of two selected non-native tree species in both urban and protected areas. The aim of this research is to shed light on the spatial distribution patterns and environmental factors influencing the presence and distribution of these case species. Through a multifactor analysis of available open access data, we identify trends in the spatial distribution of non-native tree species in urban environments and protected natural areas. Our analysis encompasses geospatial modelling of species occurrence, bioclimatic variables, protected and urban area shapefiles to develop area-specific invasive species management. Ordinary least square (OLS) test suggested significance of the model in urban and protected areas, indicating the importance of considering their spread. This study serves as a foundational exploration, highlighting the use of GIS algorithms for effective management non-native tree species in diverse landscapes.

2. INTRODUCTION

2.1 Non-native tree species

2.1.1 Definition of Non-native tree Species

The phrase "native tree species" refers to a range of trees that have been brought to areas outside of their original habitats because of human actions. These introductions can happen on purpose like, for reasons or as ornamental or by accident through trade or movement (Pötzelsberger et al., 2020). The key aspect of this definition is the fact that these trees exist in environments where they did not naturally develop. This difference plays a role, in research because it indicates a deviation, from the interconnected relationships that native species have with their ecosystems. Non-native trees, often called alien trees might not have predators, competitors, or diseases in their new habitats, which could result in uncontrolled growth (Campagnaro et al., 2023). The absence of controls and counterbalances can lead to disturbances, in ecosystems emphasizing the importance of comprehending this definition as a fundamental element in studying the intricate interplay, between human actions and the environment (Dimitrova et al., 2022).

2.1.2 Historical context of Non-native introductions

The story, behind the introduction of native trees is truly fascinating as it intertwines human exploration, colonization, and the ever-changing currents of global trade (Dimitrova et al., 2022). In the days people often sought to recreate environments, in new places resulting in significant changes, to ecosystems worldwide (Campagnaro et al., 2023). The Columbian Exchange, which was an event, in history played a role in the exchange of plants between the Old and New Worlds. This led to a transformation, in the makeup of continents (McNeill, 2019). As societies grew and trade networks thrived the inadvertent dispersal of native species started to gain momentum (Tallamy et al., 2021). Understanding the context is essential, for gaining insights into the reasons behind these introductions. These motivations can vary from interests to the desire, for beauty (Dimitrova et al., 2022). To truly grasp the outcomes and persistent difficulties presented by native tree species, in modern ecosystems it is crucial to have a deep understanding of this complex historical fabric (Campagnaro et al., 2023).

2.1.3 Ecological impacts of Non-native trees

The ecological effects of native tree species are complex and depend on the specific situation. These effects are influenced by the characteristics of the introduced species and the ecosystems they invade. While some non-native trees peacefully coexist with plants and animal's others display behaviour that can lead to significant changes, in ecosystems. Invasive non-native trees and native vegetation, which alters the overall structure and composition of native communities (Campagnaro et al., 2023). This change has the potential to decrease biodiversity since local species may find it challenging to compete for resources, against species (Wohlgemuth et al., 2022).

Ecological impacts often occur in areas invaded by native trees leading to alterations, in nutrient cycling, soil chemistry and disturbance regimes. Moreover, some non-native species release compounds that hinder the growth of neighbouring plants thereby exerting influence changes in nutrient cycling, soil chemistry, and disturbance regimes are common ecological impacts observed in areas invaded by non-native trees. Additionally, certain non-native species release allelopathic compounds, chemicals that inhibit the growth of surrounding plants, further influencing community dynamics (Byers, 2002). It is crucial to comprehend these effects in order to evaluate the wellbeing and adaptability of ecosystems when non-native tree species are introduced and established (Chaves Lobón et al., 2023).

2.1.4 Classification of Non-native species

The categorization of tree species that are not native is crucial, for researchers, conservationists and land managers who are dealing with the challenges posed by introduced species (Campagnaro et al., 2023). A key factor, in categorizing species is their invasiveness, which distinguishes between those that display behaviour and those that do not. Invasive species can pose a risk, to the diversity and functioning of ecosystems, which calls for specific management approaches to address this issue (Tobin, 2018). The intention, behind the introduction plays a role in classifying species. It involves categorizing them based on whether they were intentionally or unintentionally introduced. This classification system acknowledges that non-native trees can become part of ecosystems through human activities, such as purposeful plantings or landscaping as well as unintentional methods like the dispersal of seeds, through global trade or transportation networks (Campagnaro et al., 2023). Understanding the implications of categorizing native species contributes to the creation of customized management strategies allowing us to acknowledge the ecological consequences and potential risks associated with non-native tree species (Dimitrova et al., 2022).

2.1.5 Global distribution patterns

The way non-native tree species are distributed globally provides a perspective to explore how ecosystems are interconnected in our globalized world (Briski et al., 2023). Human actions, those related to trade and transportation have an impact on enabling the migration of species between continents. The spread of native trees is affected by various factors such, as climate suitability, soil conditions and the way humans use land (Campagnaro et al., 2023). Notable examples, such as tree of heaven originating from China and now distributed globally, and black locust a native of North America with a worldwide presence, showcase the extent of certain non-native trees reach across diverse environments. Understanding these distribution patterns gives us insights, into what influences the spread of non-native tree species. It also helps us anticipate any challenges and impacts they might have on ecosystems around the world (Sladonja et al., 2015). It plays a role in our understanding of how biodiversity changes when humans introduce new species. This adds an element to the story of our planet's ecological tapestry (Ramus et al., 2017).

3. Two important non-native tree species

3.1 Ailanthus altissima

Ailanthus altissima, commonly known as the tree of heaven is a deciduous tree species belonging to the *Simaroubaceae* family. The tree of heaven is a rapidly growing deciduous tree native to China that has become a widespread invasive species in the United States (Li et al., 2021). It was brought to the US in the late 1800s as a horticultural specimen and shade tree due to its ease of establishment, rapid growth, and absence of insect or disease problems, which made it popular for urban landscaping (Sladonja et al., 2015). However, these very characteristics have resulted in its widespread proliferation causing it to indigenous plants and impede their development. The tree of heaven has an ability to reproduce swiftly and generate an abundance of seeds, which significantly contribute to its behaviour (C. M. Enescu, 2016). Furthermore, it releases a substance into the soil that is harmful, to plants thereby assisting in its supremacy. Moreover, the tree of heaven has played a role in promoting the proliferation of the lanternfly an insect initially, from China. This insect feeds and Causes harm to native and fruit bearing trees (Li et al., 2021). Although it has been employed for purposes, its usage has environmental consequences as it can displace native vegetation diminish biodiversity and pose urban challenges. Taking measures and employing strategies are crucial in addressing the ecological and economic impacts of this species (C. M. Enescu, 2016).

3.1.1 Appearance

The tree of heaven is a species known for its appearance and tendency to spread aggressively. It can grow up, to towering heights of 25-30 meters (80-100 feet). Has smooth light Gray to pale bark with dark knots creating a distinctive pattern. Its leaves are compound consisting of lance shaped leaflets arranged along a stalk. Each leaf can have between 10-41 leaflets that can reach up to 60 cm (24 inches) in length. This compound leaf structure adds to the tree's beauty. However, despite its appeal the tree of heaven poses challenges as it tends to form dense thickets and is considered invasive in many regions. Additionally, the tree produces suckers from its roots aiding in its spread and the formation of clonal colonies. With its height, compound foliage and prolific growth tendencies the tree of heaven presents not visual allure but also significant ecological concerns, in various ecosystems (Sladonja et al., 2015).

3.1.2 Growth pattern

Ailanthus altissima is a deciduous species, growth pattern with distinct male and female trees producing small yellowish-green flowers. The male flowers form panicles, while the female flowers cluster more compactly. This reproductive dichotomy contributes to the species' overall biology (C. M. Enescu, 2016). The tree of heaven is known for its ability to grow quickly and adapt well which allows it to outperform plants and create ecological problems. Additionally, its extensive and invasive root system can worsen the situation by causing damage to infrastructure such as sidewalks and buildings (Sladonja et al., 2015). Furthermore, encountering the sap of the tree can potentially lead to skin irritation in people posing health risks. The presence of these growth characteristics highlights the nature of managing tree of heaven emphasizing the significance of comprehending its growth patterns, for conservation and mitigation endeavours (Li et al., 2021).

Figure 1: Reddish maturing samaras at the top of a branch (C. M. Enescu, 2016).

Figure 2: Ailanthus bark is smooth with light striations, even at large diameters *(Davis).*

3.1.3 Taxonomy of *Ailanthus altissima*

Kingdom: Plantae (Plants)

Phylum: Tracheophyte (Vascular plants)

Class: Magnoliopsida (Dicotyledons)

Order: Sapindales

Family: Simaroubaceae

Genus: Ailanthus

Species: *Ailanthus altissima*

Ailanthus is a short-lived early successional tree that can attain a life span of >100 years. By producing clonal offspring, the genetic individuals are nearly immortal (C. M. Enescu, 2016).

3.1.4 Cultural significance

Although *Ailanthus altissima* is known for being invasive it holds importance in traditional Chinese medicine. Despite defeature extracts from tree of heaven have been used in Chinese medicine due to their believed therapeutic properties. In the past people used extracts from this tree to treat conditions such as asthma, epilepsy, scabies, seborrhoea. It was also recognized for its antispasmodic qualities. It was considered effective against parasites and, as a sedative (Sladonja et al., 2015). This cultural app displays the significance of the tree of heaven, in healing methods. Moreover, tree of heaven has made its mark in literature gaining acclaim in Betty Smiths novel "A Tree Grows in Brooklyn." Within this masterpiece the tree symbolizes strength and perseverance adding to its importance, beyond its botanical attributes (Knüsel et al., 2017).

3.1.5 Threats and diseases

Ailanthus altissima, known for its characteristics faces challenges and diseases that impact its ecological presence. The trees' ability to release chemicals that hinder the growth of plants, known as effects, plays a significant role in displacing native species (C. M. Enescu, 2016). The allelopathic nature of tree of heaven amplifies its behaviour posing challenges for restoring affected ecosystems. In addition, this species has an ability to reproduce, with lots of seeds and the ability to regrow quickly. This makes it harder to control. Although the tree of heaven is generally resistant to pests it can still be affected by diseases, susceptible, to Verticillium wilt and cankers (Small et al., 2010). These diseases along with its ability to invade highlight the difficulties linked to the existence of tree of heaven. The challenges are further compounded by activities that facilitate its spread and the effects of climate change. To address these issues comprehensively a holistic approach to management is necessary. Successful strategies include detecting the presence of this species at a stage implementing specific control methods and raising public awareness through programs aimed at mitigating the ecological disturbances it causes (Dimitrova et al., 2022).

3.2 *Robinia pseudoacacia*

The black locust, which is commonly referred to as *Robinia pseudoacacia* is a type of tree that sheds its leaves seasonally. It is originally native to North America. Has gained attention for being one of the most influential and widely spread non-native broadleaved trees, in Europe (Vítková et al., 2017). Its distinct features include pinnately compound leaves and fragrant, white, pea like flowers that enhance its overall charm. Apart, from its attractiveness this tree is well known for its growth and ability to thrive in different types of soil. It is a tree that grows rapidly and is identifiable by the presence of thorns. Additionally, it has the capacity to produce shoots from the base (Cierjacks et al., 2013). As a species that thrives in areas, with sunlight it quickly takes root in surroundings such as grasslands, partially natural forests, and urban habitats. This enables it to endure and thrive for periods of time (Martin, 2019). The durability and rot resistance of locust wood make it highly valued for uses, like firewood, pulpwood, fencing, construction, and furniture. Due to its versatility black locust is often preferred for reforestation projects, erosion control measures and windbreaks (Nicolescu et al., 2020). However, there are concerns about the locust's invasiveness in specific regions due to its robust growth. It is important to highlight the value of this tree as it contributes to soil fertility through a process called nitrogen fixation. Additionally, the black locust holds relevance and serves multiple purposes, in various industries (Nicolescu et al., 2020). Although black locust has qualities there are certain regions, in Europe where it is viewed as an invasive species. This is mainly because it can create shade and disrupt soil conditions. It's interesting to note that its impact, on ecosystems has a nature with both negative aspects (Vítková et al., 2017).

3.2.1 Appearance

The black locust tree, scientifically known as *Robinia pseudoacacia* is a deciduous tree that has both visual appeal and ecological importance. It stands out with its features and ability to thrive in diverse environments. Typically, it grows to a height of 20 meters when alone and, up to 30 meters when in groups occasionally even reaching 35 meters. Whether standing alone or in groups the black locust makes a visually captivating presence in landscapes. Its lifespan ranges from 60 to 100 years. There have been cases in Europe where some trees have survived for over 300 years adding a historical dimension, to their visual charm (Cierjacks et al., 2013).

The unique structural qualities of the black locust tree greatly enhance its appeal. It often highlights a curved trunk. Its bark has a beautiful range of colours, from greyish brown to dark brown. Over time the bark develops cracks, which not add character to its look but also serve as a captivating testament to the trees growth and the passage of time (Nicolescu et al., 2020). The black locust tree is visually appealing due to its leaves. These leaves are composed in a pinnate pattern. Measure around 10 – 30 cm. A unique characteristic of these leaves is the presence of a pair of spines at the base, which can also be seen on shoots. The leaflets are arranged in 2-12 pairs opposite each other with a leaflet at the end of the central stem (rachis). These leaflets come in shapes such as oblong, elliptic, or ovate. Have smooth edges with this intricate arrangement of leaves adds to the beauty of the locust tree making it easily recognizable and admired in botanical settings (Martin, 2019).

3.2.2 Growth pattern

The black locust demonstrates a growth pattern that is characterized by its ability to have both female reproductive organs (Martin, 2019). The flowers, which are white, fragrant, and hermaphroditic are arranged in drooping clusters that usually measure around 10 to 20 cm in length. This particular arrangement of flowers contributes to the charm of the locust tree making it easily distinguishable when it’s in flowering period (Cierjacks et al., 2013). The locusts reproductive process involves the growth of fruits. These fruits appear as pods typically measuring 5 – 10 cm in length and can be found hanging from the branches throughout the winter season. Inside these pods the black locust tree generates 4 - 10 seeds as part of its strategy (Nicolescu et al., 2020). The seeds of these trees are mainly spread through gravity and wind which enables the tree to reproduce in types of environments (Cierjacks et al., 2013).

Fruiting in the black locust typically occurs once or twice per year, with the initiation of this reproductive phase commencing at a tree age ranging from 6 to 30-40 years. This pattern of fruiting is a part of the black locust’s life cycle and affects how it interacts with its environment ecologically (Cierjacks et al., 2013). Studying the growth patterns of the locust tree, including how it flowers and how its seeds develop and spread offers valuable insights, into the reproductive behaviours and life strategies of this important species of tree (Nicolescu et al., 2020).

Figure 3: The enchanting flowers of Robinia pseudoacacia (Giardinaggio.it).

Figure 4: The distinctive bark of Robinia pseudoacacia (Kausen).

3.2.3 Taxonomy of *Robinia pseudoacacia*:

Kingdom: Plantae (Plants)

Phylum: Tracheophyte (Vascular plants)

Class: Magnoliopsida (Dicotyledons)

Order: Fabales

Family: Fabaceae

Genus: Robinia

Species*: Robinia pseudoacacia*

3.2.4 Cultural significance

The black locust, scientifically known as *Robinia pseudoacacia* has importance due, to its historical uses and symbolic representations in addition, to its ecological and economic significance (Martin, 2019). This expanding tree has played roles in human societies adding to customs, legends, and practical uses (Nicolescu et al., 2020). Throughout societies the black locust tree has held a place due to its unique characteristics and usefulness. Its solid wood, which can withstand water and decay has been traditionally used to create tools, implements and even musical instruments highlighting its significance, in the world of craftsmanship and creativity. The trees fast growth has symbolized resilience and adaptability qualities that deeply resonate with our experience (Nicolescu et al., 2020).

Moreover, black locust has become a part of folklore and storytelling. In tales the tree frequently represents qualities, like resilience, longevity, and the unyielding essence of the world. Its beautiful white flowers with a fragrance and its designed compound leaves have served as inspiration, for various forms of art and poetry enriching the cultural heritage of regions where it flourishes (Cierjacks et al., 2013).

Black locust has long been utilized as a source of leaf forage, in agriculture highlighting its importance in providing sustenance for animals and facilitating animal husbandry. Its integration into agroforestry practices has fostered a relationship, between activities and the surrounding natural environment (Straker et al., 2015).

The cultural significance of black locust extends beyond its applications. It carries meanings that're deeply rooted in human traditions (Straker et al., 2015). This trees presence can be found in stories, artistic creations and everyday uses demonstrating the connection, between nature and society. The black locust serves not as a resource but also as a symbol that weaves its narrative into the diverse cultural fabric of communities (Cierjacks et al., 2013).

3.2.5 Threats and diseases

In addition, to its economic importance black locust also faces threats and is susceptible, to diseases that affect its ability to function in the ecosystem (Martin, 2019). A significant aspect to consider is the creation of substances, like robinetin, myricetin and quercetin. These substances could hinder the growth of types of weeds and crops. They also pose challenges to maintaining the ecological equilibrium, in areas where black locust trees thrive (Cierjacks et al., 2013). Large herbivores in Europe generally cause minimal damage to black locust trees, which suggests that these trees are quite resilient when it comes to dealing with the pressures of being eaten by herbivores (Nicolescu et al., 2020). However, the tree is not completely resistant, to some pests. Specifically, there are two types of moths (*Phyllonorycter robiniella* and *Parectopa robiniella*) and one gall midge (*Obolodiplosis robiniae*) that have been identified as factors in causing damage. These pests have the potential to impact the well-being and Vigor of locust forests underscoring the importance of implementing monitoring and management approaches (Nicolescu et al., 2020).

The introduction of locust to habitats has also resulted in the existence of multiple fungal species that thrive on wood and more, than 40 of these have been identified as parasites (Martin, 2019). Furthermore, Germany has documented the presence of 11 types of mildews and leaf spot diseases that are linked to locust trees (Vítková et al., 2017). These fungal and disease pressures add to the dynamics related to black locust and highlight the significance of comprehending how it interacts with native ecosystems (Cierjacks et al., 2013).

Moreover, the existence of viruses that could potentially harm crops within the native area is an extra cause, for worry (Straker et al., 2015). Although black locust in Europe encounters less severe challenges compared to its habitat it is still crucial to pay ongoing attention to the combined effects of pests, diseases, and pathogens to ensure the sustainable coexistence of black locust, in various ecosystems (Nicolescu et al., 2020).

3. Introduction to GBIF

The Global Biodiversity Information Facility (GBIF) plays a role, in the field of biodiversity research serving as a global network and data infrastructure (Ivanova & Shashkov, 2021). GBIF was created with the purpose of granting access to biodiversity data. It provides a collection that enables researchers, environmentalists, and policymakers to delve into and comprehend the interconnectedness of life on Earth (Petersen et al., 2021). This description explores the importance of GBIF explaining how its extensive data was utilized to study *Ailanthus altissima* and *Robinia pseudoacacia* two non-native tree species that exhibit behaviours (Nicolescu et al., 2020).

The GBIF database is a repository that contains a wide range of information, about the distribution, occurrence, and characteristics of various species. This valuable collection of data includes details on taxonomy, geographic locations, and diverse ecological features. It serves as a resource, for researchers involved in environmental studies (Ivanova & Shashkov, 2021). Having the capability to tap into a varied collection of data enables people and groups worldwide to collaborate tackle environmental issues and make well informed choices (Petersen et al., 2021).

3.1 Utilizing GBIF for *Ailanthus altissima* and *Robinia pseudoacacia.*

To better understand the growth patterns of native tree species, in cities and protected areas we relied on GBIF as our main data source. Our research focused specifically on tree of heaven and black locust. By utilizing GBIF's user platform we were able to access species occurrenceClick or tap here to enter text.data that offered insights, into the global distribution and ecological traits of these two tree species (Nilsen et al., 2018).

To gather information, about species occurrences, from GBIF we made use of the portals search features. We customized our data retrieval approach by selecting the desired species, geographic locations, and relevant ecological characteristics to match our research requirements (Petersen et al., 2021). The extensive database, from GBIF played a role in supplying us with records of occurrences, maps of distribution and ecological data. This valuable information provided a basis, for our analysis (Ivanova & Shashkov, 2021).

The use of GBIF's data infrastructure enabled us to take an approach smoothly integrating information from sources. We combined peer reviewed publications, ecological databases and reports from government agencies and non-governmental organizations, with GBIF data, which greatly enriched our research in terms of its depth and scope. This integration highlights the blend of research methods and the innovative opportunities provided by GBIF (*GBIF*, n.d.).

3.2 Significance of GBIF in biodiversity research

The analysis carried out in this study was enhanced by the global scope and depth of the GBIF database (*GBIF*, n.d.). The importance of GBIF goes beyond our investigation encompassing its role, in monitoring biodiversity changes conducting research and making informed decisions regarding the management and preservation of our planet's natural heritage (Nilsen et al., 2018). GBIF's commitment to open access and collaboration nurtures a global community of researchers and professionals dedicated to expanding our knowledge of biodiversity (Ivanova & Shashkov, 2021).

GBIF plays a role, in research by allowing us to delve into the dynamics of non-native species as demonstrated in our study on tree of heaven and black locust (Nilsen et al., 2018). By incorporating GBIF data into our analyses we showcase how this platform shapes the course of research offering a global outlook on the intricate connections, between species and their environments (Petersen et al., 2021). As we navigate the complexities of biodiversity GBIF remains a resource that propels the community towards a deeper comprehension of our planets natural systems (Ivanova & Shashkov, 2021).

4. OBJECTIVES

This research is driven by the desire to understand how non-native tree species behave in landscapes. We want to explore their impact on ecosystems and their role in human altered and protected environments. The results of this study have implications for planning, conservation strategies and the sustainable management of non-native species in the face of global environmental changes (Campagnaro et al., 2023). To achieve our goals, we will gather data from sources such as journals, ecological databases, as well as reports from government agencies and non-governmental organizations. By conducting research using an approach we aim to provide valuable insights into the ecological consequences of specific non-native tree species like *Ailanthus altissima* and *Robinia pseudoacacia,* in urban areas and protected regions (Wohlgemuth et al., 2022).

4.1 Developing a holistic framework for quantifying the spread of invasive species globally

Invasive species pose a challenge to ecosystems over the world so it's crucial to have a strong framework, for accurately measuring and monitoring their global impact. The main goal of this research is to create a framework that allows us to quantify how invasive species spread on a scale. Given the need to address the threats caused by these invasives our objective is to bring together various data sources and advanced analytical techniques. By using satellite imagery, remote sensing, and ecological databases our framework will utilize analysis and machine learning algorithms to identify patterns in the spread of species. Ultimately, we aim to develop a methodology that can be universally applied for assessing both the extent and dynamics of species expansion.

The framework aims to address the challenges caused by variations, in data collection methods and environmental contexts by synthesizing data from regions and ecosystems. Its goal is to standardize methodologies for application allowing for better comparison of results across different regions. This will help conservationists, policymakers and researchers develop targeted strategies to mitigate the impact of species on biodiversity and ecosystem functioning.

This objective aligns with the recognition of how interconnected ecosystems are globally. The importance of efforts in addressing environmental challenges. By developing a framework that considers factors this study contributes to the broader conversation on managing invasive species. It promotes an approach that goes beyond boundaries and integrates cutting edge technologies and data sources making it an innovative tool, for global biodiversity conservation.

4.2 Inclusion of protected and urban areas for area-specific management of *Ailanthus altissima* and *Robinia pseudoacacia*

The second goal of this research aims to improve strategies, for managing species by considering the landscapes found in protected areas, rural regions, and urban environments. Specifically focusing on tree of heaven and black locust this objective recognizes that these invasive species exhibit dynamics depending on the setting. Urban areas present challenges due to their combination of features and human activities which are distinct from those encountered in protected or rural landscapes. By considering these differences the study aims to develop management strategies that are tailored to areas ensuring their relevance and effectiveness in each context.

Protected areas prioritize conservation efforts with require strategies that prioritize the preservation of biodiversity. On the other hand, rural landscapes often involve activities and call for approaches that balance the needs of local communities with conservation goals. Urban environments, characterized by human infrastructure demand strategies to manage species within densely populated and developed spaces. This objective aims to bridge the gap between theory and practical application by providing insights into how invasive species can be managed. Invasive species pose a threat to biodiversity ecosystems, as well, as human activities.

The main goal of this study is to lead the way, in creating a framework for measuring how invasive species spread globally. Specifically, we're focusing on two species; tree of heaven and black locust. It's crucial to develop a standardized approach to monitor and manage species all across the world. To do this we'll bring together data sources like satellite imagery, remote sensing, and ecological databases. By using spatial analysis techniques and machine learning algorithms our framework aims to identify and track how these invasive species are spreading worldwide.

A key part of our objective involves gathering data from regions and ecosystems to create a methodology that goes beyond geographic and ecological boundaries. This will not tackle the challenges posed by variations in data collection methods. Also make it easier to compare results across different regions. By offering an approach our framework aims to improve our understanding of the distribution of invasive species in a more coherent and accurate manner. Ultimately this will contribute towards developing strategies, for global conservation efforts as we recognize the interconnectedness of ecosystems on a planetary scale.

4.3 Identifying existing management strategies for tree of heaven and black locust by assessing model precision in locating interventions

The third objective focuses on conducting an examination of management strategies, for *Ailanthus altissima* and *Robinia pseudoacacia*. This involves reviewing existing literature, conservation plans and management practices aimed at reducing the impact of these species. Additionally, the objective includes evaluating how accurate the developed model is in identifying locations where interventions are needed. This evaluation will compare the models' predictions with real world data on the distribution and impact of these species.

By analysing and assessing management strategies this objective aims to provide insights into invasive species management and conservation. It is important to understand the strengths and weaknesses of existing approaches to build upon practices and learn from challenges. Furthermore, this objective will assess how practical and accurate the developed framework is in identifying areas that require targeted management interventions. By bridging theory with application, it will contribute to improving and optimizing efforts in managing species resulting in tangible benefits for the ground conservation practices.

The consideration of factors aims to enhance the effectiveness and precision of managing these two species across different landscapes. By recognizing the difficulties and advantages offered by types of landscapes this objective aims to provide a blueprint, for conservation experts and policymakers to implement targeted and contextually suitable measures for controlling invasive species. The aim is to improve the precision and effectiveness of management efforts acknowledging that a one size fits all approach may not be sufficient in the changing and diverse environments where these invasive species thrive.

This research represents an investigation into the dynamics of *Ailanthus altissima* and *Robinia pseudoacacia* in various landscapes. Through achieving these objectives, the study seeks to establish a foundation for efficient global strategies in mitigating the impact of invasive species. The findings from this research are expected not to contribute to knowledge about non-native species but also to provide practical guidance for conservation and management strategies. By promoting coexistence between human altered environments and natural ecosystems this research aims to contribute, towards addressing the challenges posed by global environmental change. As we explore the tapestry this study endeavours to unravel the interconnected threads that enhance our understanding of managing invasive species on a global scale.

5. MATERIALS AND METHODS

5.1 Data collection and input

In the beginning we focused on gathering an amount of occurrence data, for *Ailanthus altissima* and *Robinia pseudoacacia* from the Global Biodiversity Information Facility (GBIF). This careful collection of data was crucial as it aimed to establish a foundation for analysis and ensure a comprehensive representation of these invasive species. The thoroughness and breadth of the acquired data were vital in developing an understanding of how tree of heaven and black locust distributed. This phase, characterized by attention to detail allowed us to gain nuanced insights into where these invasive species are found and their ecological impact, in landscapes.

5.2 Preprocessing and cleaning

Ensuring the datasets integrity was of importance which led to a process of preprocessing and cleaning. This essential step involved refining the dataset by removing any inconsistencies and strengthening the reliability of the information. The carefulness applied during this phase was fundamental as it laid the groundwork for analyses on a dependable dataset. The systematic approach, to cleaning not improved the data's reliability. Also contributed to the accuracy and precision of the insights drawn in subsequent stages. By giving priority to data quality this phase played a role, in bolstering the trustworthiness of the dataset ensuring that future analyses and interpretations were based on a reliable foundation.

5.3 Distribution analysis

Using the capabilities of ArcGIS Pro, we conducted analyses to understand the distribution patterns of *Ailanthus altissima* and *Robinia pseudoacacia* on a continental scale. These analyses provided insights, into how these invasive species re-spread across different regions. By examining the nuances, we gained an understanding of their presence and dynamics. This knowledge laid the foundation for an exploration of the impact caused by these invasive species in diverse landscapes. Our continent specific approach allowed us to tailor our investigation according to each region's characteristics. The findings, from this phase did not enhance our understanding of where tree of heaven and black locust prevalent geographically but also helped us analyse their ecological implications more accurately in various continental contexts.

5.4 Identification of hotspots - Optimized hotspot analysis

Our methodology relied heavily on Optimized Hotspot Analysis specifically focusing on the aspect of occurrence records. This advanced analytical technique effectively identified hotspots providing insights into the clustering patterns of *Ailanthus altissima* and *Robinia pseudoacacia*. By enhancing our understanding of their impact this approach played a role, in identifying areas that require targeted management strategies. The inclusion of the dimension based on the year of occurrence records added a layer to our analysis allowing for a more nuanced exploration of how these invasive species spatial dynamics evolve over time. The utilization of Optimized Hotspot Analysis not revealed concentrations but also facilitated a comprehensive understanding of the temporal trends. This knowledge contributes to a strategic approach, for managing the impact of tree of heaven and black locust in regions (based on the year of occurrence records).

5.5 Continent-specific impact assessment

This research conducted an analysis of the effects of *Ailanthus altissima* and *Robinia pseudoacacia* exploring how they expand their territories in response, to changes in climate, particularly warmer winters. The study laid the groundwork for developing regulations and management strategies that are responsive to climate conditions for dealing with these species. By focusing on continents, the study was able to provide an understanding of how tree of heaven and black locust adapt and pose challenges in different geographical settings with diverse landscapes and ecosystems. This continent specific approach did not enhance our knowledge of the consequences but also paved the way, for targeted interventions and adaptive measures needed for effective global management and conservation efforts.

We gather data on how tree of heaven found across different continents. In Europe, this species was brought over from China and North Vietnam in the 1740s for its appearance, as an ornamental tree. The introduction of this species began in France when the French Missionary Pierre Incarvillea sent seeds from Nanking to Bernard de Jussieu, who was a Superintendent (Sladonja et al., 2015).

5.6 Data analysis

We generally aimed to estimate the rate of spread of a globally occurring invasive species using a comprehensive ArcGIS Pro model. The methodology comprised multiple steps to address different facets of the species distribution and its relationship with environmental variables.

Table 1: data sources

	Data Collected	Data Sources
1.	Occurrence records of tree of heaven and black locust	GBIF
2.	Urban areas (Schneider et al., 2009)	https://www.naturalearthdata.com/
	Protected areas (Holenstein, 2022)	https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA
3.	Study areas (countries) shapefile	https://www.diva-gis.org/
4.	Temperature and precipitation Raster	http://www.worldclim.org/
5.	Modelling and Workflow	Optimized Hotspot Analysis

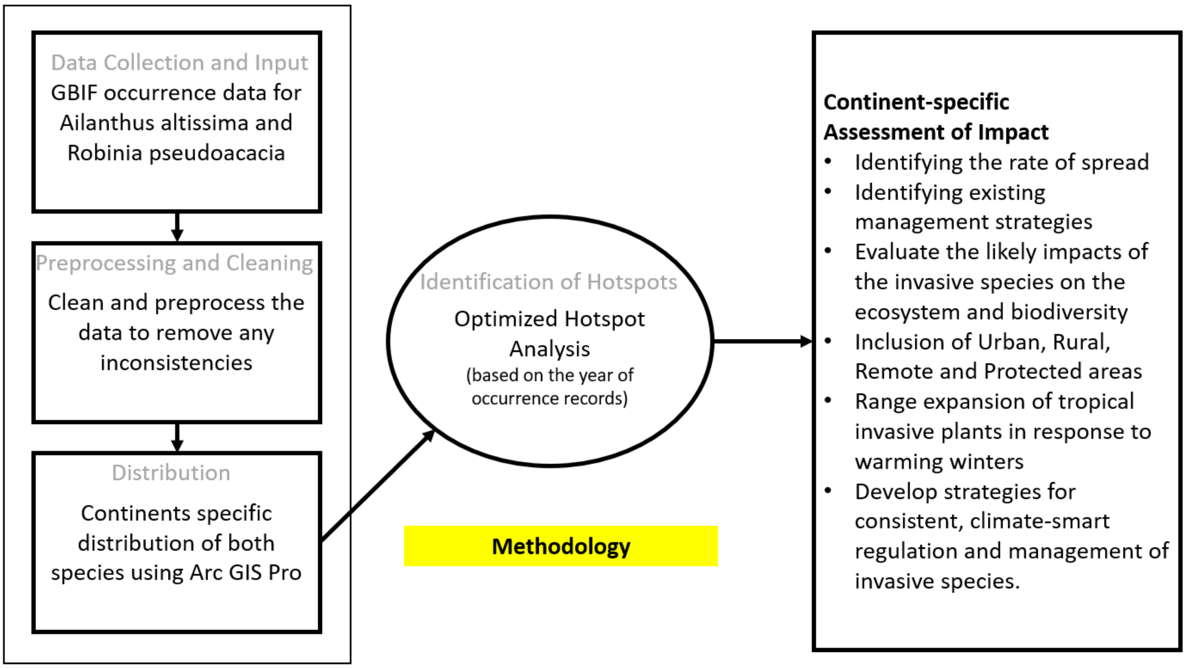

Figure 5: Basic workflow of the study.

We initiated the study by collecting a global dataset of tree of heaven occurrences, ensuring a broad spatial and temporal representation. Subsequently, continent-specific hotspot analyses were conducted using the optimized hotspot analysis tool to identify statistically significant clustering of occurrences at a continental level, providing insights into broad-scale distribution patterns. To focus our analysis on a localized scale, we then clipped the hotspot analysis results to specific study areas, namely individual countries, enabling a more detailed examination of prime hot and cold spots within these regions. Upon conducting an optimized hotspot analysis in ArcGIS Pro for the occurrences of *Ailanthus altissima* in Europe, we were able to come up with the above map depicting Hot and Cold spots.

Hot Spots: These are areas where there is a high occurrence of the species in the range of years. These could be areas where the species has become particularly invasive.
Cold Spots: These are areas where there is a low occurrence of the species in the range of years. These could be areas where the species has not yet become invasive or where control measures have been successful.

To analyse the occurrence records we considered reference years, from 1500 to 2023. Since this species was introduced to Europe in the 1740s, we can prioritize locations based on analysis. Our next step involves including rural and protected areas for each continent. Additionally, we can extract trends to determine the rate of spread for this species. The z values and p scores will indicate the clustering degree and statistical significance of hotspots and cold spots.

To gain an understanding of the factors influencing the distribution of species we gathered temperature and precipitation data for each occurrence point within our study area using the "Extract Values to Points" tool. This allowed us to associate variables with each occurrence record providing ecological context for further analysis. Finally, we conducted a Squares

(OLS) analysis using Gi Bin fixed values as the dependent variable representing the rate of spread and temperature/precipitation raster values as independent variables. The OLS analysis enabled us to evaluate the relationship, between the rate of spread and environmental factors such as annual precipitation and annual temperature (figure 6 & 7).

Each step, in the methodology had a purpose. We started by collecting occurrence data to get an understanding of how the invasive species are distributed on a larger scale. Next, we focused on analysing hotspots at the continent level to identify patterns. Then we narrowed our scope by studying areas through clipping, which gave us localized insights. To consider the context we extracted raster values. Finally, we conducted OLS analysis to measure how temperature and precipitation affect the spread of species.

The strength of this model lies in its ability to prioritize management efforts based on identification and develop targeted strategies, for regions. By incorporating variables such as protected areas and urban areas (figure 8 & 9), it enhances our understanding of how invasive species are distributed across space. This comprehensive approach helps us develop management strategies and anticipate and respond to the changing nature of invasive species distributions worldwide.

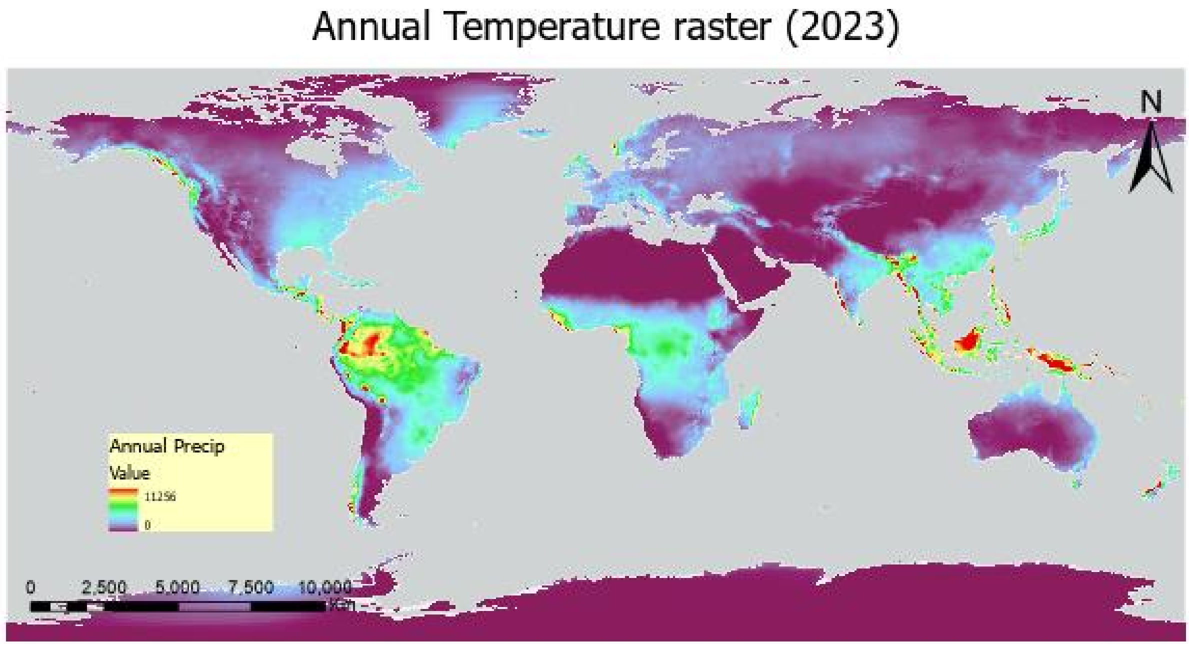

Figure 6: Global annual precipitation raster 2023.

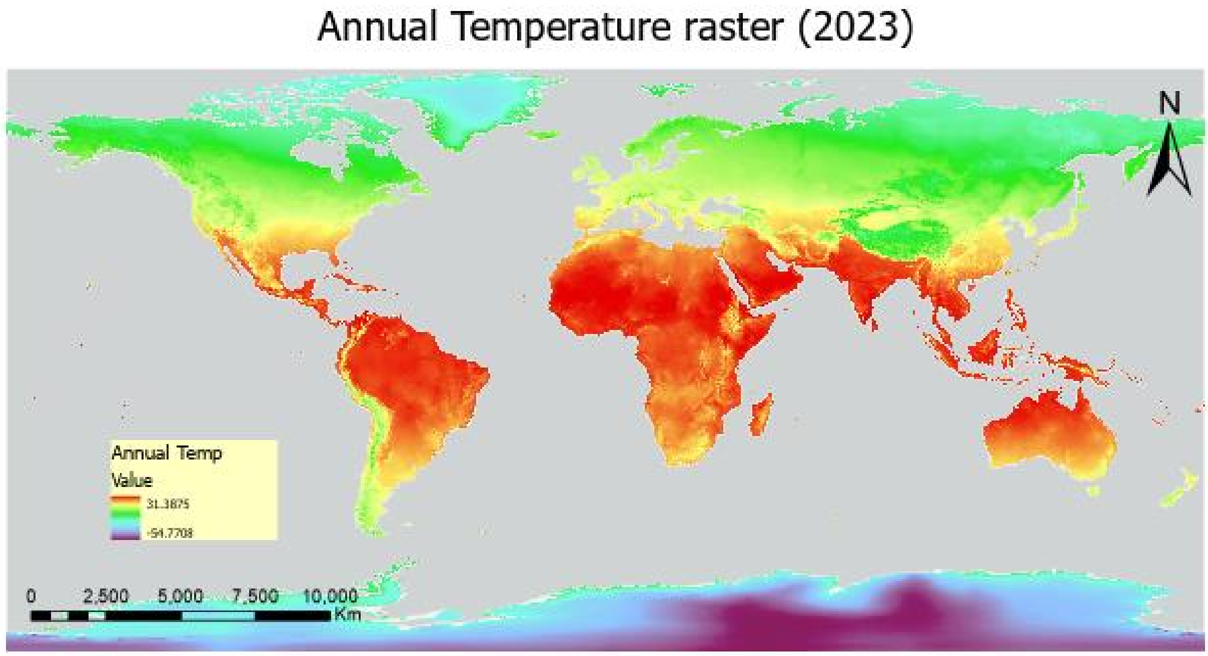

Figure 7: Global annual temperature raster 2023.

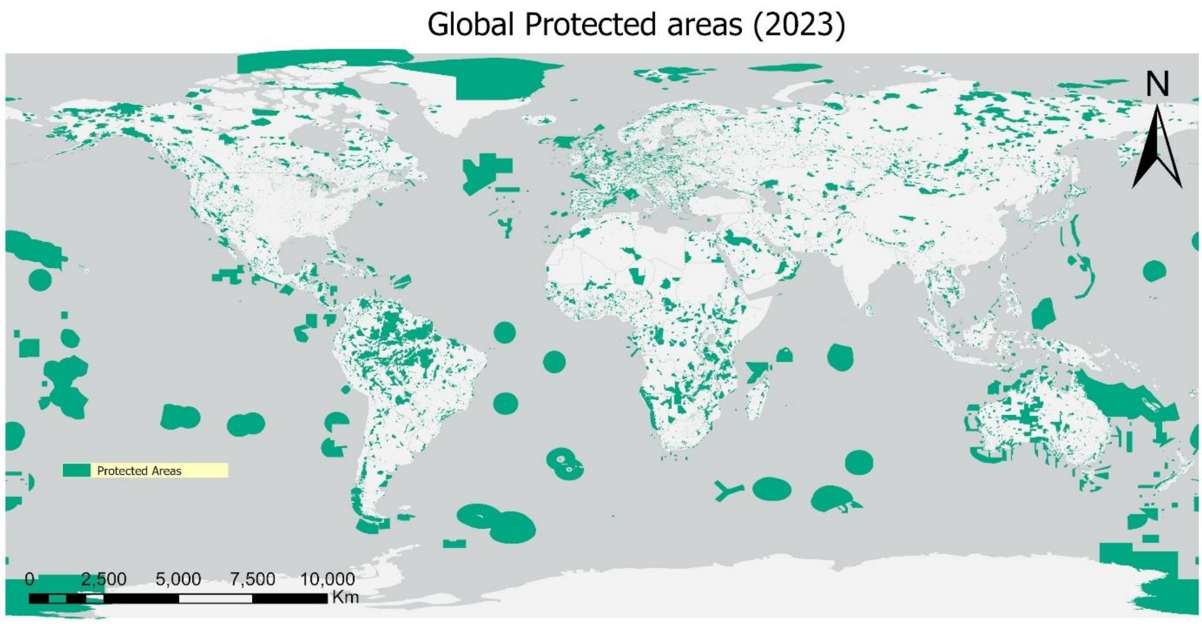

Figure 8: Global protected areas.

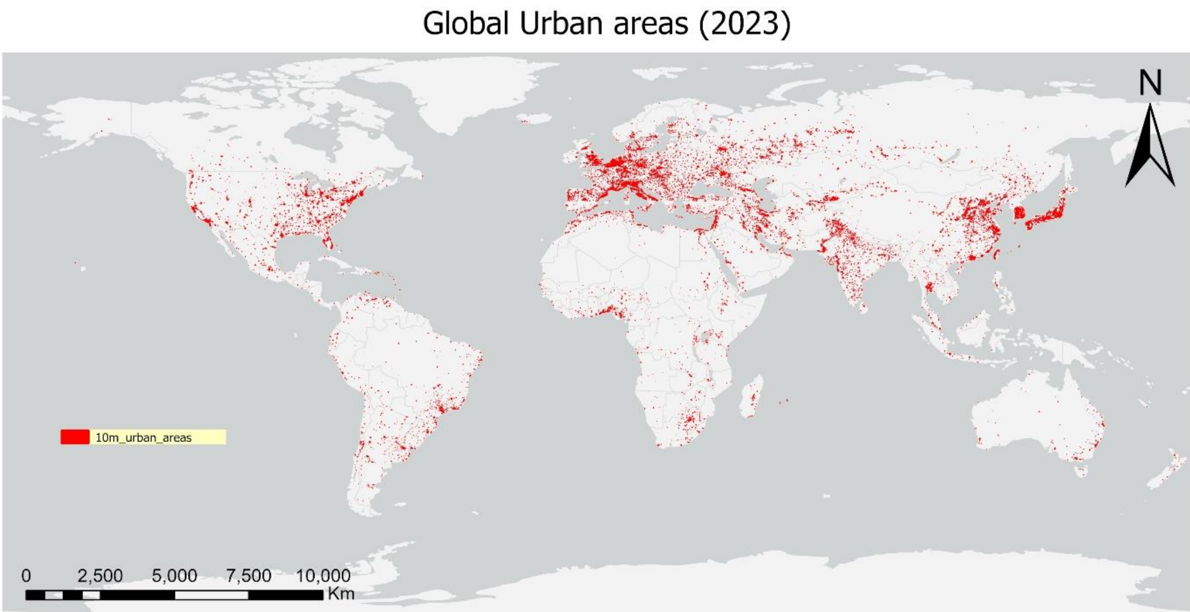

Figure 9: Global urban areas.

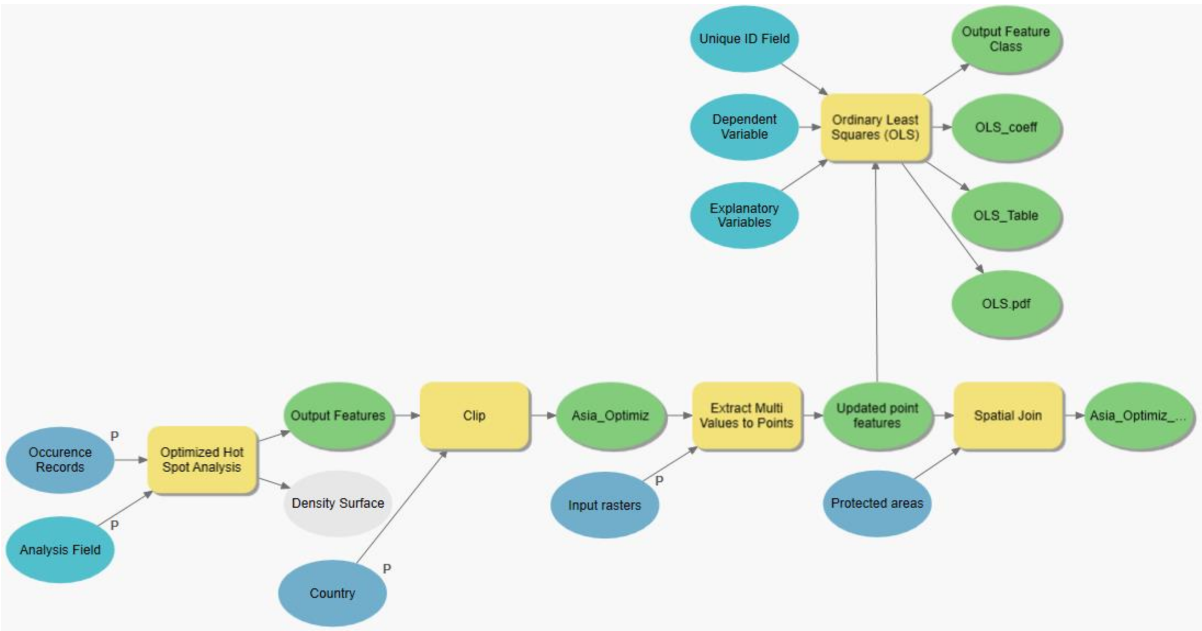

Figure 10: GIS model workflow

Basically, this model in Figure 1 acts as a holistic framework to quantify the rate of spread of invasive species globally. We can include any shapefiles pertaining to a study area to effectively identify regions that are in need of management plans for preventing the spread of *Ailanthus altissima*. We can also prioritize areas by cross-validating existing prevention strategies and their effectiveness. There is flexibility in the model to include several more independent variables as input raster's for conducting the OLS test. This gives us an idea of the contributing factors that facilitate the spread of the species.

6. RESULTS

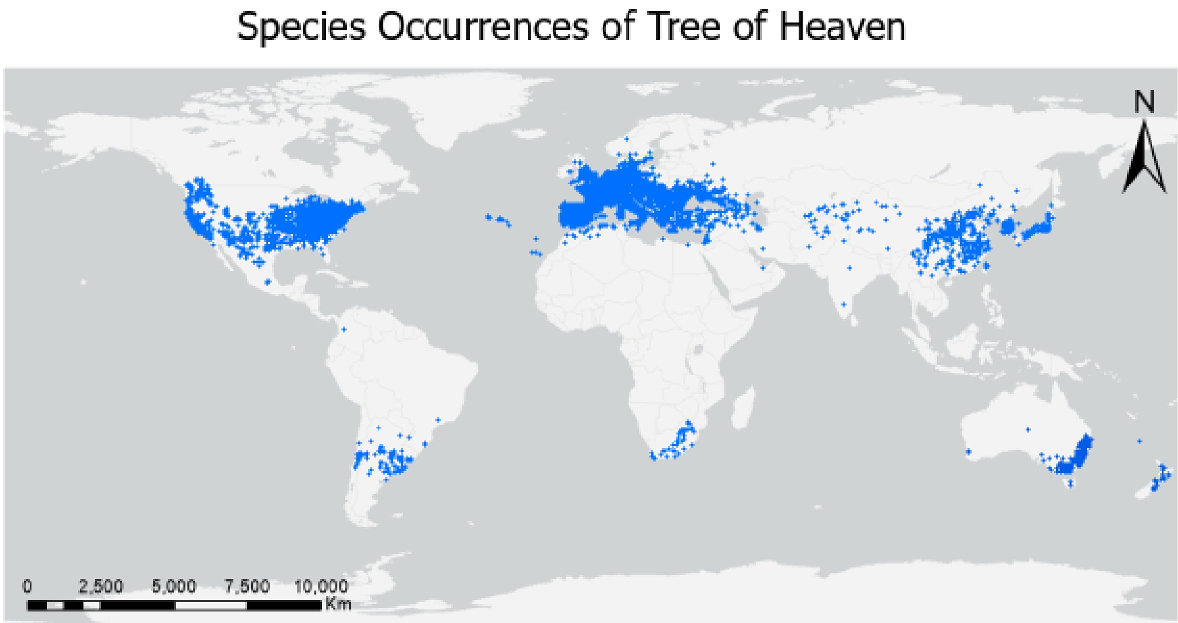

Figure 11: Global species occurrences of Ailanthus altissima.

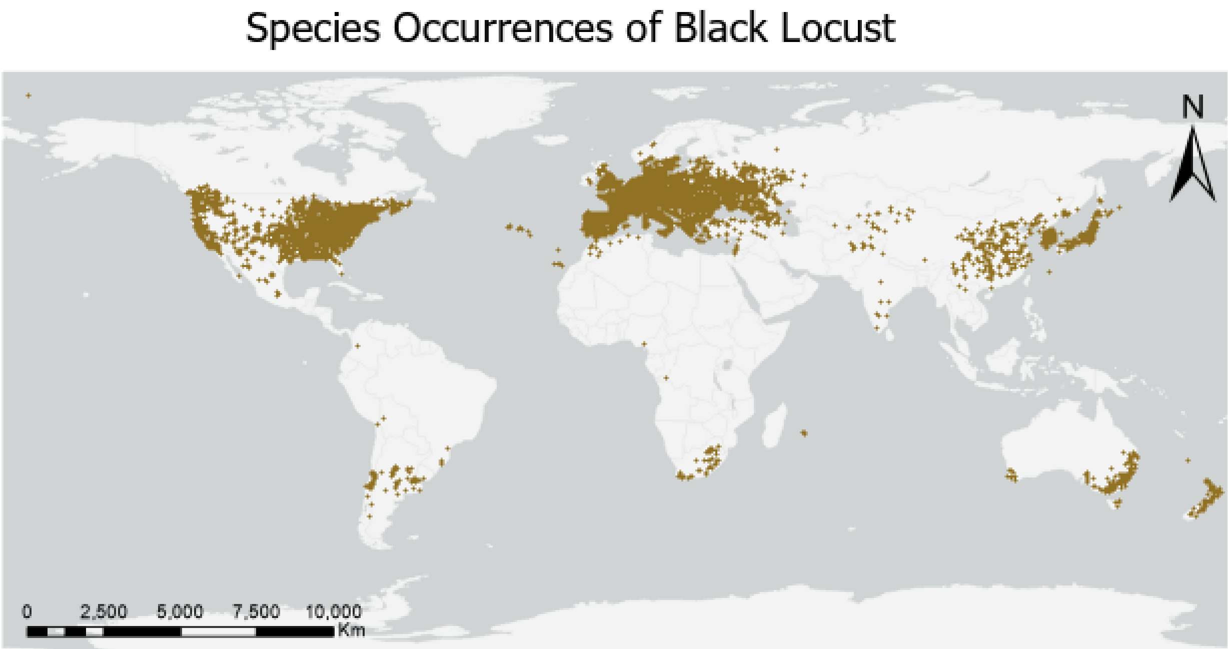

Figure 12: Global species occurrences of Robinia pseudoacacia.

The dataset of "*Ailanthus altissima*" was carefully analyzed using Optimized Hot Spot Analysis to explore the distribution of incidents in the region over time. The analysis used an approach. Identified statistically significant clusters of both high and low values within a fixed distance band of 23,074.6406 meters. Out of the 87,386 input features 681 outliers were meticulously. Excluded from the analysis to ensure its integrity. This comprehensive process does not demonstrate the robustness of the analysis. Also highlights how well the dataset was handled.

After conducting the analysis, a Least Squares (OLS) analysis was applied to investigate the relationship between occurrence records and variables such as annual precipitation and temperature. Despite considering issues with records and unprojected data insightful results were obtained from this analytical effort (ref). The coefficients derived from OLS analysis provided insights into relationships, such as the negative association between precipitation and occurrence records ("Gi_Bin") and an inverse relationship, between temperature and occurrence records ("Gi_Bin").

The calculated intercept value is determined to be 3.640292, with an error margin of 0.220912. This leads to a t statistic of 16.478456 indicating results ($p < 0.01$). Various diagnostic tests were performed to confirm the significance of the model providing insights into its accuracy and identifying potential challenges such as non-stationarity or heteroskedasticity. This comprehensive analytical approach establishes a foundation for interpreting data and making informed decisions.

We conducted an OLS analysis on the dataset regarding Poland using "Gi_Bin" as the variable and "Annual Temperature" and "Annual Precipitation" as variables. The results show significance for the intercept and temperature coefficient while precipitation did not exhibit significance (please refer to the table for details). The model achieved a R value of 0.087 indicating a moderate fit. Diagnostic statistics like Joint F Statistic and Wald Statistic suggest model significance.

Additionally, when examining optimized hotspots in Asia we proceeded with an OLS Analysis specifically focused on China. The analysis revealed relationships such as an association, between "Raster values of precipitation" and "Gi_Bin". Out of the set of 2651 input features we. Excluded 24 outliers from our analysis. Although the clustering intensity approach did not yield a distance the analysis concluded that a fixed distance band of 133618.0 meters was most suitable based on the distance, to the 30 closest neighbors. As a result, we found 2264 output features that were statistically significant. These features highlight both spots (represented in red) and cold spots (represented in blue) where there is a concentration of low values, for each year respectively.

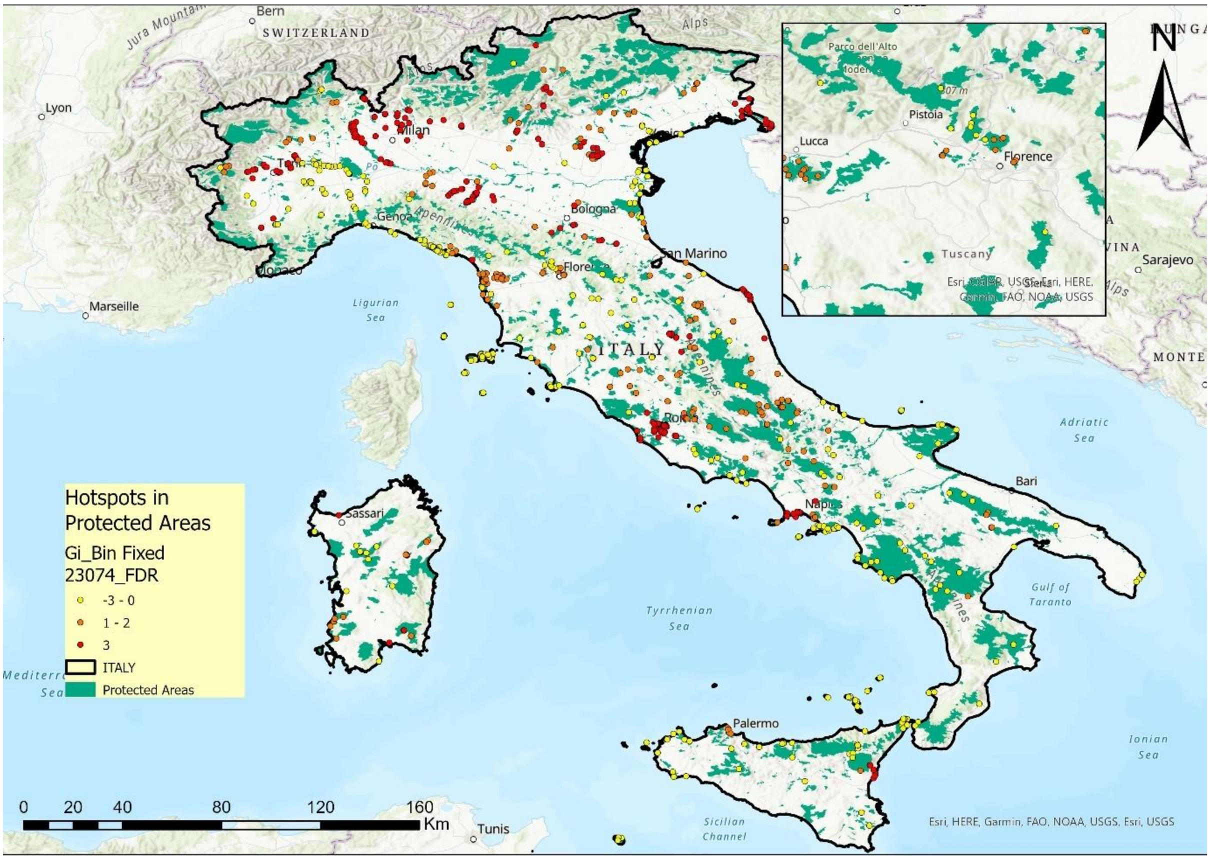

Figure 13: Identifying *Ailanthus altissima hotspot locations for protected areas in Italy.*

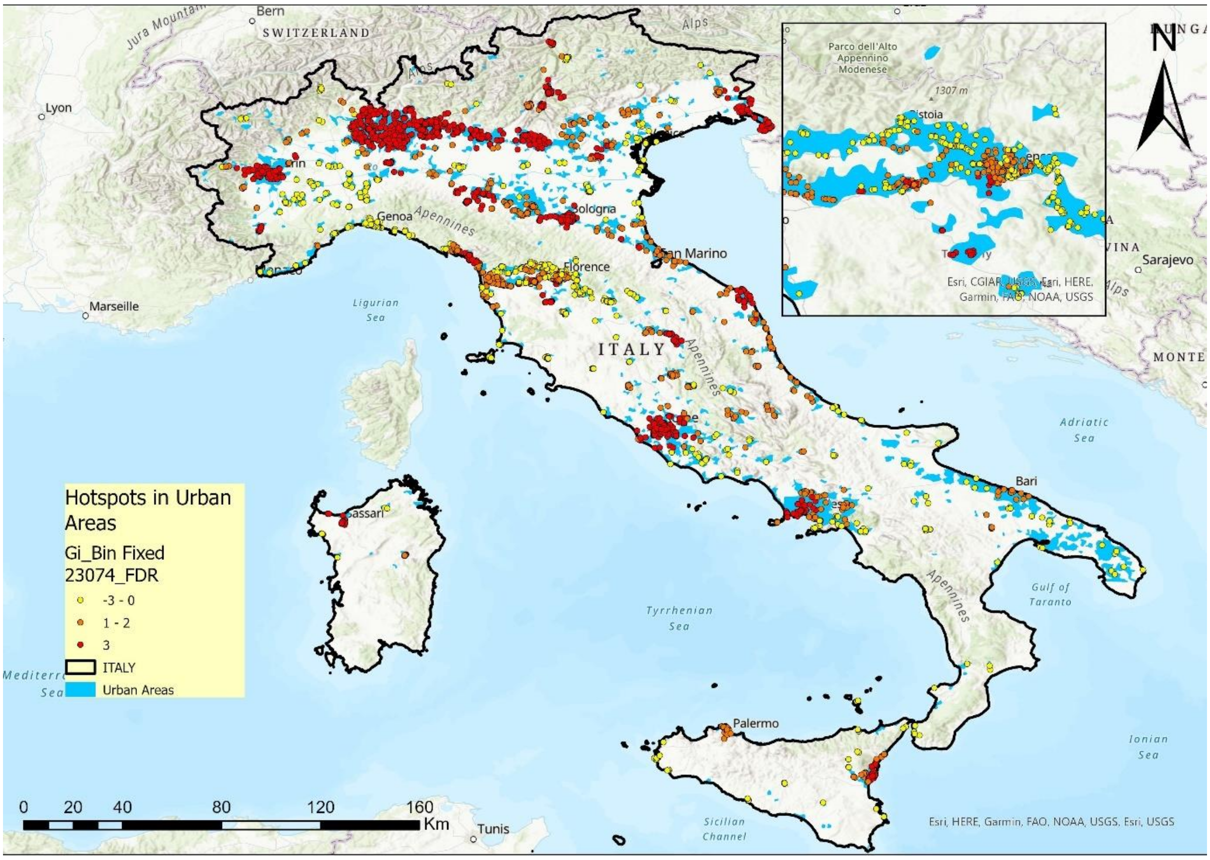

Figure 14: Identifying Ailanthus altissima hotspot locations for urban areas in Italy.

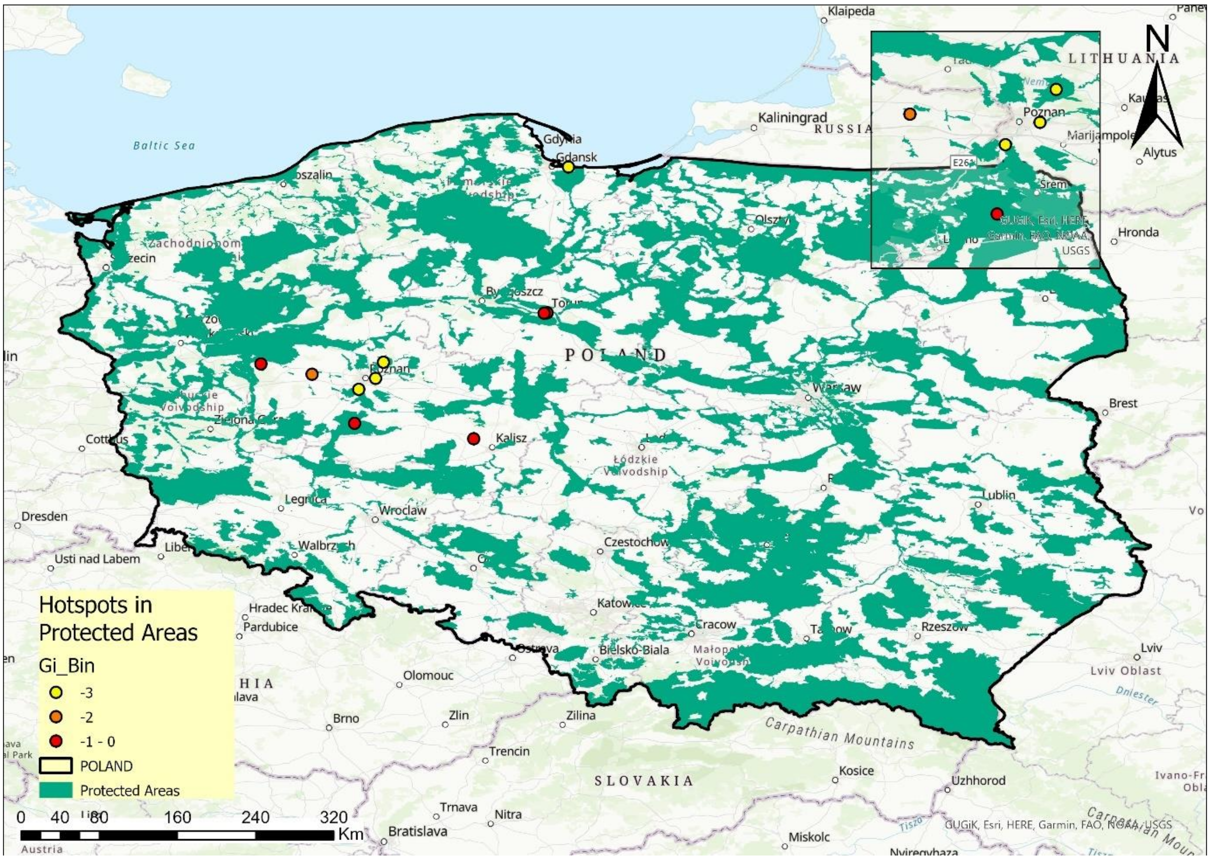

Figure 15: Identifying Ailanthus altissima hotspot locations for protected areas in Poland.

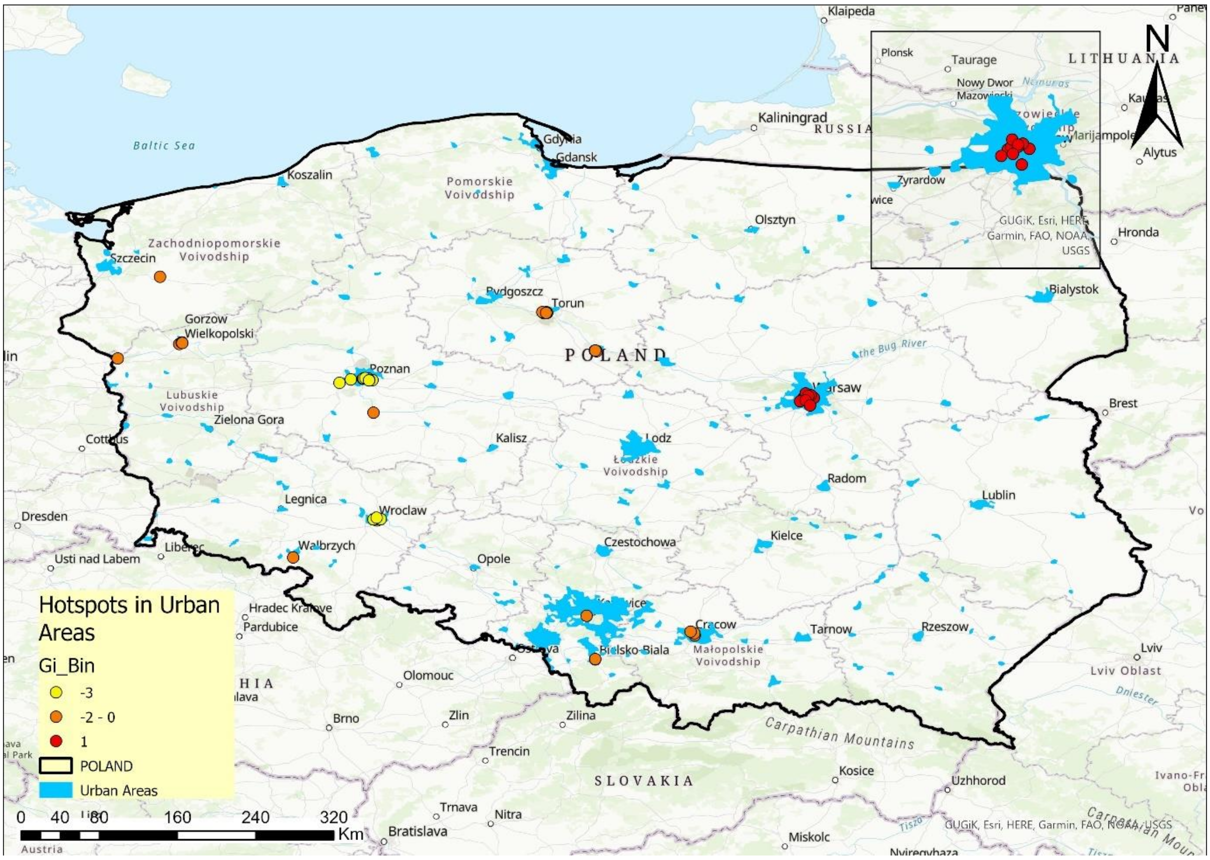

Figure 16: Identifying Ailanthus altissima hotspot locations for urban areas in Poland.

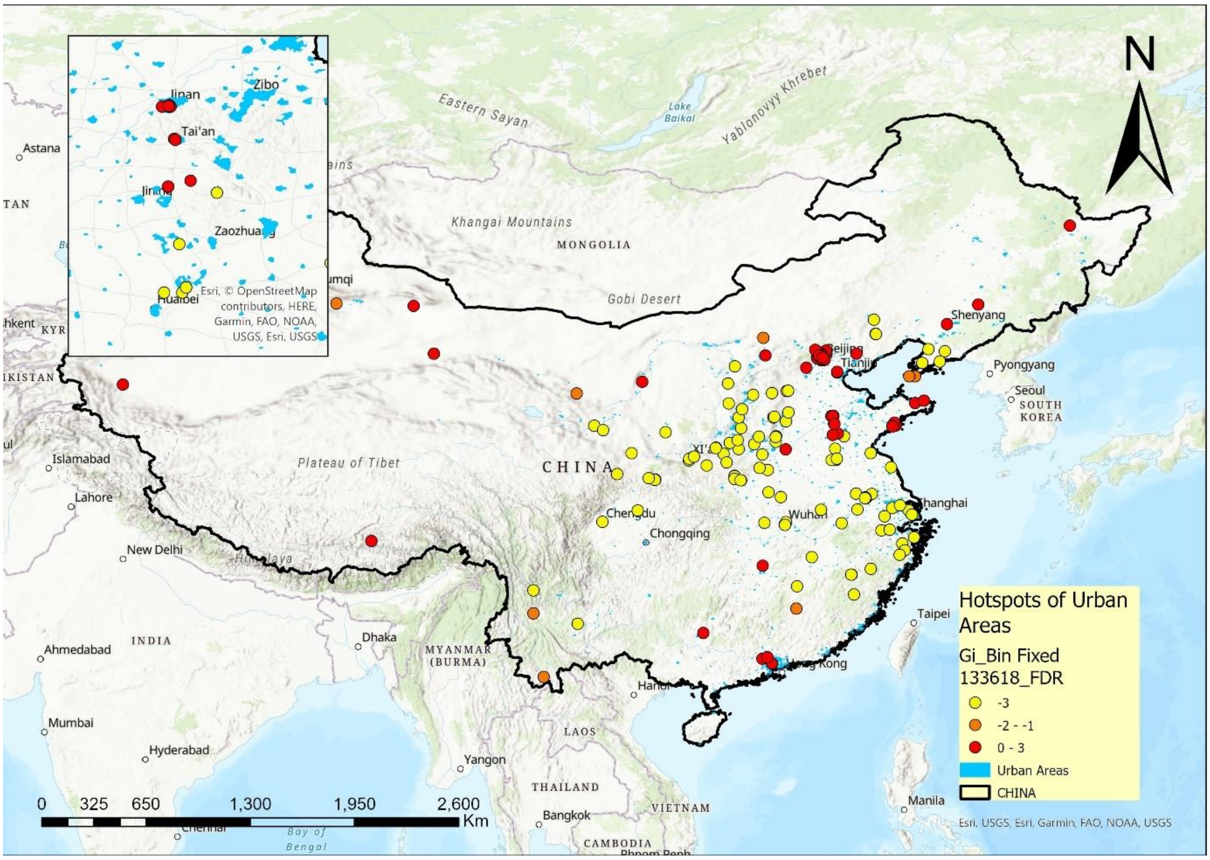

Figure 17: Identifying Ailanthus altissima hotspot locations for urban areas in China.

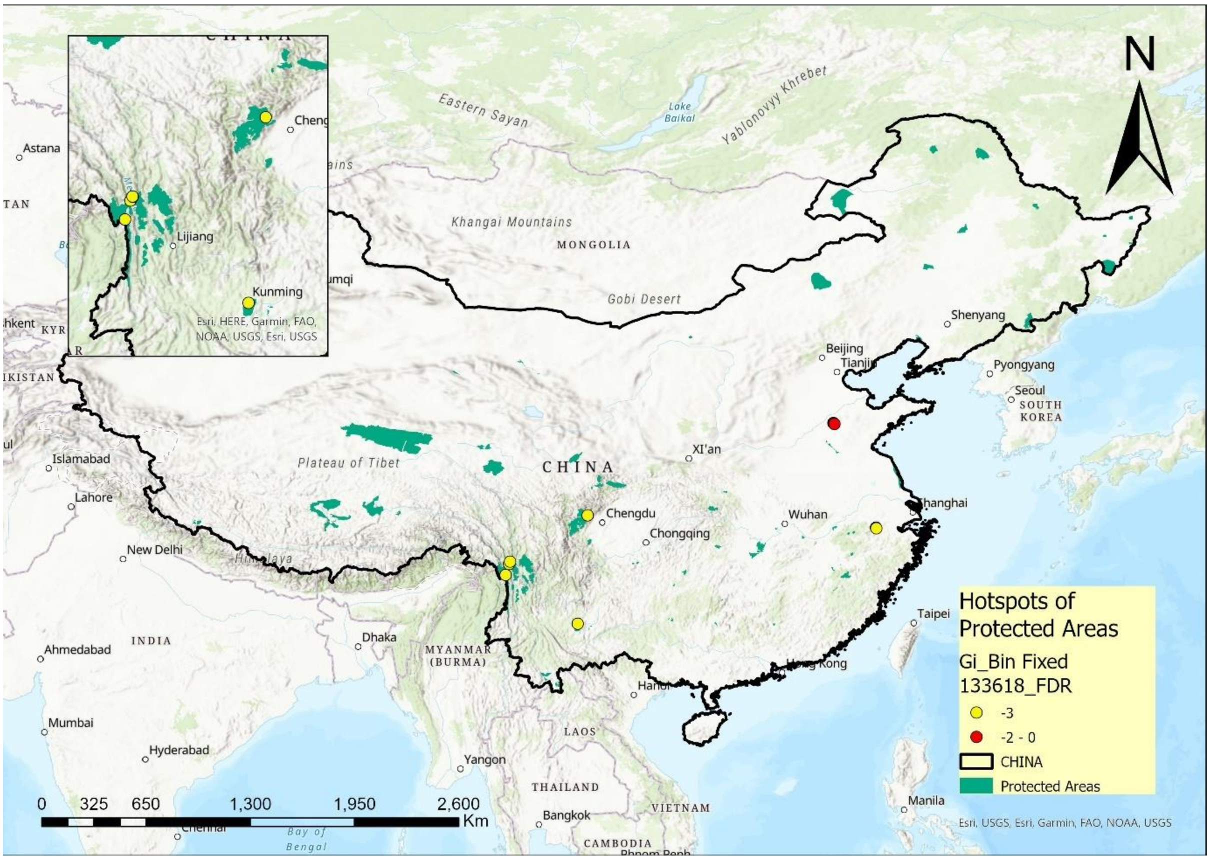

Figure 18: Identifying Ailanthus altissima hotspot locations for protected areas in China.

In this study we conducted an Optimized Hot Spot Analysis (OHA) on the dataset that focuses on the distribution of *Robinia pseudoacacia*, in North America. Our main objective was to understand how the variable "year" is spatially distributed. We carefully examined 25,083 data points. Removed 347 outliers to ensure accuracy. By determining the fixed distance band based on the distance to the 30 nearest neighbours (24,594.0 meters) we identified 17,750 statistically significant clusters. These clusters accounted for 10.7% of features with than 8 neighbours within the defined distance band. This comprehensive approach to cluster identification provides insights into how the "year" variable's distributed in space. Additionally, we carried out a Squares (OLS) analysis on another dataset called "optimized hotspot occurrence." Our goal was to explore the relationship between the variable "Gi_Bin" and two explanatory variables; " temperature" and "annual precipitation." This analysis aimed to examine how precipitation and temperature influence this variables distribution in USA.

The results revealed a negative relationship, between the dependent variable and both precipitation (coefficient; 0.001168) and temperature (coefficient; 0.137172). Please refer to the summary statistics in table 2. The findings provide evidence that adds to our understanding of how climatic variables and the specific outcome are interconnected. Similarly, when focusing on the dataset, for *Robinia pseudoacacia* in Europe there were 243,576 features. Analysing the "year" variable showed a range from 1500 to 2023. During the Optimized Hotspot Analysis, we. Excluded 1,481 location outliers before calculating the fixed distance band. Although we didn't find a scale of analysis based on clustering intensity at increasing distances, we determined the fixed distance band by considering the distance to the 30 closest neighbours resulting in 6236.00 meters. The Hot Spot Analysis revealed clusters in 136,877 output features after applying FDR correction for multiple testing and accounting for spatial dependence as shown in figures below.

In our OLS analysis of occurrences of *Robinia pseudoacacia* in France dataset we thoroughly explored relationships between the variable "Gi_Bin" and variables such as "Annual Temperature" and "Annual Precipitation." The model produced coefficients with an intercept value of 5.090726 a coefficient of precipitation at 0.002549 and a coefficient of temperature, at 0.257484. These coefficients along, with t Statistics and Probability values highlight the significance of the model. Thorough assessments were conducted to evaluate the models fit, which revealed a R value of 0.097007 and an Adjusted R Squared value of 0.096993. Together these metrics provide insights into the model's ability to explain variations. Additionally various statistical tests such as the F Statistic, Wald Statistic, Koenker (BP) Statistic and Jarque Bera Statistic all yielded results. These collective findings confirm the reliability of the model and its capability to reveal relationships between the variable and specified explanatory variables specific to the "*Robinia pseudoacacia* occurrence" dataset.

During our analysis using OLS on the "*Robinia pseudoacacia* occurrence in Italy" dataset we discovered associations with an intercept value of 5.678990. The coefficients for " precipitation" and "Annual temperature" were 0.003625. 0.153977 respectively indicating their impact, on the variable. The model demonstrated a fit as evidenced by a R Squared value of 0.130410 and an Adjusted R Squared value of 0.130177. Joint statistical tests including F Statistic, Wald Statistic, Koenker (BP) Statistic and Jarque Bera Statistic all produced results.

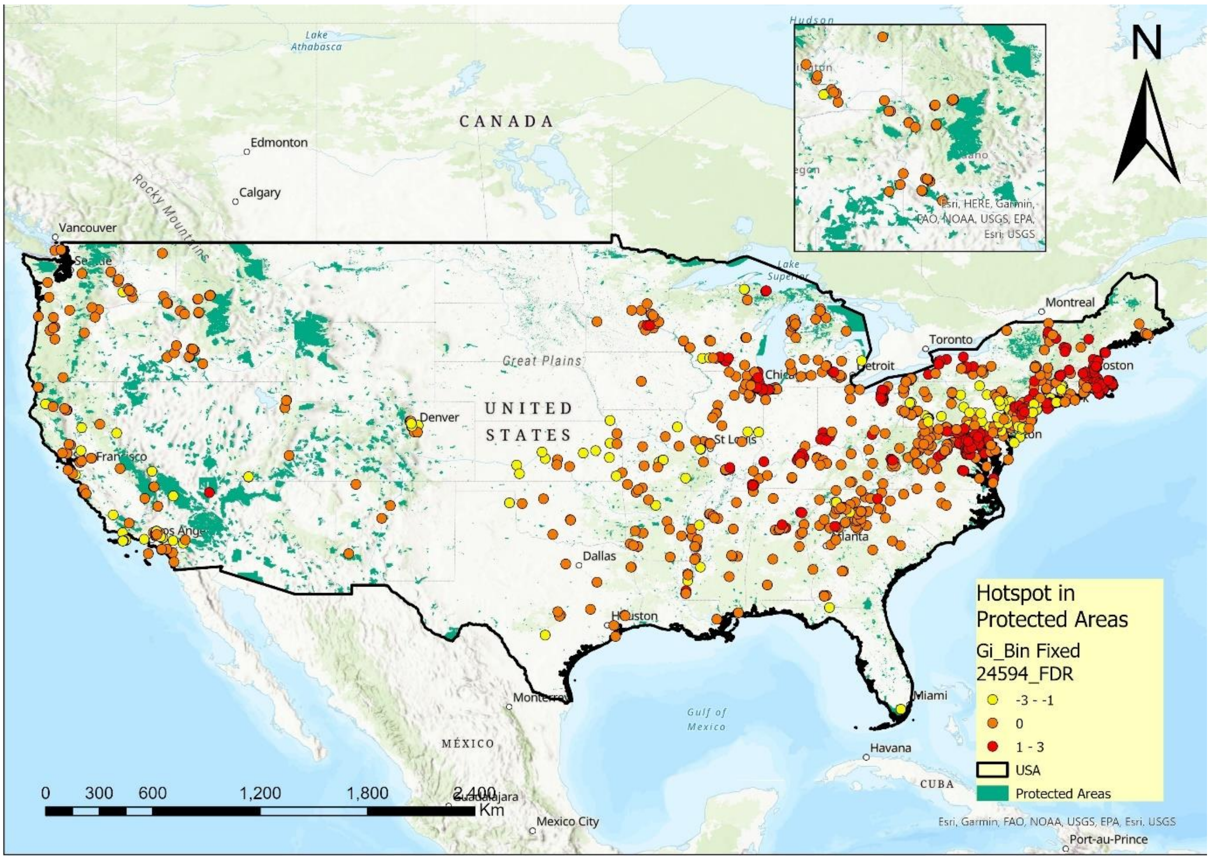

Figure 19: Identifying Robinia pseudoacacia hotspot locations for protected areas in North America.

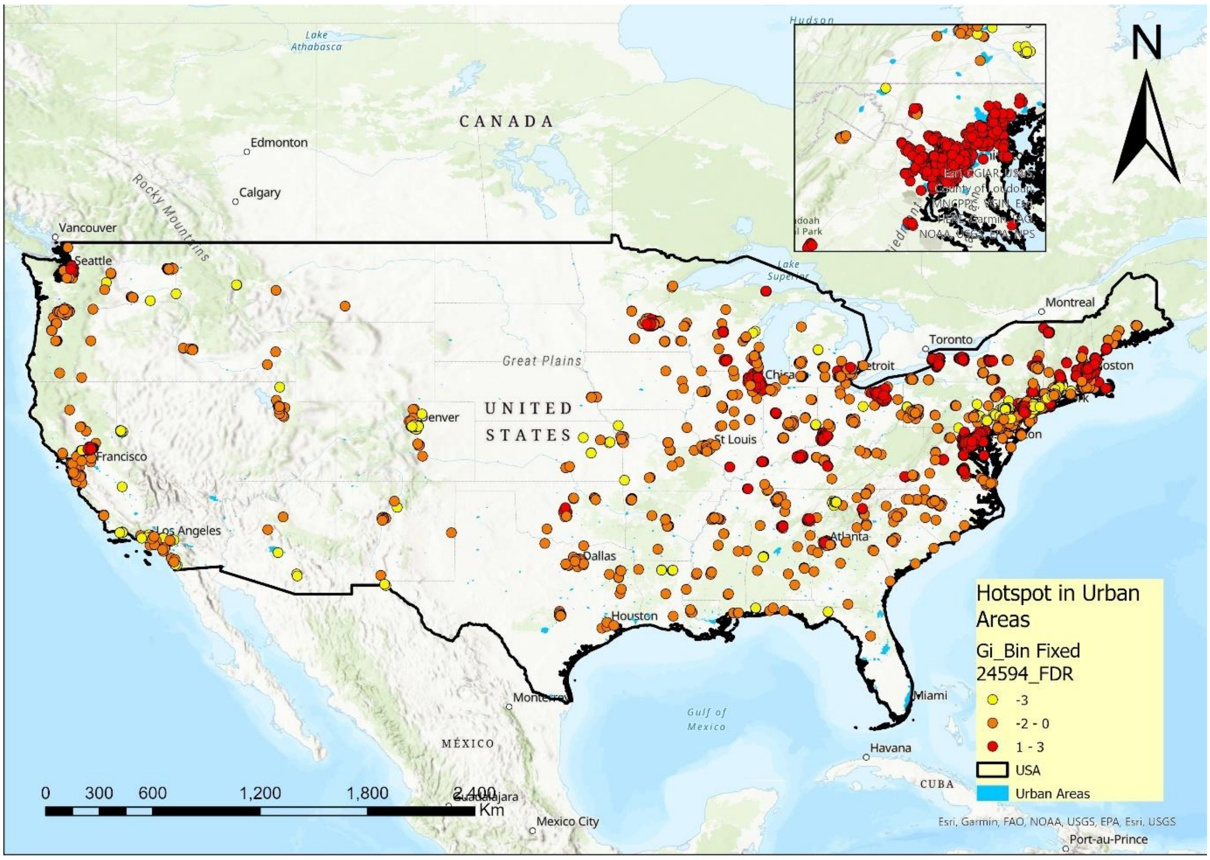

Figure 20: Identifying Robinia pseudoacacia hotspot locations for urban areas in North America.

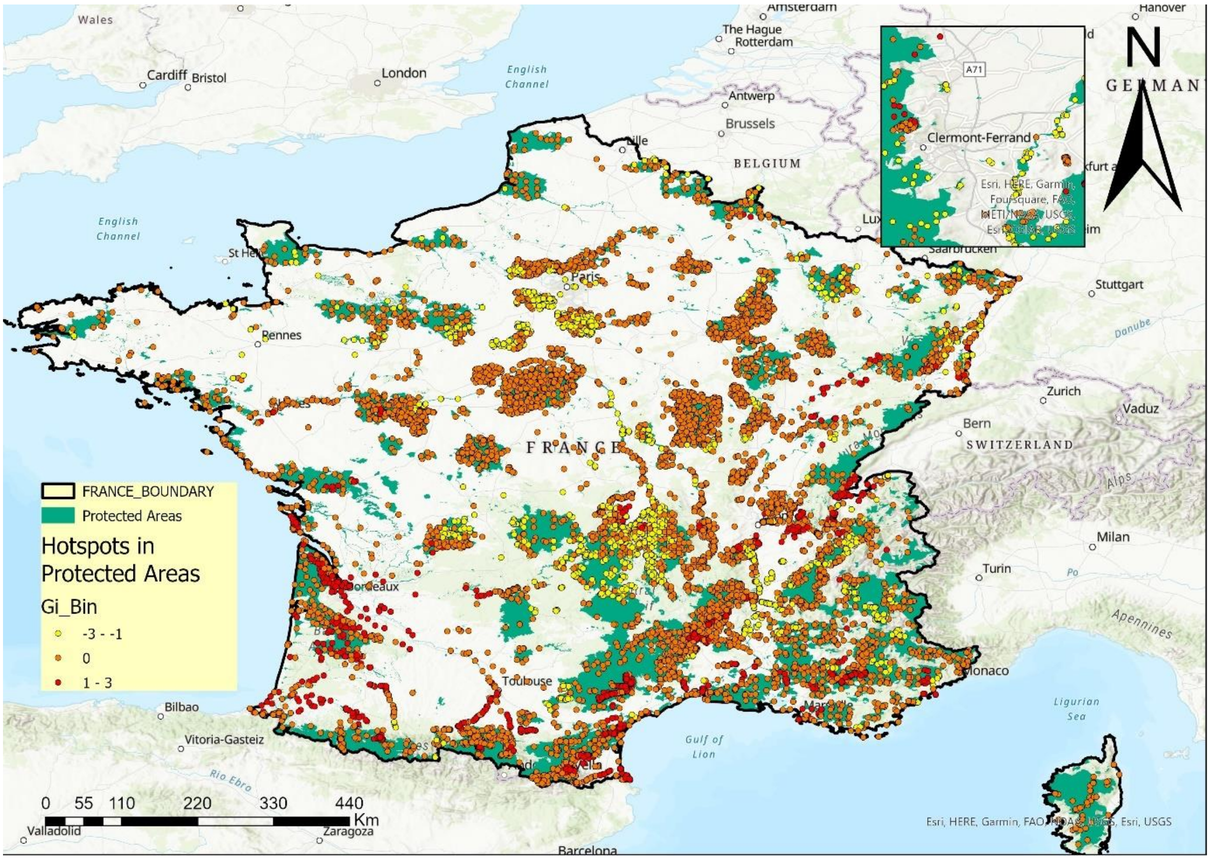

Figure 21: Identifying Robinia pseudoacacia hotspot locations for protected areas in France.

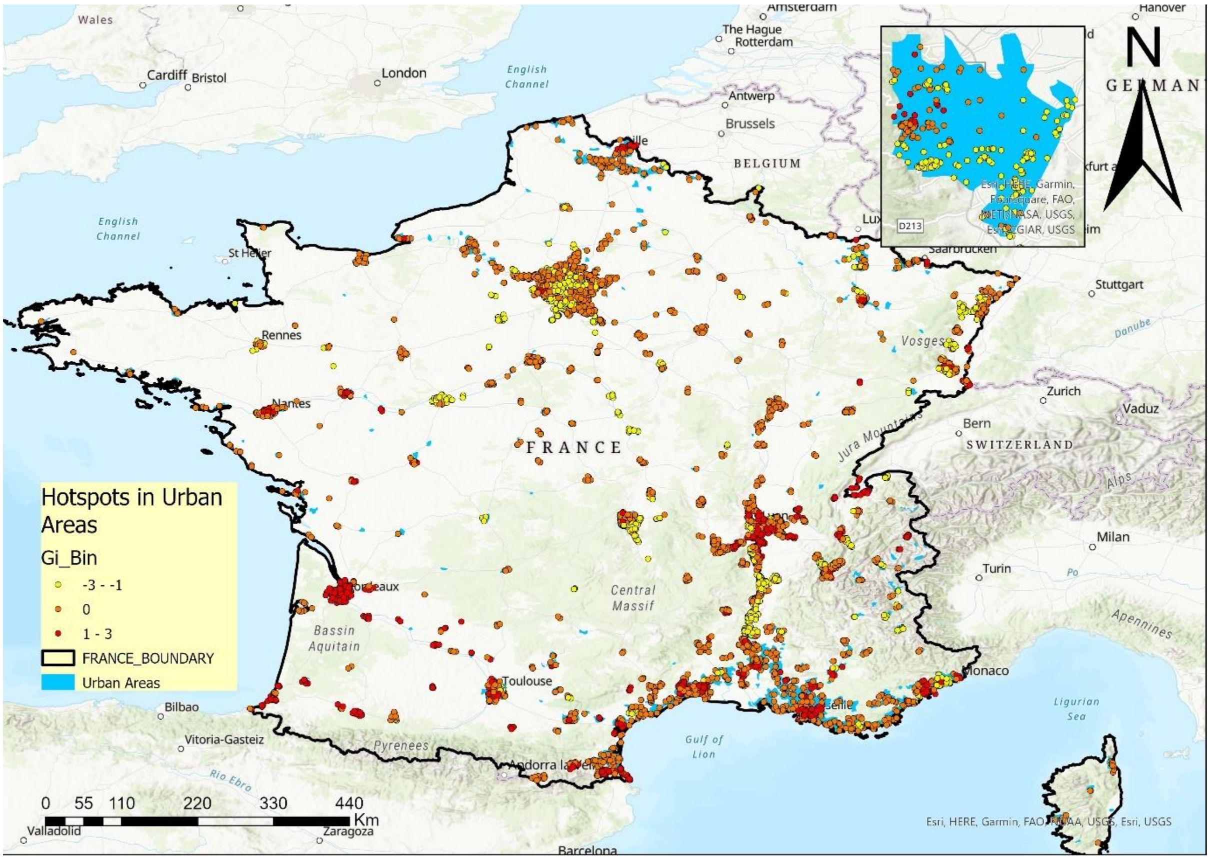

Figure 22: Identifying Robinia pseudoacacia hotspot locations for urban areas in France.

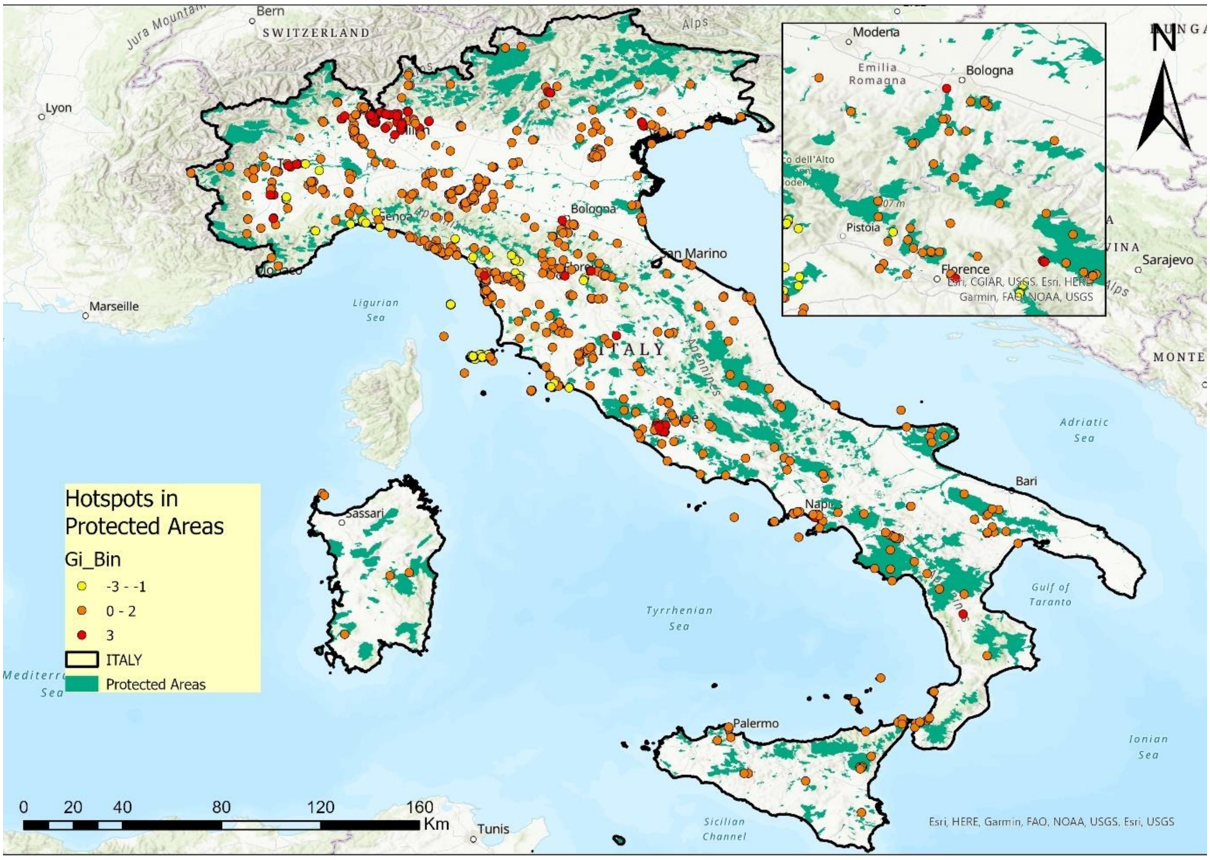

Figure 23: Identifying Robinia pseudoacacia hotspot locations for protected areas in Italy.

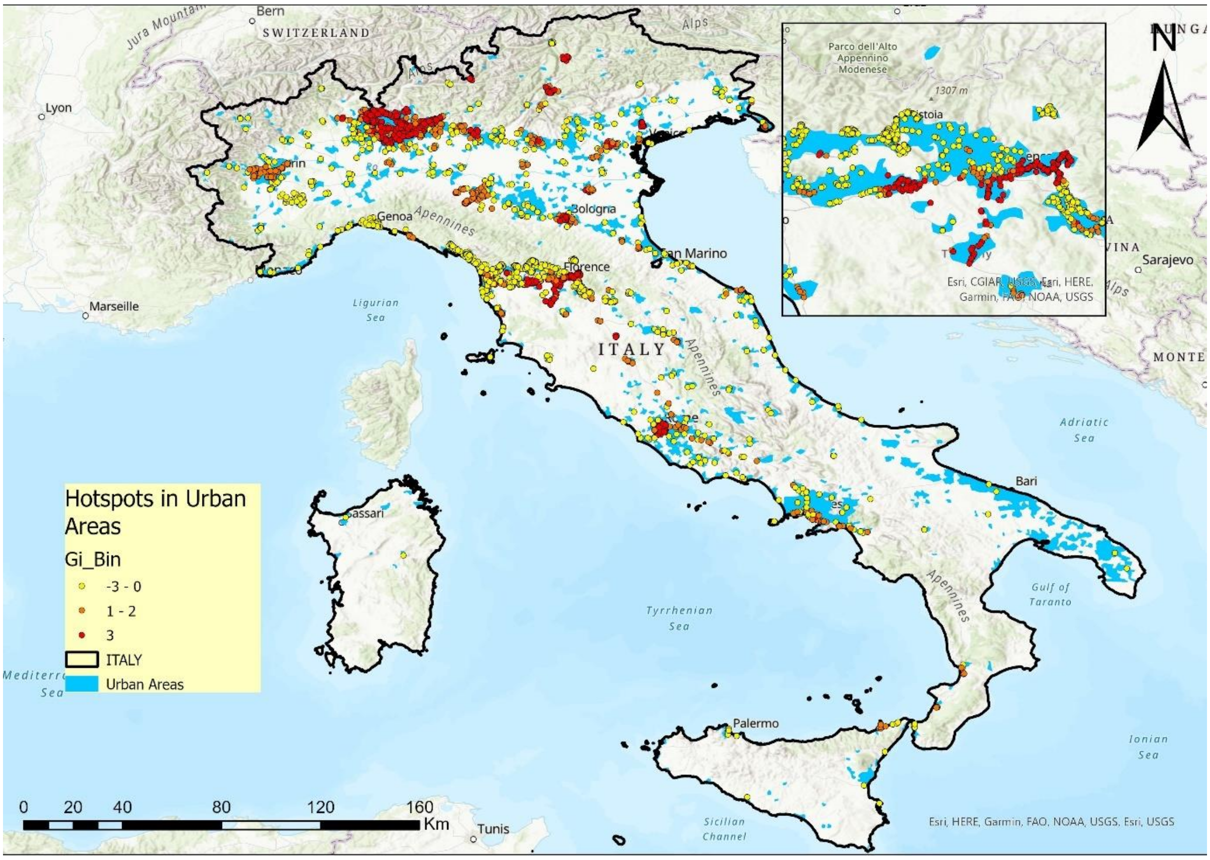

Figure 24: Identifying Robinia pseudoacacia hotspot locations for Urban areas in Italy.

Table 2: Summary statistics of Ordinary Least Square (OLS) analysis

…istic	Probability [b]	Robust_SE	Robust_t	Robust_Pr[b]	VIF [c]
…40745	0.055192	3.771289	2.026092	0.045499*	--------
…76629	0.006788*	0.434461	-2.737012	0.007373*	1.003038
…07627	0.270759	0.001699	1.439989	0.153097	1.003038
…36972	0.000000*	0.14705	-10.372936	0.000000*	--------
…36991	0.000000*	0.000126	-7.44847	0.000000*	2.207347
…58428	0.796128	0.014877	0.233053	0.815764	2.207347
…38854	0.000000*	0.26943	15.194798	0.000000*	--------
…01058	0.000069*	0.000122	-3.088771	0.002033*	1.234247
…30907	0.000000*	0.014466	-11.948374	0.000000*	1.234247
…24679	0.000000*	0.258734	21.949152	0.000000*	--------
…56539	0.000000*	0.000104	-34.943039	0.000000*	1.27035

7. DISCUSSION

The tree of heaven and black locust demonstrate patterns when it comes to their presence in protected areas. The tree of heaven shows an ability to thrive in disrupted environments while black locust commonly finds its way into urban areas due to its usefulness as a timber species (C. M. Enescu, 2016). In protected areas the presence of tree of heaven is often associated with land disturbances while black locust may establish itself in regions previously affected by agriculture or past land management practices. These findings provide insights into how versatile native species can be across different environments (Petersen et al., 2021).

Balancing Benefits and Ecological Disruption, our findings highlight that both non-native tree species, the tree of heaven and black locust contribute ecosystem services within areas. However, having these species around can disrupt the balance of ecosystems and impact the variety of plants and animals, in urban areas. The real challenge lies in finding a way for these species to coexist harmoniously by managing them to maximize their benefits while minimizing any downsides (Sladonja et al., 2015b).

Regional Variation an interesting aspect of this analysis is the variation we see in regions when it comes to native tree species. These regional differences highlight areas where these species more prevalent or less common indicating varying levels of their presence (Campagnaro et al., 2023). This finding suggests that we need targeted conservation and management strategies that consider the dynamics and challenges specific to each region. Understanding variation emphasizes the importance of considering contexts and tailoring our management practices accordingly. The implications of this analysis go beyond looking at where non-native tree species found and how they are distributed. They also delve into areas like planning, managing protected areas and overall biodiversity conservation (Campagnaro et al., 2023).

When it comes to urban planning, we need to be mindful about responsible planting practices and prioritize the use of native species. By taking measures to minimize the impacts caused by non-native species urban areas can create a healthier and more sustainable coexistence, between these non-natives and their native counterparts. Urban green spaces and landscapes should be designed in a way that supports biodiversity while also appreciating the benefits that non-native species can bring (Briski et al., 2023).

In protected area management the presence of native species such, as the tree of heaven and black locust poses challenges to the goals of protecting natural areas, which primarily focus on preserving native biodiversity (Wohlgemuth et al., 2022). It is important to control species initiate ecological restoration projects and implement region specific management strategies to ensure the thriving of native ecosystems. Protected areas should serve as havens for plants and animals requiring careful attention to the effects of invasive species. The findings from this analysis emphasize the need for tailored management strategies that take into account regional and contextual factors related to non-native species. It is crucial to acknowledge that non-native tree species like the tree of heaven and black locust are not uniform entities but rather dynamic components within different ecosystems. Therefore, management strategies must be adjusted according to conditions considering the challenges and opportunities presented by each species in various landscapes (Schneider et al., 2009).

Ecosystems constantly change, as do the dynamics of native species, within them. Therefore, it is important for management strategies to be flexible and adaptable as they need to respond to the changing interactions and the effects of evolving environmental conditions. Recognizing the aspect when introducing and managing native tree species is crucial. By involving communities, stakeholders, and land managers, in the decision-making process we can enhance the effectiveness of conservation and management efforts. Public education campaigns can also play a role in promoting planting practices and increasing awareness about the ecological importance of preserving native biodiversity (Ramus et al., 2017).

8. CONCLUSION

This thesis embarked on a preliminary analysis of the occurrence and impact of two non-native tree species, the "Tree of Heaven" (*Ailanthus altissima*) and the "Black Locust" (*Robinia pseudoacacia*), in both urban and protected areas. The examination of these non-native tree species has unveiled a complex tapestry of interactions within different ecosystems, emphasizing the multifaceted nature of their presence. The key findings of this analysis underscore the significance of understanding and addressing the presence of non-native tree species.

In this investigation our main goal was to create a framework, for accurately measuring the spread of invasive species worldwide. Specifically, we focused on studying the tree of heaven and the black locust in both protected areas. Through our analysis we discovered that these non-native tree species have relationships within various ecosystems showcasing their multifaceted nature.

Our findings highlight the urgency of comprehending and proactively addressing the presence of native trees. By delving into this research, we gained insights into the roles these species play in urban and protected landscapes. We unravelled their distribution patterns. Examined their nuanced impacts. The importance of customized management approaches emerged strongly emphasizing the challenges posed by these species.

The complexity of managing these native species within local contexts became evident emphasizing the necessity for tailored strategies that consider each ecosystems unique characteristics. As we move forward a deeper understanding of how non-native tree species interact with ecosystems will guide us in implementing management and conservation strategies. Our analysis emphasizes how dynamic these species roles are in their environments stressing the need, for context approaches.

In the realm of coexistence and maintaining a balance, between native species and native ecosystems the need for effective strategies becomes apparent. The process of moving from analysis to these insights highlights the intricate interplay of ecological factors urging us to approach the management of invasive species with a nuanced and adaptable perspective. Also sets the groundwork for a broader conversation, on global invasive species management considering the unique challenges presented by diverse ecological contexts.

In preliminary analysis we have gained insights into the roles non-native tree species play in urban and protected landscapes. This has shed light on their distribution, impacts as emphasized the significance of tailored management approaches. These findings highlight how complex it is to manage native species while emphasizing that local contexts should always be considered. As we move forward a deeper understanding of these species and their interactions with ecosystems will help guide us in implementing management and conservation strategies. Ultimately what is needed are strategies those are specific to each context ones that promote coexistence and maintain a balance, between non-native species and native ecosystems.

9. REFERENCES

Briski, E., Kotronaki, S. G., Cuthbert, R. N., Bortolus, A., Campbell, M. L., Dick, J. T. A., Fofonoff, P., Galil, B. S., Hewitt, C. L., Lockwood, J. L., MacIsaac, H. J., Ricciardi, A., Ruiz, G., Schwindt, E., Sommer, U., Zhan, A., & Carlton, J. T. (2023). Does non-native diversity mirror Earth's biodiversity? *Global Ecology and Biogeography*. https://doi.org/10.1111/GEB.13781

Byers, J. E. (2002). Impact of non-indigenous species on natives enhanced by anthropogenic alteration of selection regimes. In *Oikos* (Vol. 97, Issue 3). https://doi.org/10.1034/j.1600-0706.2002.970316.x

C. M. Enescu, T. H. D. G. C. (2016). *Ailanthus altissima in Europe: distribution, habitat, usage, and threats*.

Campagnaro, T., Badalamenti, E., Castro-Díez, P., & Freitas, H. (2023a). Editorial: Non-native tree species: Impacts and management. *Frontiers in Environmental Science*, *11*. https://doi.org/10.3389/FENVS.2023.1183804

Chaves Lobón, N., González Félix, M., & Alías Gallego, J. C. (2023). Comparison of the Allelopathic Potential of Non-Native and Native Species of Mediterranean Ecosystems. *Plants 2023, Vol. 12, Page 972*, *12*(4), 972. https://doi.org/10.3390/PLANTS12040972

Cierjacks, A., Kowarik, I., Joshi, J., Hempel, S., Ristow, M., von der Lippe, M., & Weber, E. (2013). Biological Flora of the British Isles: *Robinia pseudoacacia*. *Journal of Ecology*, *101*(6), 1623–1640. https://doi.org/10.1111/1365-2745.12162

Dimitrova, A., Csilléry, K., Klisz, M., Lévesque, M., Heinrichs, S., Cailleret, M., Andivia, E., Madsen, P., Böhenius, H., Cvjetkovic, B., De Cuyper, B., de Dato, G., Ferus, P., Heinze, B., Ivetić, V., Köbölkuti, Z., Lazarević, J., Lazdina, D., Maaten, T., … Montagnoli, A. (2022a). Risks, benefits, and knowledge gaps of non-native tree species in Europe. *Frontiers in Ecology and Evolution*, *10*, 908464. https://doi.org/10.3389/FEVO.2022.908464/BIBTEX

GBIF. (n.d.). Retrieved November 23, 2023, from https://www.gbif.org/pt/.

Ivanova, N. V., & Shashkov, M. P. (2021). The Possibilities of GBIF Data Use in Ecological Research. *Russian Journal of Ecology*, *52*(1), 1–8. https://doi.org/10.1134/S1067413621010069/FIGURES/3

Knüsel, S., De Boni, A., Conedera, M., Schleppi, P., Thormann, J. J., Frehner, M., & Wunder, J. (2017). Shade tolerance of *Ailanthus altissima* revisited: novel insights from southern Switzerland. *Biological Invasions*, *19*(2), 455–461. https://doi.org/10.1007/S10530-016-1301-4/TABLES/2

Li, X., Li, Y., Ma, S., Zhao, Q., Wu, J., Duan, L., Xie, Y., & Wang, S. (2021). Traditional uses, phytochemistry, and pharmacology of *Ailanthus altissima* (Mill.) Swingle bark: A comprehensive review. *Journal of Ethnopharmacology*, *275*, 114121. https://doi.org/10.1016/J.JEP.2021.114121

Martin, G. D. (2019). Addressing geographical bias: A review of *Robinia pseudoacacia* (black locust) in the Southern Hemisphere. *South African Journal of Botany*, *125*, 481–492. https://doi.org/10.1016/J.SAJB.2019.08.014

Nicolescu, V. N., Rédei, K., Mason, W. L., Vor, T., Pöetzelsberger, E., Bastien, J. C., Brus, R., Benčať, T., Đodan, M., Cvjetkovic, B., Andrašev, S., La Porta, N., Lavnyy, V., Mandžukovski, D., Petkova, K., Roženbergar, D., Wąsik, R., Mohren, G. M. J., Monteverdi, M. C., … Pástor, M. (2020). Ecology, growth and management of black locust (*Robinia pseudoacacia* L.), a non-native species integrated into European forests.

Journal of Forestry Research, *31*(4), 1081–1101. https://doi.org/10.1007/S11676-020-01116-8/TABLES/9

Nilsen, E. T., Huebner, C. D., Carr, D. E., & Bao, Z. (2018). Interaction between *Ailanthus altissima* and Native *Robinia pseudoacacia* in Early Succession: Implications for Forest Management. *Forests 2018, Vol. 9, Page 221*, *9*(4), 221. https://doi.org/10.3390/F9040221

Petersen, T. K., Speed, J. D. M., Grøtan, V., & Austrheim, G. (2021). Species data for understanding biodiversity dynamics: What, where and when of species occurrence data collection. *Ecological Solutions and Evidence*, *2*(1), e12048. https://doi.org/10.1002/2688-8319.12048

Pötzelsberger, E., Spiecker, H., Neophytou, C., Mohren, F., Gazda, A., & Hasenauer, H. (2020). Growing Non-native Trees in European Forests Brings Benefits and Opportunities but Also Has Its Risks and Limits. *Current Forestry Reports*, *6*(4), 339–353. https://doi.org/10.1007/S40725-020-00129-0/FIGURES/3

Ramus, A. P., Silliman, B. R., Thomsen, M. S., & Long, Z. T. (2017). An invasive foundation species enhances multifunctionality in a coastal ecosystem. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(32), 8580–8585. https://doi.org/10.1073/pnas.1700353114

Schneider, A., Friedl, M. A., & Potere, D. (2009). A new map of global urban extent from MODIS satellite data. *Environmental Research Letters*, *4*(4). https://doi.org/10.1088/1748-9326/4/4/044003

Sladonja, B., Sušek, M., & Guillermic, J. (2015a). Review on Invasive Tree of Heaven (*Ailanthus altissima* (Mill.) Swingle) Conflicting Values: Assessment of Its Ecosystem Services and Potential Biological Threat. *Environmental Management*, *56*(4), 1009–1034. https://doi.org/10.1007/S00267-015-0546-5/TABLES/3

Small, C. J., White, D. C., & Hargbol, B. (2010). Allelopathic influences of the invasive *Ailanthus altissima* on a native and a non-native herb1,2. *Https://Doi.Org/10.3159/10-RA-034.1*, *137*(4), 366–372. https://doi.org/10.3159/10-RA-034.1

Straker, K. C., Quinn, L. D., Voigt, T. B., Lee, D. K., & Kling, G. J. (2015). Black Locust as a Bioenergy Feedstock: a Review. *BioEnergy Research 2015 8:3*, *8*(3), 1117–1135. https://doi.org/10.1007/S12155-015-9597-Y

Tallamy, D. W., Narango, D. L., & Mitchell, A. B. (2021). Do non-native plants contribute to insect declines? *Ecological Entomology*, *46*(4), 729–742. https://doi.org/10.1111/EEN.12973

Vítková, M., Müllerová, J., Sádlo, J., Pergl, J., & Pyšek, P. (2017). Black locust (*Robinia pseudoacacia*) beloved and despised: A story of an invasive tree in Central Europe.

Forest Ecology and Management, *384*, 287–302. https://doi.org/10.1016/J.FORECO.2016.10.057

Wohlgemuth, T., Gossner, M. M., Campagnaro, T., Marchante, H., van Loo, M., Vacchiano, G., Castro-Díez, P., Dobrowolska, D., Gazda, A., Keren, S., Keserű, Z., Koprowski, M., Porta, N. La, Marozas, V., Nygaard, P. H., Podrázský, V., Puchałka, R., Reisman-Berman, O., Straigytė, L., … Silva, J. S. (2022a). Impact of non-native tree species in Europe on soil properties and biodiversity: a review. *NeoBiota*, *78*, 45–69. https://doi.org/10.3897/NEOBIOTA.78.87022