Innovative Research Journal of **Plant and Agricultural Biology** (IRJPAB)
2025; 1(1): 1-34
DOI: https://doi.org/10.62497/irjpab.246

Review Article

A Review of Herbaceous Ornamental Plants as Contributors to Plant Invasion Risk in Subtropical Urban Parks: Effects on Plant Composition, Diversity, and Climate-Driven Changes in Alpine Heaths

Musharraf Ahmed Ghori[1], Ahmed Raza[2], Hammad Ahsan[3], Amir Tanveer[2], Abbasi Hoosh Muhammad[4], Muhammad Zakir Khan[5], Adnan Altaf[2], Mansoor Akram[6*]

1) *College of Ecology and Environment, Chengdu University of Technology, Chengdu 610059, Sichuan, China*
2) *College of Civil and Environment, Chengdu University of Technology, Chengdu, Sichuan, China*
3) *College of Materials Chemistry & Chemical Engineering, Chengdu University of Technology, Chengdu, Sichuan, China*
4) *College of Geography and Planning, Chengdu University of Technology, Chengdu, Sichuan 610059, PR China*
5) *College of Humanities and Law, Chengdu University of Technology, PR China*
6) *State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, College of Energy Resources, Chengdu University of Technology, 610059 Chengdu, China.*

Citation: Ghori MA, Raza A, Ahsan H, Tanveer A, Muhammad AH, Khan MZ, et al. A Review of Herbaceous Ornamental Plants as Contributors to Plant Invasion Risk in Subtropical Urban Parks: Effects on Plant Composition, Diversity, and Climate-Driven Changes in Alpine Heaths. Innovative Research Journal of Plant and Agricultural Biology. 2025;1(1):1-34. Available from: https://irjpl.org/irjpab/article/view/246

Article Info
Received: May 19, 2025
Revised: June 9, 2025
Accepted: June 12, 2025

Keywords
Herbaceous ornamental plants, plant invasion, biodiversity, climate change, urban parks

Abstract

Urban parks in the subtropics are increasingly invaded by herbaceous ornamental plants, many of which were introduced for aesthetic reasons but have become great sources of plant invasion risks. Traits of rapid growth, high reproductive capacity capable of adapting in disturbed environments, allow them to overcompete with native species and change ecosystem functions. This systematic review investigates the ecological consequences of ornamental plant invasions for native biodiversity and plant composition, that is, disrupting ecosystem services, such as pollination, nutrient cycling, and water retention. Moreover, it examines how climate change enhances invasion dynamics, most notably in sensitive alpine heath ecosystems, through lengthening growing seasons and augmenting native species stress. The review uses existing literature to identify key invasive species, the mechanisms driving their success, and the ecological consequences of their success. The review explores management strategies to mitigate these risks, including early detection, control measures and sustainable landscaping practices that favor the use of native or non-invasive plants. The review also emphasizes the value of policy interventions and interdisciplinary collaborations for mitigation of risks of plant invasion in urban parks. Future research should capitalize on the development of predictive models for invasion risk assessment to create future energy futures to explore and further invent management techniques and understand the socio-economic impacts of invasive species management. This review synthesizes current knowledge to inform conservation efforts, support sustainable urban planning, and contribute to the conservation of subtropical and alpine ecosystems under climate change pressure.

***Corresponding Author:**
Mansoor Akram
Email: mansoorakramlone@outlook.com

Introduction

Urban parks are important ecological assets, serving as refuge for biodiversity, supplying ecosystem services and improving human wellbeing. Because of their potential to host a diversity of flora and fauna, these green spaces are of special importance in subtropical regions [1]–[3]. Nevertheless, the introduction of non-native herbaceous ornamental plants, mainly for landscaping purposes, has become an issue of ecological concern. These plants provide some aesthetic value for cities but have significant invasive potential because they threaten native plant diversity and ecosystem function [2]–[4]. Phenotypic plasticity, conspicuous aesthetic traits, and resilience to variable environmental conditions are often the reasons that herbaceous ornamental plants are chosen for cultivation. Although these characteristics are good for urban landscapes, they generally coincide with the ones that enable biological invasions [3]–[5]. In other words, approximately 70% of all invasive plant species in urban settings around the world were introduced as ornamentals.

The paradox of ornamental plants simultaneously serving as ecological assets and potential ecological disruptors is creating a challenge that urban planners and ecologists are attempting to resolve [5]–[7]. It has an optimal climate for many ornamental plants that are grown in the subtropical climate with high annual precipitation and moderate seasonal variability [7]–[9]. Nevertheless, this same climate promotes their potential to become invasive by extending growing seasons and increasing seed dispersal (Propagule pressure), a central factor in biological invasions, in urban parks where ornamental species are frequently replanted and maintained. Introduction of non-native herbaceous ornamental plants, primarily for landscaping purposes, has raised ecological concerns [8]. While these plants contribute aesthetically to urban landscapes, their invasive potential poses risks to native plant diversity and ecosystem functionality. Herbaceous ornamental plants are frequently chosen for their phenotypic plasticity, conspicuous aesthetic traits, and resilience under variable environmental conditions [9]. These characteristics, while desirable in urban landscapes, often overlap with traits that enable biological invasions. Studies estimate that approximately 70% of invasive plant species in urban environments worldwide were initially introduced as ornamentals [10]. This dual role of ornamental plants as both ecological assets and potential ecological disruptors creates a paradox that urban planners and ecologists are striving to address [11], [12]. The subtropical climate, characterized by high annual precipitation and moderate seasonal variability, provides optimal growing conditions for many ornamental plants [13]. However, this same climate accelerates their potential to become invasive by supporting prolonged growing seasons and enhancing seed dispersal Propagule pressure, a critical factor in biological invasions, is amplified in urban parks due to the frequent replanting and maintenance of ornamental species [14]. This inadvertently creates a seed bank in urban soils and increases the risk to spontaneously spread into nearby natural ecosystems. The Impact of Herbaceous Ornamental Plants on Invasion Risk is shown in Figure 1.

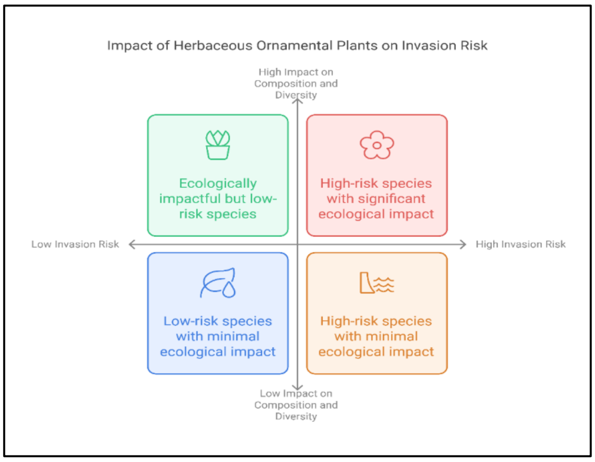

Figure 1: Impact of Herbaceous Ornamental Plants on Invasion Risk [41]

Over the past few decades, research has shown that invasive ornamental plants have great ecological consequence [15]. To provide an example, in a study of 15 urban parks in Spain, we found that the proportion of non-native plant species was strongly correlated (positively and negatively) with the urbanization levels and climatic variables (e.g. average annual temperature and rainfall) [16]. Plant community composition is altered by ornamental plant invasion, often decreasing species richness and functional diversity, and we also demonstrate that this alteration decreases seedling abundance. Tradescantia fluminensis and Lantana camara, common landscape plants, have been shown to invade native vegetation by displacing native species for sunlight, water and nutrients [17]. Herbaceous ornamental plants pose risks in alpine heath ecosystems that are magnified by climate change. The growing range of a growing number of invasive species is expanding and they are colonizing previously inhospitable habitats, because they are able to do so because of rising global temperatures and changing precipitation patterns [18]. For example, studies show that herbaceous species invading alpine ecosystems often have adaptive root foraging and high reproductive capacity, two traits that are favored under changing climatic conditions [19]. But these invasions not only put at risk endemic plant species, but also cause disturbance to ecosystem services such as water retention and nutrient cycling. The potential for herbaceous ornamental plants to invade, because of these complexities, must be approached ecologically, climatically and economically [20]. Ornamental species are introduced into urban parks aesthetically and economically, but their ecological consequences are not often assessed. However, more and more, ornamental plant invasive potential is being evaluated using predictive modeling tools such as Plant Risk Evaluation (PRE). The tools combine seed viability, dispersal mechanisms and climate adaptability to predict invasion risks [21].

Challenges and Issues in Previous Studies

In recent years, the study of herbaceous ornamental plants as contributors to plant invasion risk has advanced significantly. Yet many of these ecological threats continue to present huge challenges and limitations, therefore preventing us from fully understanding and effectively managing them. Previous studies adopt certain methodological approaches, which one major issue [22]. However, observational data and short-term field surveys are used by many, and while helpful, they fail to capture the long-term dynamics of plant invasions [23]. The underutilization of predictive modeling, e.g. Species distribution models (SDMs) or Plant Risk Evaluation (PRE) tools, prevents us from predicting future invasion scenarios under changing climatic conditions [24]–[26].

A serious impediment to this is the absence of comprehensive and standardized data on ornamental plant invasions. The current studies are highly biased with respect to region, having a marked disparity in emphasis on temperate ecosystems compared to subtropical and alpine ecosystems [25]. Additionally, there is limited data on less well-known ornamental species, which leaves blind spots in understanding their invasive potential. Inconsistive conclusions about invasion drivers and impacts are due to the regional and species-specific gaps [27].

Moreover, the integration of climatic and socioeconomic factors to invasion studies is still insufficient. While propagule pressure and climate change are recognized as significant drivers, their interaction with urbanization, trade, and horticultural practices is less explored [28]. This oversight leaves critical pathways for plant invasions inadequately understood, particularly in urban parks where ornamental plants are frequently introduced and maintained [29]. Figure 2 shows the Challenges and Issues in Previous Studies.

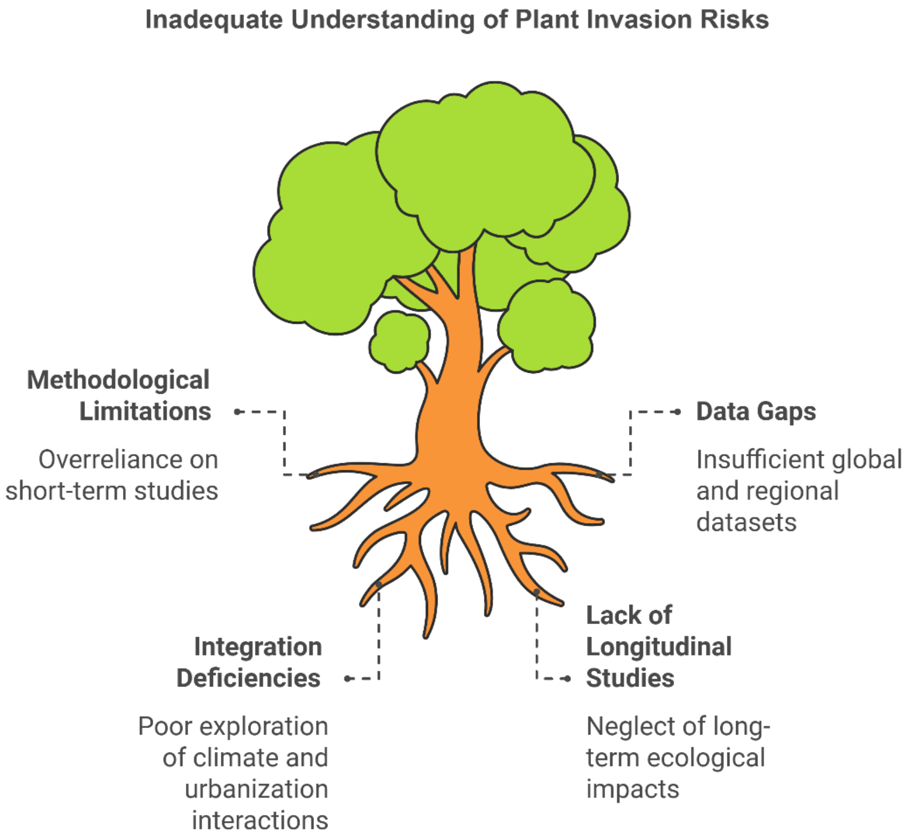

Figure 2: Challenges and Issues in Previous Studies [53]

Finally, longitudinal studies examining the delayed ecological effects of ornamental plant invasions are limited. Most studies fail to address long-term impacts such as seed bank persistence, changes in successional dynamics, and cumulative ecosystem service losses [30]. This gap impedes the development of effective management strategies that account for future ecological scenarios [31].

- **Methodological Limitations:** Short term observational studies overreliance; insufficient use of predictive modeling tools such as SDMs and PRE.
- **Data Gaps:** Lack of standardized global datasets; under representation of subtropical and alpine ecosystems; lack of data for lesser-known ornamental species.
- **Integration Deficiencies:** Inadequate investigation of invasion drivers interacting with climate change and urbanization.
- **Lack of Longitudinal Studies:** Few studies of delayed effects of plant invasions (e.g. seed bank persistence, long term ecosystem effects).

Scope and Objectives of Review

In this review, the knowledge gaps identified in previous studies are bridged by the comprehensive analysis of the role of herbaceous ornamental plants in plant invasion risks in subtropical urban parks and alpine heath ecosystems [32]. This review synthesizes findings from global and regional studies in order to inform future research and to guide future sustainable urban landscaping practices [33].

This review examines the invasion risks from herbaceous ornamental plants, particularly in subtropical urban parks and alpine heath ecosystems that are considered highly vulnerable to ecological disruption, within the scope. The ecological impacts of these invasions are explored, including their capacity to change plant composition and biodiversity, and disrupt such ecosystem services as pollination, nutrient cycling, and water retention. It also analyzes the part that climate change plays as an essential driver that increases the invasion potential of ornamental plants by extending their growing ranges and altering ecosystem dynamics [34]. One aspect of this review is an evaluation of present management strategies designed to reduce these risks, including advanced tools, sustainable landscaping practices, and policy intervention. This comprehensive review seeks to provide a robust framework for understanding and managing the dual role of herbaceous ornamental plants as contributors to urban aesthetics, and as ecological disruptors [35].

The objectives of the present review are the following:

- I investigate what makes herbaceous ornamental plants invasive by identifying key traits and mechanisms.
- In order to assess the ecological impacts of these invasions on plant diversity, ecosystem services and community dynamics.
- In order to quantify the role of climate change in amplifying invasion risks, especially in sensitive ecosystems like alpine heathlands.
- We evaluate current management strategies to propose actionable solutions for sustainable urban landscaping and biodiversity conservation.
- In order to highlight research gaps and outline future directions for the study of ornamental plant invasions.

The objective of this review is to present a robust framework for understanding and managing the dual role of herbaceous ornamental plants as both an ecological disruptor and an aesthetic contributor through addressing these objectives [36]. It highlights the importance of an interdisciplinary approach that involves ecological, climatic and socioeconomic dimensions and the mitigation of risks of these plants in urban and natural ecosystems [37].

The ecological impacts, as well as the compounding effects of climate change, of herbaceous ornamental plants as contributors to plant invasion risks in subtropical urban parks is reviewed in this article [38]. This paper attempts to inform sustainable urban landscaping practices and to guide policy interventions by synthesizing findings from global and regional studies. The invasion risks are also discussed in alpine heath ecosystems, and the discussion also extends to interdisciplinary strategies for mitigating the adverse impacts of ornamental plant invasions.

Ecological and Climatic Context of Subtropical Urban Parks

Urban parks in the subtropical zone are essential urban infrastructure components with numerous ecological and social benefits [39]. These parks are biodiversity hotspots, provide essential ecosystem services, and improve urban quality by mitigating heat island effects and increasing the extent of outdoor thermal comfort [40]. Nevertheless, they are becoming increasingly threatened with ecological integrity from the introduction and spread of non-native species, particularly herbaceous ornamental plants. Some of these species have traits that allow them to out compete native plants in ways that disrupt the ecological balance of these parks [41].

The subtropical climate is characterized by high rainfall, warm temperatures, long growing season, and is suitable for growth of both the native and non-native species [42]. The combination of these climatic contexts with urban pressures (habitat fragmentation and high propagule pressure) makes subtropical urban parks particularly prone to plant invasions [43]. However, the ecological and climatic dynamics of these parks need to be understood in order to manage invasive species, and to preserve urban biodiversity [44].

Ecological Features of Subtropical Urban Parks

Subtropical urban parks are important ecological systems, serving as biodiversity hotspots in urban environments where they are increasingly being developed [45]. Maintaining native plant communities that are the base of local ecosystems: these parks are an important supporting role of urban biodiversity. Pollinators, birds and small mammals are supported native vegetation in subtropical parks, providing ecological stability as urban development occurs [46]. Nevertheless, the introduction of non-native ornamental species for landscaping purposes commonly perturbs these ecosystems. Research suggests that in some parks, invasive species dominate up to 40 per cent of total vegetation and that they reduce native species richness and alter plant community dynamics [47]. The Ecological Features of Subtropical Urban Parks are shown in Figure 3.

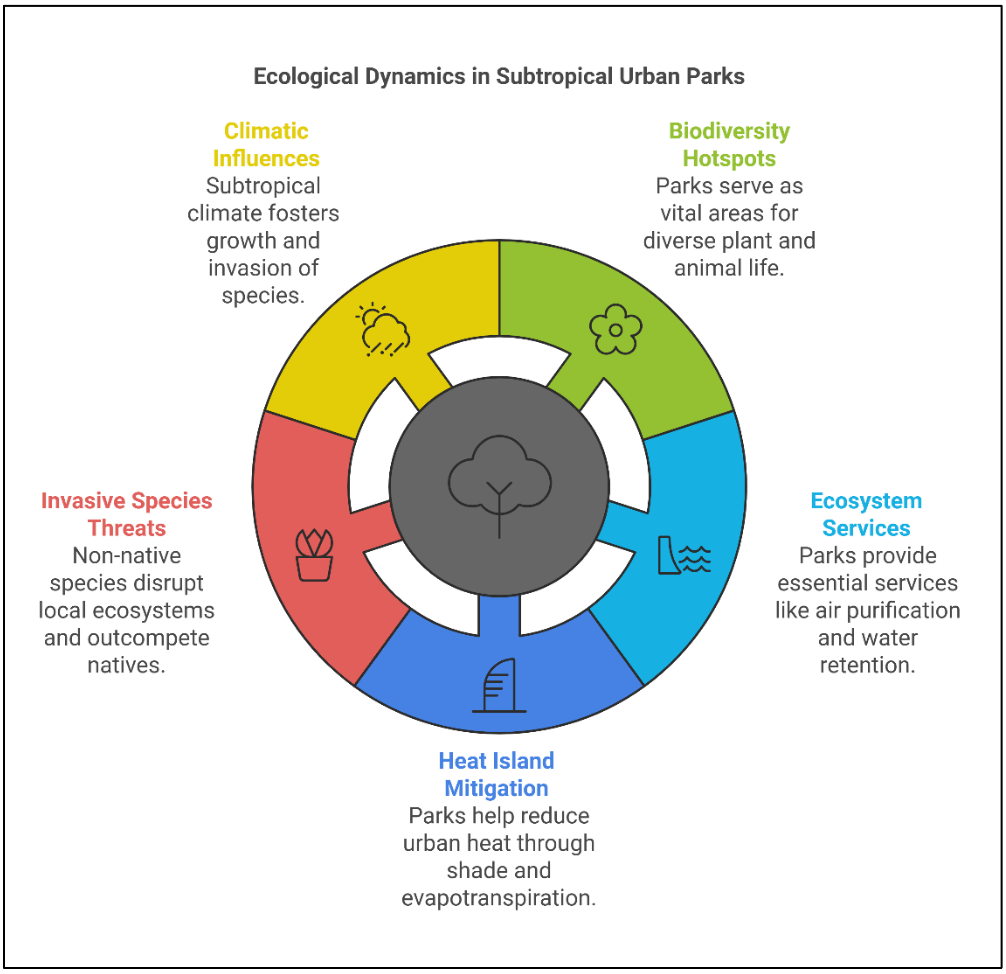

Figure 3: Ecological Features of Subtropical Urban Parks [29]

Subtropical urban parks are functionally more complex and therefore, ecologically more valuable. Most of these parks have multiple vegetation layers (tree canopies, shrub layers, and herbaceous ground covers) [48], [49]. Ecosystem services, including air purification, carbon sequestration and water regulation, are all provided by each layer. In particular, larger parks with interconnected green spaces are particularly successful in improving air quality and lowering urban temperatures, reducing ambient temperatures by 2–4°C versus non-shaded areas [50]. Unfortunately, however, this functionality is threatened by the spread of invasive ornamental species which outcompete native plants, disrupt mutualistic relationships and alter soil nutrient cycles [51]. The structural complexity of subtropical urban parks in China is illustrated in Figure 4.

Figure 4: The structural complexity of subtropical urban parks in China [63]

Table 1 summarizes ecological benefits and challenges of subtropical urban parks by contrasting contributions of native and invasive species to key ecosystem functions.

Table 1: Comparison of Native and Invasive Plant Contributions to Ecosystem Functions in Subtropical Urban Parks

Studies	Ecosystem Function	Native Species Contribution	Invasive Species Impact
[47]	Biodiversity Support	Maintains high species richness and mutualistic relationships	Reduces native species richness and disrupts pollination
[48]	Air Quality Improvement	Effective removal of particulate matter and carbon sequestration	Minimal contribution; alters vegetation composition
[49]	Urban Heat Island Mitigation	Lowers temperatures by 2–4°C in shaded areas	Limited shading capacity; outcompetes shading vegetation
[50]	Soil Stability and Water Retention	Prevents erosion and enhances water infiltration	Reduces soil stability; alters water dynamics
[51]	Functional Diversity	Supports a range of ecosystem services	Homogenizes plant communities and reduces service diversity

Table 1 illustrated the different roles played by native and invasive species in subtropical urban parks. Surveying the diverse roles of native and invasive species in park management reveals that, although native plants contribute greatly to biodiversity support as well as urban heat mitigation and air quality improvement, invasive species often do the opposite, underscoring the importance of sustainable park management.

Like other subtropical urban parks, however, they are also subject to increasing pressures from urbanization such as habitat fragmentation, pollution, and overuse for recreational purposes [52]. In particular, habitat fragmentation induces edge effects that favor the colonization of invasive species propagules, while human activities provide inadvertent means of invasive plant propagules. Because of this, these parks need to be planned with considerable care and then managed in order to conserve their ecological integrity. Such critical urban ecosystems should be prioritized for efforts, including native plant landscaping, invasive species monitoring programs and restoring degraded areas to help with the long term sustainability of these critical urban ecosystems [53].

Climatic Factors and Their Influence

In subtropical regions, where temperatures are high, rainfall is heavy and the humidity high (see Figure 5), the climatic conditions provided an environment favorable to both native and invasive plant species. The growth of these regions was extended, allowing native biodiversity and the germination and establishment of non-native ornamental plants [54]. High precipitation and temperature variability studies indicated that climatic factors enhanced the seed dispersal, root development and reproductive rates of invasive species, allowing them to dominate urban park ecosystems [55].

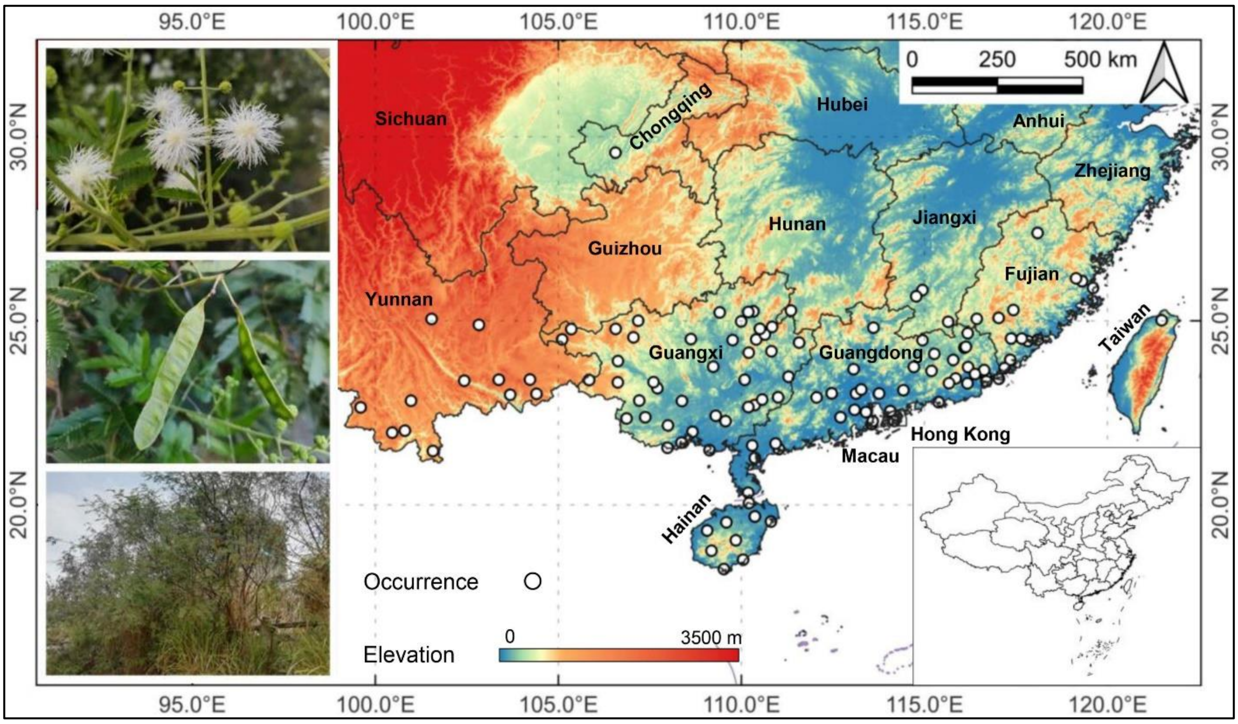

Figure 5: climatic conditions of subtropical regions, marked by elevated temperatures, significant rainfall, and high humidity levels [109]

The dynamic was further complicated by Urban Heat Island effects. Temperatures in urban areas were 2–5°C warmer than in surrounding rural areas because of human activities and heat absorbing materials [56]. This stress exacerbated competition between native plant species and favoured heat tolerant invasive plants. Also, disturbances caused by climate variability (e.g., increasing number of extreme weather events, such as storms and droughts) contributed to the establishment and spread of invasive plants [57]. Table 2 shows the comparative influence of key climatic factors, temperature, rainfall, and UHI effects, on native and invasive plant species, cited and quantified [58]. These data highlighted the increased adaptability of invasive species under these climatic conditions, and therefore call for climate resilient urban park management strategies.

Table 2: Comparison of Climatic Factors Influencing Native and Invasive Plant Species in Subtropical Urban Parks

Studies	Climatic Factor	Native Plant Species	Invasive Plant Species	Quantitative Impact
[54]	Temperature	Vulnerable to heat stress; reduced competitiveness	Heat-tolerant; higher germination and growth rates	Invasives grew 15–20% faster in UHI conditions
[55]	Rainfall	Sensitive to prolonged extremes; supported	High adaptability to both excessive and	Invasive germination rates increased by 30%

		biodiversity	deficient rainfall	during floods
[56]	Urban Heat Island (UHI)	Increased stress; reduced photosynthetic efficiency	Enhanced growth and dominance in disturbed environments	UHI temperatures favored invasives by 2–5°C advantage
[57]	Climate Variability	Vulnerable to extreme weather events; limited adaptive capacity	Exploited disturbances for establishment and spread	Extreme events caused native losses of up to 25%
[58]	Extended Growing Seasons	Favored native growth but increased competition with invasives	Prolonged growth cycles and higher reproductive success	Reproduction cycles extended by 10–15 days for invasives

Table 2 shows that invasive species were more adaptable to key climatic factors than native species. For example, invasive species grew 15 – 20% faster under UHI conditions and 30% faster in extreme rainfall events, demonstrating that they can take advantage of urban climatic conditions [59].

Characteristics of Herbaceous Ornamental Plants

Herbaceous ornamental plants are used in urban landscaping because of their aesthetic value and adaptability in changing environmental conditions. The plants have several characteristics which enable them to cope with urban life, and in some cases become invasive in subtropical areas. Key traits include rapid growth, high reproductive output and the ability to survive urban stress, such as compaction of the soil, air pollution, fluctuating moisture levels. Such characteristics make them good for urban use, and may allow them to out compete native species [60].

Herbaceous ornamental plants are rapid growers and can grow rapidly to establish themselves very quickly leaving instant greenery and aesthetic value [61]. However, this same trait is also capable of aggressive competition with native plants for resources. Furthermore, a lot of ornamental plants are known to be phenotypically plastic, and therefore be better adapted to a variety of environmental conditions. Has a high reproductive rate (sexually, through prolific seed production, and asexually, through rhizomes or stolons) that increases spread even more [62].
These plants possess a competitive edge in disturbed environments, often at the expense of native species, by their ability to tolerate urban stressors such as pollution and compacted soils. Key characteristics of herbaceous ornamental plants are compared with native species in Table 3, and the ecological impacts of the two groups in subtropical regions are discussed [63].

Table 3: Comparison of Characteristics between Herbaceous Ornamental Plants and Native Plants in Subtropical Urban Parks

Studies	Trait	Herbaceous Ornamental Plants	Native Plants
[60]	Growth Rate	Rapid (up to 30% biomass increase in 2 months)	Moderate (10–15% biomass increase in 2 months)
[61]	Reproductive Output	High (2000–5000 seeds per plant annually)	Low (500–1500 seeds per plant annually)
[62]	Stress Tolerance	Tolerant to soil compaction, pollution, and drought	Limited tolerance to urban stressors
[63]	Phenotypic Plasticity	High; adaptive to varying light, moisture, and temperature	Moderate; limited adaptive range
[64]	Dispersal Mechanism	Wind, water, and animal-mediated; rapid colonization	Primarily animal-mediated; slower colonization

Table 3 shows that reproductive outputs, growth rates and stress tolerance were higher for herbaceous ornamental plants than for native plants. In urban environments, these traits enable rapid spread, adaptation and outcompete of native species, causing ecosystem dynamics in flux.

Role of Herbaceous Ornamental Plants

in Plant Invasion

Herbaceous ornamental plants have dual roles in urban landscapes. They serve on the one hand to enhance the aesthetic and functional value of green spaces by meaning visual appeal and providing ecological services like pollinator support, and microclimate regulation. But these plants are also often highly invasive with traits that threaten native biodiversity and ecosystem stability [64]. However, the subtropical regions under consideration have a combination of favorable climatic conditions and high use of ornamentals in landscaping that expose them to greater risks of plant invasions [65]. The Role of Herbaceous Ornamental Plants in Plant Invasion is shown in Figure 6.

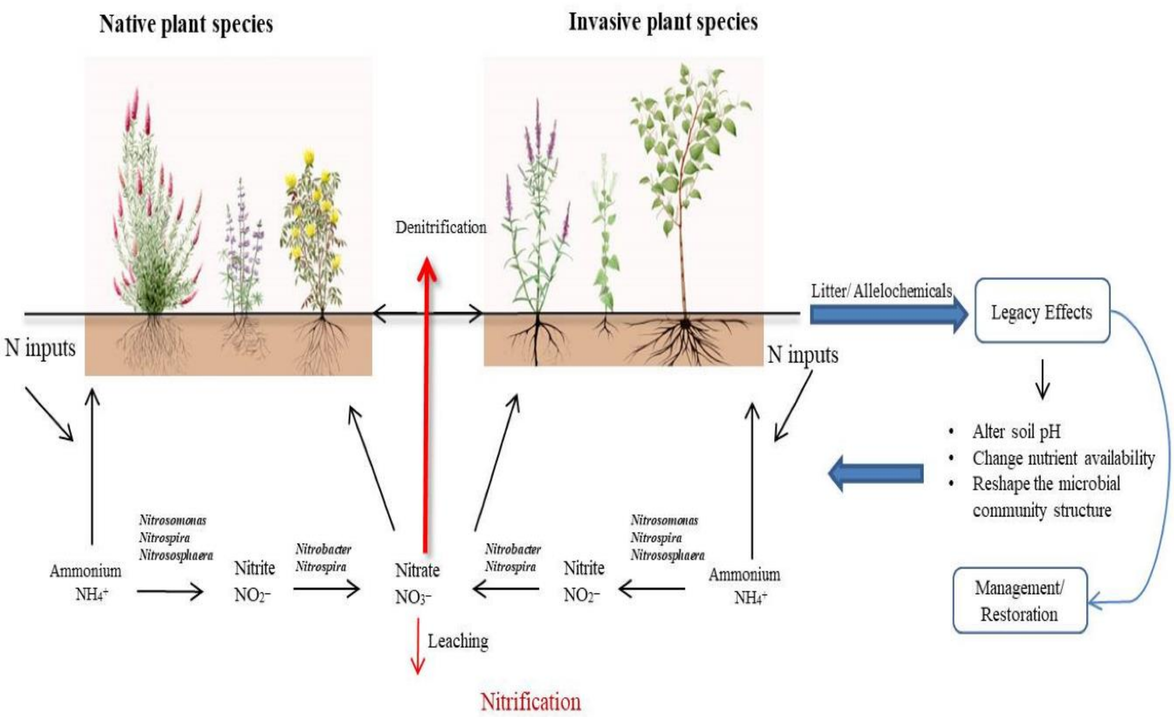

Figure 6: Role of Herbaceous Ornamental Plants in Plant Invasion [18]

Introduction of herbaceous ornamental plants in urban areas is mainly motivated by economic and aesthetic considerations, while their ecological effects are neglected. These plants are once established able to spread aggressively, outcompete native vegetation, change soil chemistry, and disrupt trophic interactions [66]. They are particularly invasive in disturbed environments, where they exploit native species which have vacated ecological niches [67].

Introduction to Herbaceous Ornamental Plants

Herbaceous ornamental plants are grown to their maximum extent on account of their decorative value, ease of maintenance and adaptability to diverse environmental conditions. Because of their ability to grow in a wide variety of climatic and soil conditions, these plants are commonly used in urban landscaping projects (parks, gardens, roadside greenways) [68]. But their invasive potential is frequently underestimated at the selection stage.

Despite the many characteristics that make them ornamental, many herbaceous ornamental plants have characteristics that contribute to their invasiveness, such as rapid growth, high reproductive capacity and adaptability to urban stressors [69]. The ability to quickly become established in new habitats while relegating native species, is a trait of these genetically modern humans [70]. Ornamental plants once introduced such as Lantana camara and Tradescantia fluminensis have been shown to spread out of managed landscapes into adjacent natural habitats, and displace native flora [71]. A comparative analysis of the invasive potential of commonly cultivated herbaceous ornamental plants and native plants is presented in table 4.

Table 4: Comparison of Invasive Traits between Herbaceous Ornamental Plants and Native Plants

Studies	Trait	Herbaceous Ornamental Plants	Native Plants
[66]	Growth Rate	Rapid; biomass increases by 25–35% in 3 months	Moderate; biomass increases by 10–15% in 3 months
[67]	Reproductive Capacity	High; up to 10,000 seeds annually	Low; typically 1,000–3,000 seeds annually
[68]	Urban Stress Tolerance	Thrives in polluted, compacted soils	Limited ability to tolerate urban stressors
[69]	Dispersal Mechanism	Wind, water, and animal-mediated; rapid colonization	Primarily animal-mediated; slower spread
[70]	Competitive Advantage	Strong; allelopathic properties hinder native plants	Weak; no significant allelopathic traits

Table 4 shows that herbaceous ornamental plants possess superior growth rate, reproductive capacity, and stress tolerance compared to native species. Uniquely, they derive these advantages, which allow them to set up and dominate urban ecosystems, often with disastrous ecological consequences [72]. However, the unchecked proliferation of these plants emphasizes the importance of retention ecological considerations in design principles for buildings and development of effective management strategies for their potential invasiveness [37].

Mechanisms of Invasion

The invasion and colonization of herbaceous ornamental plants is facilitated by a suite of biological and ecological traits. These traits have let them colonize new environments, proliferate and persist in new environments at the expense of native biodiversity [73]. The most important mechanisms of their invasiveness are reproductive strategies, stress tolerance and allelopathy.

Reproductive Strategies: Herbaceous ornamental plants have shown prolific reproduction through sexually and asexually. Production of large numbers of seeds (10,000 to 12,000 seeds / plant per year) is a part of the process of sexual reproduction. Normally these seeds are small, light and could be blown, washed or eaten by animals. Vegetative spread in dense colonies relatively quickly has been evolved in these plants through asexual reproduction by rhizomes, stolons or bulbils. A dual reproductive strategy maintains rapid colonization of disturbed habitats and range expansion in ornamental plants [73]–[75].

Stress Tolerance: Typically, urban environments are characterized with a variety of difficult conditions including pollution, soil compaction and variable moisture levels. Remarkable stress tolerance has evolved in herbage ornamental plants, which allow them to survive in such adverse conditions. These plants have been studied to show that they can continue to photosynthesize and grow under high pollution levels and compacted soils, while native species rarely achieve vigor or establish. This adaptability provides ornamental plants with a major competitive advantage in urban landscapes [74]–[76].

Allelopathy: Many herbaceous ornamentals release allelopathic chemicals and inhibit the germination and growth of nearby plants. The exuded through roots, leaves and decaying litter alter soil chemistry and microbial communities in ways unfavorable to native plants, creating the area not suited to supporting native plant growth. For example, germination of native seeds is strongly suppressed by phenolic compounds released by *Parthenium hysterophorus*. Reducing competition is not the only function of allelopathy; it changes the ecological balance of invaded habitats [76]–[78].

Other Invasive Traits: But there are other mechanisms through which herbaceous ornamental plants can adjust to fluctuating light, temperature, and moisture conditions, and these plants often show a lot of phenotypic plasticity. In addition, they also use disturbed habitats efficiently and exploit them with rapid colonization efficiency in order to outcompete native vegetation [77]–[79]. A detailed comparison of these traits between herbaceous ornamental and native plants is given in Table 5.

Table 5: Comparison of Invasive Mechanisms between Herbaceous Ornamental Plants and Native Plants

Study	Mechanism	Herbaceous Ornamental Plants	Native Plants
[72]	Reproductive Strategies	High seed output (10,000–12,000 seeds annually); asexual reproduction through rhizomes and stolons	Low seed output (1,000–2,500 seeds annually); limited vegetative spread
[73]	Stress Tolerance	Thrives under pollution, soil compaction, and moisture fluctuations	Limited tolerance to urban conditions
[74]	Allelopathy	Releases phenolic and other inhibitory compounds; alters soil chemistry	No significant allelopathic effects
[75]	Phenotypic Plasticity	Highly adaptable to varying light, moisture, and temperature	Moderate adaptability; constrained by ecological conditions
[76]	Colonization Potential	Rapid colonization of disturbed habitats; dense monocultures	Gradual colonization; limited to stable environments

Combining the traits that make herbaceous ornamental plants highly effective invaders (Table 5) as shown. Their strategies of rapid establishment, stress tolerance of adverse conditions and allelopathy to suppress native species ensure formation of successful assemblages, both temporally and spatially. Together these mechanisms allow these plants to dominate urban ecosystems, and therefore necessitate proactive management and ecological monitoring to mitigate their impacts.

Case Studies of Invasive Ornamental Plants

Herbaceous ornamental plants have become important drivers of ecological change in many ecosystems throughout the world. The introduction of many of these species, usually aimed at beautification or convenience, has resulted in unintended consequences: many have become unwanted, aggressive invaders [80]. This subsection presents the invasion mechanisms and ecological impacts of three detailed case studies of Lantana camara, Tradescantia fluminensis and Parthenium hysterophorus [81]. These examples emphasize the need for evidence-based management practice and policy intervention to counter the risks of invasive ornamental plants [82].

Case Study 1: Lantana camara in Subtropical Forests of India

Lantana camara is one of the most notorious invasive ornamental plants in the world and featured in the IUCN list of the 100 worst invasive species. L. camara, which was initially brought to India for its colorful flowers and for its potential to help prevent soil erosion, has become a weed in subtropical and tropical regions. It covers more than 13 million hectares of forest land in India, forming dense impenetrable thickets that disrupt native ecosystems [83]–[85].

This species exhibits a combination of traits that contribute to its invasiveness: They have high reproductive capacity (up to 12,000 seeds per plant annually) rapid vegetative growth, and allelopathy. L. camara allelochemicals have been shown to suppress the germination and growth of native understory plants. It also has dense canopy structure, which reduces the amount of light available to native species added to that, it doesn't help their growth [86]–[88]. This plant has invaded to the extent that native species diversity in these areas has been reduced 50–70%, altering ecosystem functions and availability of habitat for wildlife [89].

Case Study 2: Tradescantia fluminensis in New Zealand Urban Parks

Wandering Jew (Tradescantia fluminensis) is an introduced, fast growing herbaceous plant that has been planted as a ground cover in urban parks and gardens [90]. It is tolerant of low light conditions, can thrive in compacted soils, and spreads vegetatively through stem fragments, making it a dominant invader in many urban and semi natural areas. Dense mats of this species smother native plants and prevent seedling recruitment and regeneration [91].

Research into T. fluminensis in urban parks across New Zealand reveals that native ground cover can be reduced by as much as 70%, and this has serious consequences for overall biodiversity [92], [93]. In addition, T. fluminensis is competitive and alters soil properties by increasing soil moisture retention and decreasing organic matter decomposition rates. This planting leads to changes in soil dynamics that are unfavorable for native species and thus compounds the successes of invasive plant. Mechanical removal and chemical control have been used to manage T. fluminensis but its ability to regrow rapidly continues to pose challenges [94]–[96].

Case Study 3: Parthenium hysterophorus in East African Grasslands

Parthenium hysterophorus was originally introduced as an ornamental plant, but it has become a widespread invasive species in East Africa, notably in Ethiopia, Kenya and Uganda. We describe this plant as having a high reproductive output (up to 15,000 seeds per plant per year) and as a species that tolerates disturbed habitats (roadsides, overgrazed grasslands, and agricultural fields). It is also very allelopathic releasing phenolic compounds that inhibit germination and growth of native plants [97]–[99]. Ecologically P. hysterophorus has severe impacts, with native plant cover reduced by up to 90%. In addition to being dangerous to humans and livestock, this species is also a public health concern. Its allergenic pollen causes problems for the lungs, and its toxic foliage is dangerous for grazing animals [100]. Estimates of the economic costs of managing P. hysterophorus and its impacts on agriculture are in the millions of dollars per year, suggesting far reaching effects of this invasive ornamental plant.

Table 6: Comparative Analysis of Invasive Ornamental Plant Case Studies

Study	Plant Species	Region and Habitat	Invasive Traits	Ecological Impacts
[77]	Lantana camara	Subtropical forests, India	High seed output (12,000 seeds annually), rapid growth, allelopathy	Reduces native flora diversity by 50–70%, disrupts habitat availability
[78]	Tradescantia fluminensis	Urban parks, New Zealand	Vegetative reproduction, tolerance to shade and soil compaction	Reduces native ground cover by up to 70%, alters soil dynamics
[79]	Parthenium hysterophorus	Grasslands, East Africa	High seed production (15,000 seeds annually), allelopathy, rapid colonization	Reduces native plant cover by up to 90%, causes health risks to humans and livestock

The selected ornamental plants were highlighted in Table 6 for their invasive traits and ecological impacts. These case studies show the different ways ornamental plants can get in the way of the native ecosystem by changing soil properties or out competing native species or by posing health and economic threats. Taken together, they call for proactive management strategy, specific to the particular challenge imposed by each invasive species.

Impacts of Herbaceous Ornamental Plants on Plant Composition and Biodiversity

Herbaceous ornamental plants profoundly and multifaciously affect plant composition and biodiversity in natural and urban ecosystems. While they are implemented for aesthetic and functional reasons, an often detrimental ecological result results from these invasive tendencies. They are competitive with native plants based in part on their aggressive growth rates, outstanding reproductive capabilities and the ability to use disturbed environments to their maximum advantage [101]. The result is that they change plant community structures, lower species richness, and alter ecosystem functions. The Impacts of Herbaceous Ornamental Plants on Plant Composition and Biodiversity are shown in Figure 7.

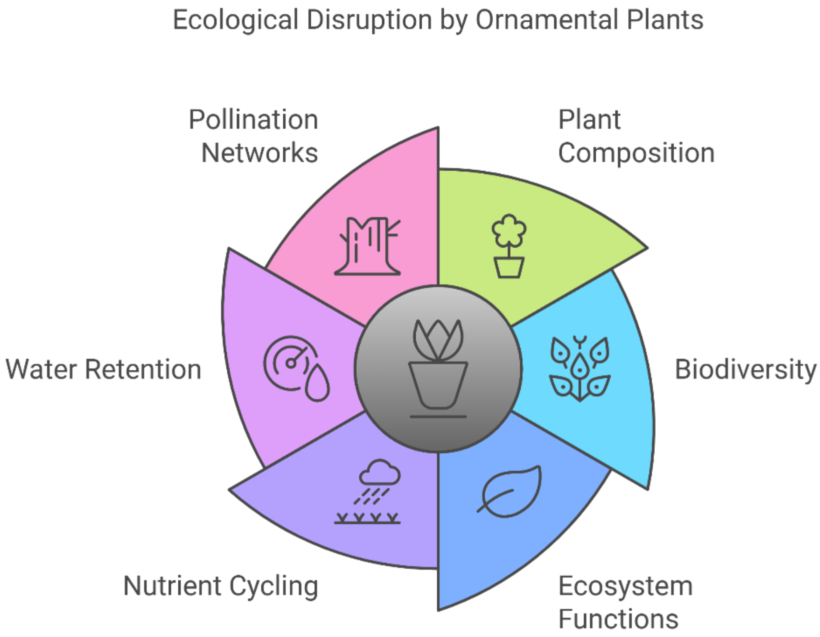

Figure 7: Impacts of Herbaceous Ornamental Plants on Plant Composition and Biodiversity [25]

Often there is dominance of invasive ornamental plants that result in monocultures replacing diverse native plant communities with homogeneous vegetation. As a result, this shift has cascading effects on ecosystem processes from nutrient cycling to water retention and pollination networks. Also, loss of native plant diversity is associated with reduction in dependent faunal communities (pollinators, herbivores, and soil microorganisms), creating a major weakness in ecosystem integrity [102]. In the following subsections, the specific ways in which herbaceous ornamental plants can alternative plant communities and ecosystem functions are explored [103].

Alteration of Native Plant Communities

Ornamental plants invasions frequently displace native vegetation, resulting in fundamentally changed plant communities. The namesake for this research implies that the plants are inherently more competitive and exhibit rapid growth, prolific seed production and high tolerance for urban stressors such as pollution and soil compaction [104]. The existence of this competitive advantage gives them the power to take landscapes for themselves and deny the native plants the resources needed to survive: sunlight, water, and nutrients [105].

Monocultures of invasive ornamental plants homogenize plant communities. Homogenization of this reduces unique characteristics of native ecosystems and local biodiversity is eroded. Replacing native plants with several generalist invasive species that have lost functional diversity [106]. Pollination services also decline in areas where native plants are being outcompeted by foreign plants because many pollinators are adapted to specialized native flora [107].

Regeneration of native species is also affected by invasive ornamentals, in addition to structural and functional change to plant communities. By example, an invasive plant could form a dense canopy or ground cover that will prevent light from penetrating to allow native seeds to grow, or change soil moisture levels. Over time these changes can continue to decline native vegetation to the point where invasive species are further reinforced in dominating the vegetation [108].

Wild plant communities that are impacted by invasive ornamental plants are often left irreversibly altered unless intervention is active. Mechanical removal, ecological restoration and reestablishment of native plants are important management strategies that will reduce these effects and help restore biodiversity [109]. The high adaptability and resilience of invasive ornamentals, however, makes such efforts difficult and resource intensive.

Table 7: Comparison of Impacts on Native Plant Communities Due to Invasive Herbaceous Ornamental Plants

Studies	Aspect	Resource Competition	Homogenization of Communities	Effects on Seed Germination	Functional Diversity Impact
[80]	Displacement of Native Plants	Outcompetes natives for sunlight, water, and nutrients	Dense monocultures replace diverse native flora	Dense invasive cover inhibits native seed germination	Loss of niche-specific plants, decline in specialist species
[81]	Soil Resource Alteration	Changes soil composition and nutrient availability	Simplifies ecosystem structure	Alters soil pH and microbial communities, reducing seed viability	Reduces availability of resources for native-dependent species
[82]	Competition with Native Pollinators	Reduces access to floral resources for native pollinators	Dominance of invasive plants disrupts pollination networks	Limited native seed propagation due to pollinator preference for invasives	Decline in pollinator-dependent native species
[83]	Urban Stress Adaptability	High adaptability allows dominance in urban settings	Creates uniform landscapes unsuitable for natives	Alters light and water availability for germination	Reduced functional redundancy in plant communities
[84]	Long-Term Regeneration Suppression	Prevents recovery of native vegetation in disturbed areas	Maintains long-term dominance, suppressing native growth	Persistent canopy or ground cover prevents seedling establishment	Decline in ecosystem resilience and adaptability

Results from Table 7 show that invasive herbaceous ornamental plants reduce native plant communities by affecting multiple aspects, including resource competition, community homogenization, seed germination and functional diversity. Basic incompatibility for these plants with natural vegetation, including for essential resources, makes them be dominant, forming dense monocultures, and interfere against natural regeneration leading to great biodiversity deficiency and natural balance distortion.

Effects on Ecosystem Services

Invasive Herbaceous Ornamental Plants Majorly Disrupt Crucial Ecosystem Services Essential to Keeping Both Natural and Urban Ecosystems Stable and Sustainable. Failure to consider these plant-service gradients can result in dominance of one plant species over native ones, which are often replaced by plants taken from a far distance, altering ecological processes, and bringing out additional cascading effects on biodiversity and ecosystem functionality [85]. The specific ways in which invasive ornamentals affect pollination, water retention and nutrient cycling are explored in this subsection, along with broader implications for ecosystem services [86].

Pollination: Invasive ornamental species displace native flowering plants, reducing resources availability for native pollinator species, such as bees, butterflies and birds. Specialized relationships with local pollinators typically exist between native plants and nectar and pollen provision at specified times. If these plants are out competed by invasives, pollinators will have resource shortages and population may decline [87]. More importantly, invasive plants tend to attract generalist pollinators, adding another layer of pollinator effects to reduce those already being experienced by native species and also disrupting their reproductive success. These disruptions over time can cascade in the ecosystem to herbivores and predators dependent on native plant pollinator networks [88].

Water Retention: Invasive ornamental plant root systems can be vastly different than native species root systems resulting in altered soil stability and water retention. For example, deep rooted, expansive native plants help hold soil structure and keep soil in place, soaking up water, preventing runoff and trapping soil and eroding materials in place. On the other hand, an overwhelming majority of invasive ornamentals have shallow or fibrous roots, losing soil anchorage [89]. When this occurs the soil erodes easier and the runoff moves quicker, decreasing the total water holding capacity of the soil. Such changes are particularly problematic in urban areas where storm water management is a critical means of preventing flooding and ensuring water quality [90].

Nutrient Cycling: In addition, invasive ornamental plants change soil composition and microbial communities and thereby affect nutrient cycling. Symbiotic relationships with soil microbes — like nitrogen fixing bacteria and mycorrhizal fungi — are often present in native plants, and help make nutrients available as well as increase soil health. These relationships are disrupted when there are high levels of invasive plants. Many invasives emit allelopathic chemicals that suppress the nutrition cycling of native communities. Furthermore, invasive species tend to concentrate or exhaust particular soil nutrients, leading to unhealthy collections which inhibit the growth of native vegetation [91]. These disruptions gradually worsen food production for native plants and over time they will often diminish soil fertility, making it more difficult for native plants to reestablish [92].

However, changes in one area can result in dramatic amplification in the effects elsewhere. This includes increased nutrient runoff related to reduce water retention and soil stability, along with declines in pollinator populations that exacerbate the terminal regeneration of native plant populations. Taken together, these disruptions emphasize the ecological price paid for invasive ornamental plants and demonstrate the value that preserving their spread has in conserving ecosystem functionality and resilience [93].

Table 8: Comparative Analysis of Ecosystem Service Impacts by Native and Invasive Herbaceous Plants

Study	Ecosystem Service	Native Plant Contribution	Impact of Invasive Ornamental Plants	Ecological Consequences
[85]	Pollination	Provide consistent nectar and pollen resources for specialist and generalist pollinators	Attract generalist pollinators, reducing visitation to native plants	Decline in native pollinator populations, disruption of plant-pollinator networks
[86]	Water Retention	Deep root systems stabilize soil and enhance water infiltration	Shallow roots increase runoff and reduce soil water-holding capacity	Increased soil erosion, higher flood risks in urban areas
[87]	Nutrient Cycling	Symbiotic relationships with soil microbes improve nutrient availability	Disrupt soil microbial communities, deplete or accumulate certain nutrients	Imbalanced soil fertility, reduced native plant regrowth
[87]	Soil Stability	Extensive roots prevent erosion and maintain soil structure	Weak or fibrous roots destabilize soil and increase erosion risk	Loss of topsoil, reduced habitat quality for soil organisms
[88]	Habitat Provision	Create diverse microhabitats for fauna and microorganisms	Form dense monocultures, reducing habitat complexity	Decline in biodiversity, loss of ecosystem resilience

Table 8 shows that invasive ornamental plants contribute less in the way of critical ecosystem services than native plants. This column of studies supports these findings with empirical research and emphasizes the importance of targeted management to mitigate ecological damage and to preserve ecosystem stability.

Implications for Faunal Diversity

The spread of invasive herbaceous ornamental plants has profound implications for faunal diversity as changes in plant composition occur. Native plant species are quite intimately linked in their faunal communities: food, shelter, and breeding ground. In response to the loss of the latter, these dependent faunal species suffer substantial resource shortages and habitat alterations resulting in cascading ecological impacts [45].

Impacts on Insect Populations: In many cases, the insect species that native plants have coevolved relationships with are also pollinators—bees, butterflies, and beetles, for instance. Native flowers specialize in providing specific nectar and pollen resources at the life cycle times of local pollinators. Invasive ornamentals set upon these coevolved interactions by replacing native flora with generalist species that may not supply suitable resources [48]. Specifically, invasive plants may produce nectar that is chemically incongruous with the native pollinators, or bloom at a time that falls out of phase with their pollinator activity cycles. The negative results of this disruption result in reduced abundance and diversity of pollinators and spillover effects on plant – pollinator networks and ecosystem stability [52].

Effects on Bird Communities: Changes in plant composition also affect another faunal group — birds. Native plants provide many birds with fruits, seeds, and insects they depend on in native vegetation. Fruits of these invasive ornamental plants may be unpalatable or their structure unsuitable for nesting, and they often also fail to provide equivalent resources [54]. For instance, a switch from native to thickets of invasive plants can mean fewer ground nesting birds. Furthermore, population declines are favored by invasive dominance lowering insect populations, which in turn decreases food availability for insectivorous birds [55].

Alterations in Mammalian Habitats: Studies of invasive plant dominance can also be done with mammals, large and small, which also experience habitat loss and resource scarcity. Frequently, invasive ornamentals are toxic or of poor nutritional value, so herbivorous mammals that feed on native plants are unable to consume the invasive ornamentals. For example, there could be invasive plants with allelopathic properties that keeps invaded herbivory, so that native herbivores have no food to eat [76]. Conversely, the indirect effects of declines in the prey population (e.g., insects and small mammals) on carnivorous mammals are also observed. Because native vegetation is lost and invasive species are introduced in urban settings, mammalian habitats become further fragmented, increasing competition for resources, and reducing population stability [77].

Impact on Soil Fauna and Microbial Communities: Even changes in plant composition extend below ground, affecting soil fauna and diversity of microbes. The soil organism symbiotic relationships with native plants (both plant roots, and nematodes, earthworms mycorrhizal fungi &c) provide benefits to soil health and nutrient cycling. However, invasive plants can modify soil properties by the release of allelopathic chemicals, or by altering root structure. These changes destroy existing soil communities, decreasing the abundance of and diversity within beneficial organisms and increasing those species that thrive in degraded soils [78]-[80].

Cascading Ecological Impacts: Cascading effects of displacement of native plants and accompanying faunal declines roll through the food web. The loss of reduced pollination services further limits the reproduction of native plants, which are already declining. Insectivorous birds decline with a decline in insect populations, which has consequences for predator species. Just as community structures respond to habitat changes by shifting the balance of ecosystems towards the dominance of a few generalist species and overall biodiversity and ecosystem resilience reduced.

Mitigation and Conservation Strategies: Management and conservation of faunal diversity is required in stopping the impacts of invasive ornamental plants. Key strategies include:

- **Restoration of Native Vegetation:** Restoring habitats for dependent faunal species and building up disrupted ecological networks can be achieved by reintroduction of native plants.

- **Invasive Plant Monitoring and Removal:** Invasive ornamentals can be removed early if they are not spread and the long term impacts on faunal communities can be avoided.
- **Community Engagement:** Telling the public about and working with local communities to use native plants in urban landscaping may be an education.
- **Policy Interventions:** Sale and distribution regulations for invasive ornamentals can help to reduce introduction into vulnerable ecosystems.

Table 9: Comparative Impacts of Invasive Herbaceous Ornamental Plants on Faunal Diversity

Studies	Faunal Group	Native Plant Contribution	Impact of Invasive Ornamental Plants	Ecological Consequences
[95]	Insects	Provide specialized nectar and pollen resources, support pollination networks	Generalist pollinators attracted, specialist pollinators decline	Disrupted plant-pollinator networks, reduced pollinator populations
[96]	Birds	Supply fruits, seeds, and insects for food; provide nesting habitats	Invasive plants offer fewer resources and unsuitable nesting structures	Decline in bird diversity, especially insectivorous and ground-nesting species
[97]	Mammals	Herbivores consume native plants; diverse vegetation supports prey for carnivores	Invasive plants often toxic or unpalatable; reduced prey availability	Resource scarcity, increased competition, and habitat fragmentation
[98]	Soil Fauna and Microbes	Symbiotic relationships with roots enhance soil health and nutrient cycling	Altered soil chemistry and root structures disrupt soil communities	Decline in soil biodiversity, reduced nutrient cycling efficiency
[99]	Overall Ecosystem	Diverse native vegetation sustains complex trophic interactions and high biodiversity	Homogenization of vegetation disrupts trophic levels and ecosystem balance	Loss of biodiversity, reduced ecosystem resilience and functionality

In table 9 impacts of invasive herbaceous ornamental plants on faunal diversity were compared. It focuses on how native plants support insects, birds, mammals, and soil organisms, and how invasive species are doing damage. Cascading effects of invasive plants are expressed in terms of ecological consequences, including species loss, disruption of trophic interactions, and reduction in ecosystem resilience for species assemblages and for entire ecosystems. In summary, invasive ornamental herbaceous plants have wide ranging consequences for faunal diversity. These plants disrupt complex ecological interactions by displacing native vegetation and cause declines of insect, bird and mammal populations and changes in soil fauna and microbial communities. The mitigation of these impacts and conserving biodiversity requires proactive and restoration management.

Climate Driven Changes in Alpine Heaths and Impacts on Invasion Dynamics

Climate change is impacting upon alpine heath ecosystems in unprecedented ways. These ecosystems comprise a unique flora, sparse vegetation and are highly sensitive to changes in temperature, precipitation, and disturbance regimes [81]. Alpine heaths are disrupted by climate driven changes including rising temperatures, changes in precipitation pattern, and increasing disturbance events, which provide opportunities for invasive species to establish and flourish [82]. This section examines the sensitivity of alpine heaths to climate change and the dynamics of plant invasions that follow.

Sensitivity of Alpine Heaths to Climate Change

Alpine heath ecosystems are highly specialized environments found within narrow climatic thresholds. These ecosystems are adapted to cold temperatures, short growing seasons and nutrient poor soils; native species in them are adapted to these conditions. These finely balanced conditions are disrupted by climate change, forcing many species beyond their tolerance limit. Rising temperatures, precipitation variability, soil changes and increased disturbance events are the key climate driven changes that make alpine heaths particularly vulnerable [83].

Rising Temperatures: The warming of alpine regions is nearly twice the global average rate. Many alpine environments have already observed increases of 1.5 to 2.0°C per decade. They lengthen growing seasons and, up to 30%, shorten the time the snow stays on the ground. But native plants, which depend on having snow to insulate them from freezing, are losing their protective cover, while invasive species better adapted to warmer conditions are winning out [84].

Precipitation Variability: Rainfall is becoming more intense in some places and prolonged drought in others, as a result of climate change. These changes impose stress on moisture dependent alpine plants but favor drought tolerant invasive species. For example, native plant resilience in ecosystems is weakened by nutrient leaching during intense rain events and water scarcity during droughts, both of which increase the likelihood of invasion [85].

Soil Changes: Soil processes, including those related to freeze thaw cycles, microbial activity and nutrient availability, and are influenced by rising temperatures. Warmer soils help decompose stored carbon, but also destabilize soil structure. These changes tend to reward invasive plants, which can use disturbed soil conditions better that more native species.

Increased Disturbance Events: Climate change is causing more frequent and intense disturbances such as wildfires, storms and avalanches. Invasive species can rapidly spread under disturbed conditions, when competition is decreased and open niches are created. After such events, native alpine plants with slower growth rates and limited reproductive capacity are slow to recover.

Table 10: Comparative Sensitivity of Alpine Heath Ecosystems to Climate Change

Study	Climate Driver	Native Plant Response	Invasive Plant Advantage	Ecological Consequences
[43]	Rising Temperatures (1.5–2.0°C per decade)	Reduced snow cover disrupts insulation; shorter growing seasons limit reproduction	Extended growing seasons and faster growth rates	Decline in native plant populations; increased dominance of invasives
[44]	Precipitation Variability (10–20% increase in extremes)	Moisture-dependent plants stressed during droughts; nutrient leaching during heavy rainfall	Drought-tolerant invasives thrive; rapid colonization after extreme events	Erosion, habitat fragmentation, and reduced biodiversity
[76]	Soil Changes (2–4°C annual increase)	Disrupted microbial activity; destabilized root structures and nutrient cycling	Exploits disturbed soil; faster nutrient uptake	Altered soil properties; competitive exclusion of native species
[77]	Increased Disturbance Events (wildfire frequency up 30%)	Slow recovery due to limited reproductive capacity and growth rates	Quick establishment in disturbed habitats	Loss of native species; invasive monocultures

The comparative impacts of climate change on alpine heath ecosystems are highlighted in Table 10. The native plants are at a disadvantage compared with rapidly changing climatic shifts. These changes provide an opportunity for invasive species to exploit them in their desire to dominate. The sensitivity highlighted here indicates that targeted conservation strategies are required to mitigate both the dual threats of climate change and biological invasions.

Synergies between Climate Change and Plant Invasion

Together, climate change and plant invasions are mutually reinforcing processes. The disproportionate benefits of climate variability to ornamental plants for their adaptability and aesthetic value. Not only does this synergy enhance the invasion potential of these plants but also sharpens the degradation pace of native ecosystems. Extended growing seasons, increased stress on native species, and enhanced dispersal mechanisms combine to make habitats that were resistant to colonization vulnerable to invasion by invasive plants [77].

Extended Growing Seasons: In temperate and alpine regions, climate warming is lengthening growing seasons. This gives these invasive ornamental plants a place that otherwise they would not be able to take because of their rapid growth and reproductive cycles and they take full advantage of long favorable conditions. For example, these plants harvest more seed and thereby more colonize in a year with a longer growing season. These conditions make it difficult for native plants, often adapted to shorter growing periods, to compete, and plant community composition shifts [78].

Increased Stress on Native Species: Native species are stressed in a range of ways by climate change, including higher temperatures, water scarcity and altered nutrient cycles. The increase in these stresses reduces the resilience and competitive ability of native plants and increases their vulnerability to displacement by spread of invasives [79]. In particular, native alpine plants are highly specialized and cannot adapt fast to sudden changes in temperature or moisture availability. By contrast, these changing conditions enhance the survival of invasive ornamentals, with their high phenotypic plasticity and tolerance to environmental variability [80].

Enhanced Dispersal and Establishment: Dispersal and establishment of invasive plants in previously resistant habitats is facilitated by climate change. Increased temperatures and decreased length of the frost period, together increase the breadth of habitable zone for invasive species, extending their range upwards and latitudinally. Extreme weather events including storms and floods, common now, and increasing with climate change, are also sources of dispersal for invasive plant propagules. Once established, these plants also change local ecosystems to the point that native species have difficulty recovering or competing [81].

Interaction with Disturbance Regimes: Ornamental invasions are further amplified by climate driven disturbances, such as wildfires, storms and droughts. Disturbances resulting in these disturbances remove native vegetation and disturb soil structure, creating open niches. These disturbed areas quickly become the location of invasive plants, which are often fast colonizers. For example, regions prone to wildfire receive an influx of fire adapted invasive species that take advantage of the absence of competition and changed soils, amplifying a cycle of invasion and disturbance [82].

Feedback Loops between Invasion and Climate Change: Feedback loops that exacerbate climate impacts are created by invasive ornamental plants. Localized warming is for instance caused by invasive species which replace native vegetation with lower albedo (a measure of the reflective capacity, or ability to reflect and resist warming). In addition, they may spoil carbon storage processes by altering soil microbial communities or lowering biomass, which will drive climate change swiftly. These feedback mechanisms indicate the reciprocal relationship between plant invasions and climate change: one amplifies the other [83].

Implications for Management: Integrated strategies that address the synergy of plant invasion with climate change are needed. Key approaches include:

- **Predictive Modeling:** To identify high risk areas and prioritize intervention using climate and invasion models.
- **Restoration of Native Vegetation:** Restoring depleted coastal estuaries through the where and when of species introduction to improve ecosystem stability.
- **Policy Interventions:** Regulating the introduction and spread of high risk ornamental plants.
- **Community Engagement:** To raise awareness of ecological risks of invasive plants as well as to encourage native landscaping practices.

Climate change and plant invasion synergies represent a major threat to biodiversity and ecosystem stability. Climate change exacerbates ecological damage by creating conditions that favor invasive plants and thereby increase their establishment and spread. To mitigate these impacts requires a proactive, cross disciplinary approach aimed to mitigate both drivers of climate change and mechanisms of plant invasion.

Table 11: Synergies Between Climate Change and Plant Invasion: Drivers, Impacts, and Ecological Consequences

Study	Climate Driver	Impact on Invasive Plants	Ecological Consequences	Examples
[78]	Extended Growing Seasons	Increased seed production and multiple reproductive cycles	Displacement of native species; altered community structure	Lantana camara dominating subtropical regions
[79]	Increased Stress on Native Species	Reduced competition from stressed native plants	Decline in native biodiversity; reduced ecosystem resilience	Parthenium hysterophorus in drought-prone areas
[80]	Enhanced Dispersal and Establishment	Expansion into higher altitudes and latitudes	Colonization of previously resistant habitats	Tradescantia fluminensis spreading to alpine regions
[81]	Interaction with Disturbance Regimes	Rapid colonization of disturbed habitats	Formation of invasive monocultures; reduced habitat complexity	Cirsium arvense establishing after wildfires
[82]	Feedback Loops	Altered soil properties, reduced carbon storage	Accelerated climate impacts; disrupted nutrient cycling	Imperata cylindrica in degraded soils

For example, Table 11 summarized the synergies between climate change and plant invasion in a concise way. It shows how climate drivers like longer growing seasons and greater stress on native species are good for invasive plants. It also shows the cascading ecological consequences: biodiversity loss, altered nutrient cycles, formation of invasive dominated ecosystems.

Case Examples from Alpine Ecosystems

Alpine heathlands are being invaded by increasingly invasive ornamental plants that pose a threat to endemic species and alter fundamental ecosystem processes. These case examples demonstrate the mechanisms of invasion, the species involved, and the ecological consequences, and the importance of intervention [86].

Rhododendron ponticum in European Alpine Heathlands: Rhododendron ponticum has been introduced as an ornamental shrub and has spread widely in European alpine heathlands. It has a dense canopy sufficient to suppress some native ground flora by excluding sunlight and changing soil acidity by breakdown of leaf litter. This has resulted in a very steep decline in native heathland species, with fields of Calluna vulgaris and Erica tetralix now only minor locations in the landscape. In addition, R. ponticum supports fewer insect pollinators and hence less biodiversity in these ecosystems [87].

Lupinus polyphyllus in Scandinavian Alps: In Scandinavia, lupines have invaded alpine meadows, including Lupinus polyphyllus, the garden lupine. Introduced originally for ornamental purposes and soil stabilization, its nitrogen fixing capability changes nutrient cycles to favor its own growth and displace low nutrient tolerant native species such as Festuca ovina and Silene acaulis. Areas dominated by Lupinus polyphyllus reduce native plant diversity by 40% [88].

Hieracium aurantiacum in New Zealand's Southern Alps: Hieracium aurantiacum is an important invasive species in the Southern Alps of New Zealand. It has a reputation for an intense vegetative spread through stolons and forms dense mats that block native seed germination. However, it has out competed native alpine grasses and herbs, thereby reducing forage availability for endemic herbivores such as the alpine kea [89].

Acer pseudoplatanus in Swiss Alpine Regions: Acer pseudoplatanus, the sycamore maple, is now invading alpine zones in Switzerland, but has value as an ornamental and forestry species. It grows rapidly and produces copious seed, and it is capable of dominating areas previously occupied by native alpine shrubs such as Rhododendron ferrugineum. Changes in the resulting canopy cover affect light availability and microclimate conditions, which affects ground dwelling fauna and flora [90].

Impatiens glandulifera in UK Highlands: Impatiens glandulifera is commonly known as Himalayan balsam and has spread into upland heathlands of the UK. It is a formidable invader, in part, because it thrives in disturbed soils and has a highly reproductive rate. It displaces native species of Vaccinium myrtillus and Arctostaphylos uva-ursi, with reduced quality of habitat for pollinators and herbivores [91].

Pennisetum setaceum in North African Alpine Zones: Originally introduced as a landscaping plant, the fountain grass, Pennisetum setaceum, has invaded alpine ecosystems in North Africa. Because of its deep root system and drought tolerance, it has a competitive advantage over native grasses and herbs in arid alpine environments where it outcompetes the natives, resulting in soil erosion and changing fire regimes.

Taraxacum officinale in the Rocky Mountains, USA: Common dandelion, Taraxacum officinale, may be overlooked but has invaded subalpine meadows in the Rocky Mountains. It is able to reproduce asexually and to live in a wide variety of conditions, making it a fast spreader of native wildflowers like Aquilegia coerulea, the state flower of Colorado.

Berberis thunbergii in Japanese Alpine Meadows: The Japanese barberry has been intentionally introduced as a decorative plant, and is now spreading and invading alpine meadows in Japan. Due to its spiny structure, which discourages herbivory, it has an advantage over native alpine shrubs. It has spread reducing biodiversity and disturbing soil microbial communities important for the growth of native plants.

Table 12: Case Examples of Invasive Ornamental Plants in Alpine Ecosystems

Study	Invasive Plant	Region	Impact on Native Flora	Key Mechanism of Spread
[47]	Rhododendron ponticum	European Alps	Suppresses native ground flora; reduces biodiversity	Dense canopy and soil acidification
[52]	Lupinus polyphyllus	Scandinavian Alps	Displaces low-nutrient-tolerant species	Nitrogen fixation and competitive growth
[58]	Hieracium aurantiacum	Southern Alps, New Zealand	Outcompetes native grasses and herbs	Stolons and dense mat formation
[75]	Acer pseudoplatanus	Swiss Alpine Regions	Alters microclimate; impacts native shrubs	Prolific seed production and rapid growth
[76]	Impatiens glandulifera	UK Highlands	Displaces native upland heath species	High reproductive rate and soil adaptability
[77]	Pennisetum setaceum	North African Alpine Zones	Outcompetes native grasses; increases soil erosion	Drought tolerance and deep root system
[78]	Taraxacum officinale	Rocky Mountains, USA	Reduces diversity of native wildflowers	Asexual reproduction and environmental tolerance
[79]	Berberis thunbergii	Japanese Alpine Meadows	Displaces native shrubs; disrupts soil microbiome	Herbivory resistance and competitive growth

Key case studies of invasive ornamental plants were summarized in Table 12, which listed the plant, its region of origin, impacts to native flora and mechanism of spread. These examples illustrate the wide range of strategies by which invasive species have become dominant in alpine heath ecosystems, and thus emphasize the necessity for targeted management and conservation.

Management Strategies for Reducing Plant Invasion Risk

Proactive and comprehensive management strategies for the increasing threat of plant invasion, especially from herbaceous ornamental plants, are needed. Intervention is most effective when it is initiated early and monitored constantly, and when a response is made quickly and restoration is done over a long period of time. The follow is a section on the key strategies to mitigate the risk of plant invasion using new and proven technology, community association with the same and the policy that can protect the vulnerable ecosystem [86].

Early Detection and Monitoring

Invasive species management is strongly dependent on early detection and monitoring. Targeted interventions in response to invasive plant identification before widespread distribution are more cost effective and ecologically sustainable. Through community engagement advanced techniques can make monitoring programs more accurate and efficient [85].

Remote Sensing and GIS Mapping: Remote sensing and Geographic Information System (GIS) are becoming increasingly powerful monitoring tools for invasive plant species. Vegetation patterns can be detected over large areas using satellite imagery, drone surveillance and aerial photography. The technologies allow researchers to map the spread of invasive species over time and determine where and how they are spreading [88]. Hyperspectral imaging can, for example, discriminate native from invasive plant species by their spectral signatures. Then GIS tools can integrate this data into predictive models to predict where future invasions are most likely to occur.

Citizen Science Initiatives: One of the best ways to expand monitoring efforts is to involve local communities interested in citizen science. Mobile applications and online platforms are used by community members, including hikers, farmers and recreational park visitors to report invasive plant sightings [89]. Here, we show how programs such as iNaturalist and the Global Biodiversity Information Facility (GBIF) have enlisted citizen scientists to provide valuable data on invasive species distribution. This dynamic brings about not only the better collection of the data but also public awareness of the ecological consequences of invasive plants [90].

Periodic Ecological Surveys: To monitor the progress of invasive species, and assess their impacts on native ecosystems, regular ecological surveys by trained professionals are particularly important. On the ground surveys collect plant populations, habitat conditions and ecological changes. In addition, these surveys can identify new invasive species introductions, and can serve as a baseline for evaluating the effectiveness of management interventions [91].

Integration of Techniques: When combined, these approaches improve the robustness of monitoring programs. For example, remote sensing can generate data at the broad scale, but ecological surveys can validate what is found at the ground level. The missing link are citizen science efforts that provide real time observations from many different locations to build a comprehensive monitoring framework [110].

Challenges and Opportunities: However, early detection and monitoring are fraught with limited funding, technological barriers, and data integration barriers. But partnerships can be formed between government agencies, research institutions and community organizations to overcome these hurdles. Many of the gains also come through advancements in machine learning and artificial intelligence, including better accuracy in invasive species identification and predictive modelling [92].

Foundations for managing plant invasions are effective early detection and monitoring strategies. Using technology, engaging in community involvement, and using systematic surveys stakeholders can identify and address invasive threats before they grow, thus reducing the ecological and economic impacts [93].

Table 13: Comparison of Monitoring Techniques for Early Detection of Invasive Plants

Study	Monitoring Technique	Advantages	Limitations	Examples of Application

[89]	Remote Sensing	Covers large areas; detects patterns over time; high accuracy	Expensive equipment; requires technical expertise	Hyperspectral imaging to track invasive spread
[90]	GIS Mapping	Integrates spatial data; predicts high-risk areas	Relies on quality input data; requires validation	Predictive models for invasive hotspots
[91]	Citizen Science	Expands geographic reach; engages communities	Inconsistent data quality; limited expertise of participants	iNaturalist platform for invasive plant sightings
[92]	Periodic Ecological Surveys	Ground-truths remote sensing data; detailed local insights	Resource-intensive; limited to smaller areas	On-site assessments of invasive plant populations
[93]	Integrated Approaches	Combines multiple data sources for robust monitoring	High coordination requirements; costly implementation	Integration of remote sensing with on-ground surveys

Various methods for early detection of invasive plants were summarized in Table 13. Different techniques have their own advantages: remote sensing for the broad scale, citizen science for the community. Nevertheless, comprehensive monitoring requires integrated approaches given limitations of costs, data quality and resource requirements [94].

Control and Mitigation

Controlling and mitigating invasive plant species is crucial if we are to prevent their ecological impacts and effective strategies for doing do are needed. The focus of these strategies is to eliminate or reduce populations of invasives and to stop dissemination, as well as to restore native ecosystems [95]. The optimal outcome requires a combination of mechanical, chemical and biological approaches that vary, depending on the context of the invasion.

Mechanical Removal: Mechanical removal is the physical removal of invasive plants (and roots) to prevent subsequent regrowth. This is a very effective method for localized infestations, and is used where chemical or biological methods are not possible, for example, where water bodies are nearby or in sensitive habitats [96]. Techniques include:

- **Manual Removal:** Manual removal is labor intensive but precise and is effective for small infestations or high ecological value areas.
- **Machine Assisted Clearing:** Heavy machinery like an excavator or mowers can quickly clear large scale invasions of vegetation but does this without disturbing soil and native plants.

Mechanical removal works well short term, but requires follow up treatments to prevent regrowth from remaining roots or seeds.

Chemical Control: Herbicides are used to control invasive plants selectively, with chemical control. This method is especially useful for managing widespread infestations which cannot be managed by mechanical means [96]. Common chemical control strategies include:

Spot Application: Herbicides are applied to individual plants so that they do not damage native species.

Broad-Spectrum Spraying: This method, which uses herbicides to spray a wide area, is used for large infestations, but could affect non target plants and soil health.

Most herbicides for invasive species management include glyphosate and triclopyr. Yet the application of their use must be planned with care in order to minimize an environmental risk of contamination of water sources or deleterious effects on non-target organisms [97].

Biological Control: Biological control is the introduction into the environment of natural predators, pathogens or herbivores to control the population of certain plants. This is an environmentally sustainable, cost-effective long-term method especially for invasive species that have no native competitors or predators [98]. Examples of biological control agents include:

Insects: Those beetles or weevils that feed only on the target invasive plant.

Fungal Pathogens: These introduced pathogens reduce the competitive ability of invasive plants by infecting and weakening them.

Among species such as Parthenium hysterophorus and Lantana camara, biological control is successfully implemented. Yet rigorous testing is needed to make sure that control agents do not harm native flora or fauna.

Integrated Approaches: In most cases, the best results are obtained by combining mechanical, chemical, and biological control methods. Mechanical removal can be followed by spot herbicide application to treat residual plants, while biological agents can be introduced to control longer term regrowth. Adaptive management is facilitated by integrated approaches, which facilitate practitioners' ability to respond to changing conditions and invasion dynamics [99].

Challenges and Considerations: One challenge to control and mitigation strategies for invasive plants is resource constraints, non-target impacts, and resistance development. It also is hindered by public opposition to the use of chemical control or the release of biological agents. Addressing these challenges requires:

- Community support building based on stakeholder engagement.
- The development of safer herbicides, and targeted biological agents.
- Monitoring and evaluation to assess effectives of control measures and ecological impact.

Control and mitigation strategies are vital tool for managing invasive plant species, but they are only as good as the careful planning, execution and integration. The methods are tailored to the particular characteristics of the invasion and the surrounding environment, increasing the effectiveness and sustainability of outcomes for stakeholders.

Table 14: Comparison of Control and Mitigation Methods for Managing Invasive Plants

Study	Control Method	Effectiveness	Scalability	Environmental Impact	Examples
[105]	Mechanical Removal	Highly effective for small-scale, localized infestations	Limited to small or medium areas	Low if done carefully; can disturb soil	Manual removal of Rhododendron ponticum
[106]	Chemical Control	Effective for large infestations when used selectively	Suitable for large-scale operations	Moderate to high; risks of non-target effects	Spot application of herbicides for Lantana camara
[107]	Biological Control	Long-term solution; works well with specific targets	Scalable for widespread infestations	Minimal when agents are species-specific	Introduction of beetles for Parthenium hysterophorus
[108]	Integrated Approaches	Most effective when combining methods	Scalable across all infestation levels	Varies based on methods used	Manual removal followed by herbicide application

The main methods for controlling invasive plants are summarized in Table 14, comparing their effectiveness, scalability, environmental impacts, and example of application. Often the most comprehensive and sustainable results are obtained by integrated approaches combining mechanical, chemical, and biological methods, especially for complex or large-scale invasions.

Research Gap and Future Directions

Despite significant progress in deciphering the herbaceous ornamental plants' role in plant invasions and their interactions with climate change, there is still a gap in the current literature. Such gaps need to be addressed in order to develop effective management strategies and to protect the biodiversity of subtropical urban parks and alpine heath ecosystems. Existing research gaps are highlighted and future research direction is suggested in this section.

Research Gaps

1. Limited Understanding of Long-Term Impacts: In most studies, immediate ecological impacts of invasive ornamental plants are studied. Yet, their dominance has had little long term consequences studied: changes in ecosystem resilience, nutrient cycling, and functional diversity. More must be done to explore the interplay between invasive plants and ecosystem processes over decades.

2. Lack of Comprehensive Monitoring Frameworks: Although remote sensing or citizen science monitoring have been explored individually, yet integrated frameworks are needed to monitor using these multiple techniques holistically. The lack of standard protocols makes monitoring efforts unscalable and unreplicable.

3. Inadequate Focus on Synergies with Climate Change: The combined effect of climate change and plant invasions has received little attention. More attention is needed to synergistic interactions such as how climate driven shifts in phenology impact the invasion dynamics of ornamental plants.

4. Underrepresentation of Socioeconomic Factors: Most studies do not include drivers of socioeconomic nature, including urbanization patterns, horticultural practices or public awareness, in their modelling of invasion risks. Human dimensions need to be understood for effective intervention design.

5. Limited Application of Predictive Modeling: Few such predictive models exist that include climate projections, land use changes, and species-specific traits. Such models are needed to predict future invasion scenarios and to identify areas of priority for management.

Future Directions

1. Long-Term Ecological Studies: Valuable insights into temporal dynamics of invasions can be gained by establishing long term observational studies or experimental plots in subtropical urban parks and alpine heaths. Ecosystem processes under invasive dominance, including nutrient cycling and carbon storage, should be the focus of these studies.

2. Development of Integrated Monitoring Frameworks: It is future research that should work to further development of integrated monitoring systems that combine remote sensing, citizen science and ecological surveys. However, these frameworks can contribute to early detection capabilities and provide full data for management decision making.

3. Investigation of Climate-Invasion Synergies: Quantification of the combined effects of climate change and plant invasions on biodiversity and ecosystem functions requires further studies. These interactions can be clarified using experimental setups that simulate climate change scenarios (e.g. warming chambers, precipitation manipulations).

4. Socioeconomic and Policy Research: One aspect of interdisciplinary research should focus on how socioeconomic factors influence invasion risk. Current policies regulating ornamental plant trade could be studied for their effectiveness and community engagement integrated into management strategies could be assessed.

5. Application of Advanced Modeling Techniques: It can be done through the use of machine learning and artificial intelligence to develop predictive model that can indeed be acted upon by (policy) makers and land managers. Variable such as species traits, climate projections, and land use patterns should be included in these models to identify high risk areas and to prioritize interventions.

6. Focus on Restoration Ecology: Future work should also consider post-invasion recovery through studies of best practices for native vegetation and ecosystem service restoration. The successful restoration efforts will depend crucially on research on seed bank dynamics, soil rehabilitation and reintroduction of native species.

7. Global Comparative Studies: Case study comparisons across regions may exhibit universal patterns of plant invasion dynamics and context specific differences. By applying this approach, generalizability of findings may be improved and the global perspective on the issue is enhanced.

To bridge these research gaps, it requires a multidisciplinary approach that combines ecological, socioeconomic and technological perspective. Future research can improve our understanding of plant invasion dynamics and can be more effective in providing management strategies to mitigate plant invasion. Because the ecological and economic impacts of invasive ornamental plants will require collaborative efforts between scientists, policymakers and communities.

Conclusion

Increasingly herbaceous ornamental plants are being recognized as important contributors to the plant invasion risk in subtropical urban parks and alpine heath ecosystems. Often their introduction is intentional for aesthetic or economic reasons and often ignores their invasive potential, creating major challenges to native biodiversity, ecosystem stability and the services these ecosystems provide. The combination of climate change to alter temperature, precipitation, and disturbance regimes, as well as to create favorable conditions for invasives to establish and spread, greatly exacerbates these risks. Invasive ornamental plants and climate change call for combined efforts of multi-disciplinary approach to conservation and management. Maligning these threats requires integrating ecological research with the planning and implementation of urban policy. Strategies for the early detection and monitoring of this newly discovered species, and strategies for minimizing impact if it becomes established include: 1) Setting priorities for planting native plants in urban landscaping, 2) Implementing comprehensive early detection and monitoring programs, and 3) Implementing targeted control and mitigation measures. These efforts may aid the ecological balance of urban parks and minimize the adverse effect of the invasive species. Research and management should move in the future towards predictive modeling of invasion risks under different climate scenarios and towards innovative control techniques targeted to particular ecosystems. Scientist, policymakers, and local community collaboration is going to be necessary to develop sustainable solutions. Safeguarding the biodiversity and functionality of subtropical urban parks and alpine heath ecosystems for future generations is possible by dealing with the dual challenge of plant invasions and climate change.

Credit authorship contribution statement

Musharraf Ahmed Ghori: Conceptualization; Methodology; Investigation; Writing – original draft; Writing, review & editing under the supervision of Mansoor Akram.

Acknowledgments

We are thankful the editor and all anonymous reviewers for their valuable comments.

Availability of data and materials

The data is available from the corresponding author on reasonable request.

Conflict of interest

The authors reported no conflict of interest.

References

[1]. Bayón Á, Vilà M. Horizon scanning to identify invasion risk of ornamental plants marketed in Spain. NeoBiota. 2019;52:47–86. doi: 10.3897/neobiota.52.38113.

[2]. Kaukoranta T, Juhanoja S, Tuhkanen EM, Hyvönen T. Invasion potential of herbaceous ornamental perennials in northern climate conditions. Agric Food Sci. 2019;28(1):45–57. doi: 10.23986/afsci.77398.

[3]. Hu S, et al. Herbaceous ornamental plants with conspicuous aesthetic traits contribute to plant invasion risk in subtropical urban parks. J Environ Manage. 2023 Dec;347:119059. doi: 10.1016/j.jenvman.2023.119059.

[4]. Bayón Á, Godoy Ó, Maurel N, van Kleunen M, Vilà M. Proportion of non-native plants in urban parks correlates with climate, socioeconomic factors and plant traits. Urban For Urban Green. 2021;63:127215.

[5]. Hu S, et al. Herbaceous ornamental plants with conspicuous aesthetic traits contribute to plant invasion risk in subtropical urban parks. J Environ Manage. 2023;347:119059. doi: 10.1016/j.jenvman.2023.119059.

[6]. Francini A, Romano D, Toscano S, Ferrante A. The Contribution of Ornamental Plants to Urban Ecosystem Services. Earth (Switzerland). 2022;3(4):1258–74. doi: 10.3390/earth3040071.

[7]. Mukubu Pika L, et al. Practice and Biodiversity of Informal Ornamental Horticulture in Kinshasa, Democratic Republic of Congo. Ecologies. 2024;5(1):83–100. doi: 10.3390/ecologies5010006.

[8]. Keser LH, et al. Herbaceous plant species invading natural areas tend to have stronger adaptive root foraging than other naturalized species. Front Plant Sci. 2015;6(APR):1–9. doi: 10.3389/fpls.2015.00273.

[9]. Conser C, Seebacher L, Fujino DW, Reichard S, Di Tomaso JM. The development of a plant risk evaluation (PRE) tool for assessing the invasive potential of ornamental plants. PLoS One. 2015;10(3). doi: 10.1371/journal.pone.0121053.

[10]. Acar C, Acar H, Eroğlu E. Evaluation of ornamental plant resources to urban biodiversity and cultural changing: A case study of residential landscapes in Trabzon city (Turkey). Build Environ. 2007;42(1):218–29. doi: 10.1016/j.buildenv.2005.08.030.

[11]. Weber E, Gut D. Assessing the risk of potentially invasive plant species in central Europe. J Nat Conserv. 2004;12(3):171–9. doi: 10.1016/j.jnc.2004.04.002.

[12]. Esperon-Rodriguez M, Gallagher RV, Souverijns N, Lejeune Q, Schleussner CF, Tjoelker MG. Mapping the climate risk to urban forests at city scale. Landsc Urban Plan. 2024;248(April):105090. doi: 10.1016/j.landurbplan.2024.105090.

[13]. Wong GKL, Ma ATH, Cheung LTO, Lo AY, Jim CY. Visiting urban green space as a climate-change adaptation strategy: Exploring push factors in a push–pull framework. Clim Risk Manag. 2024;43:100589. doi: 10.1016/j.crm.2024.100589.

[14]. Othman R, Suid S, Mohd Noor NF, Baharuddin ZM, Hashim KSHY, Mahamod LH. The influence of urban park green spaces, plant material specifications and spatial design organization and pattern towards carbon sequestration rate. Appl Ecol Environ Res. 2019;17(4):8079–88. doi: 10.15666/aeer/1704_80798088.

[15]. Jaganmohan M, Knapp S, Buchmann CM, Schwarz N. The Bigger, the Better? The Influence of Urban Green Space Design on Cooling Effects for Residential Areas. J Environ Qual. 2016;45(1):134–45. doi: 10.2134/jeq2015.01.0062.

[16]. McPhearson T, et al. Urban Ecosystems and Biodiversity. In: Clim Chang Cities Second Assess Rep Urban Clim Chang Res Netw. 2018. p. 257–318. doi: 10.1017/9781316563878.015.

[17]. Upmanis H, Chen D. Influence of geographical factors and meteorological variables on nocturnal urban-park temperature differences. Clim Res. 1999;13(1998):125–39.

[18]. Yu Z, Guo X, Jørgensen G, Vejre H. How can urban green spaces be planned for climate adaptation in subtropical cities? Ecol Indic. 2017;82:152–62. doi: 10.1016/j.ecolind.2017.07.002.

[19]. Manatsa D, Chingombe W, Matarira CH. The impact of the positive Indian Ocean dipole on Zimbabwe droughts. Int J Climatol. 2008;2029(March 2008):2011–29. doi: 10.1002/joc.

[20]. Potchter O, Cohen P, Bitan A. Climatic behavior of various urban parks during hot and humid summer in the Mediterranean city of Tel Aviv, Israel. Int J Climatol. 2006;26(12):1695–711. doi: 10.1002/joc.1330.

[21]. Zheng S, Liu L, Dong X, Hu Y, Niu P. Dominance of Influencing Factors on Cooling Effect of Urban Parks in Different Climatic Regions. Int J Environ Res Public Health. 2022;19(23). doi: 10.3390/ijerph192315496.

[22]. Malik A, Zubair M, Manzoor SA. Valuing the invaluable: park visitors' perceived importance and willingness to pay for urban park trees in Pakistan. Ecosphere. 2021;12(1). doi: 10.1002/ecs2.3348.

[23]. Hernandez JGV, Pallagst K, Hammer P. Urban Green Spaces as a Component of an Ecosystem Functions, Services, Users, Community Involvement, initiatives and Actions. Int J Environ Sci Nat Resour. 2018;8(1). doi: 10.19080/ijesnr.2018.08.555730.

[24]. Yan M, Chen L, Sun R. Climatic effects on landscape multifunctionality in urban parks: a view for integrating ecological supply and human benefits. Environ Res Lett. 2023 Dec;19(1):14032. doi:

10.1088/1748-9326/ad10d8.

[25]. Roth M. Review of urban climate research in (sub)tropical regions. Int J Climatol. 2007;27(14):1859–73. doi: 10.1002/joc.1591.

[26]. Aram F, Higueras García E, Solgi E, Mansournia S. Urban green space cooling effect in cities. Heliyon. 2019 Apr;5(4):e01339. doi: 10.1016/j.heliyon.2019.e01339.

[27]. Verma R, Zawadzka JE, Garg PK, Corstanje R. The relationship between spatial configuration of urban parks and neighbourhood cooling in a humid subtropical city. Landsc Ecol. 2024;39(2):1–20. doi: 10.1007/s10980-024-01818-y.

[28]. Aram F, Solgi E, Garcia EH, Mosavi A. Urban heat resilience at the time of global warming: evaluating the impact of the urban parks on outdoor thermal comfort. Environ Sci Eur. 2020;32(1). doi: 10.1186/s12302-020-00393-8.

[29]. Zhang J, Zhang H, Qi R. A study of size threshold for cooling effect in urban parks and their cooling accessibility and equity. Sci Rep. 2024;14(1):1–17. doi: 10.1038/s41598-024-67277-2.

[30]. Mangal S, Kumar D, Dhupper R, Kumari M, Gupta AK. Identifying influential climatic factors for urban risk studies in rapidly urbanizing Region. Comput Urban Sci. 2024;4(1). doi: 10.1007/s43762-024-00121-5.

[31]. Geng X, Yu Z, Zhang D, Li C, Yuan Y, Wang X. The influence of local background climate on the dominant factors and threshold-size of the cooling effect of urban parks. Sci Total Environ. 2022;823:153806. doi: 10.1016/j.scitotenv.2022.153806.

[32]. Li Z, Zhou L, Hong X, Qiu S. Outdoor thermal comfort and activities in urban parks: An experiment study in humid subtropical climates. Build Environ. 2024;253:111361. doi: 10.1016/j.buildenv.2024.111361.

[33]. Rao F, Xiao P, Zhang Y, Lai D. Unravelling key environmental factors influencing urban park visits: Thermal comfort and air quality. Urban Clim. 2024;57:102096. doi: 10.1016/j.uclim.2024.102096.

[34]. Li Z, et al. Cooling effects of urban parks under various ecological factors. Urban Clim. 2024;58:102134. doi: 10.1016/j.uclim.2024.102134.

[35]. Wu S, Yao X, Qu Y, Chen Y. Ecological Benefits and Plant Landscape Creation in Urban Parks: A Study of Nanhu Park, Hefei, China. Sustain. 2023;15(24). doi: 10.3390/su152416553.

[36]. Myalkovsky R, Plahtiy D, Bezvikonnyi P, Horodyska O, Nebaba K. Urban parks as an important component of environmental infrastructure: Biodiversity conservation and recreational opportunities. Ukr J For Wood Sci. 2023;14(4):57–72. doi: 10.31548/forest/4.2023.57.

[37]. van Kleunen M, et al. The changing role of ornamental horticulture in alien plant invasions. Biol Rev. 2018;93(3):1421–37. doi: 10.1111/brv.12402.

[38]. Downey PO. Invasive Species and Plant Conservation: Woody weeds. 2018.

[39]. Nāburga I. Alien herbaceous ornamental plants as a risk of biodiversity degradation in habitats of urban areas. Acta Hortic. 2022;1345(September 2022):327–33. doi: 10.17660/ActaHortic.2022.1345.44.

[40]. Byun C, de Blois S, Brisson J. Management of invasive plants through ecological resistance. Biol Invasions. 2018;20(1):13–27. doi: 10.1007/s10530-017-1529-7.

[41]. Schippers P, van Groenendael J, Vleeshouwers L, Hunt R. Herbaceous plant strategies in disturbed habitats. Oikos 95. 2001;95. doi: 10.1034/j.1600-0706.2001.950202.x.

[42]. Tay D. Herbaceous ornamental plant germplasm conservation and use: Theoretical and practical treatments. Flower Breed Genet Issues, Challenges Oppor 21st Century. 2006;113–75. doi: 10.1007/978-1-4020-4428-1-5.

[43]. García-Caparrós P, Llanderal A, Pestana M, Correia P, Lao M. Tolerance mechanisms of three potted

ornamental plants grown under moderate salinity. Sci Hortic (Amsterdam). 2016;201:84–91. doi: 10.1016/j.scienta.2016.01.031.

[44]. van der Valk A. Herbaceous plant ecology: Recent advances in plant ecology. 2009. doi: 10.1007/978-90-481-2798-6.

[45]. Mongkhonsin B, Nakbanpote W, Meesungnoen O, Majeti P. Adaptive and Tolerance Mechanisms in Herbaceous Plants Exposed to Cadmium. 2019. p. 73–109. doi: 10.1016/B978-0-12-814864-8.00004-8.

[46]. Saeed M, Rasheed M, Saeed T. Researchable Issues of Ornamental Plant Nurseries: A Case Study of Pattoki. J Hortic Sci Technol. 2019;98–101. doi: 10.46653/jhst190204098.

[47]. Culley TM, Feldman TH. the Role of Horticulture in Plant Invasions in the Midwestern United States. Int J Plant Sci. 2023;184(4):260–70. doi: 10.1086/724662.

[48]. Dehnen-Schmutz K, Conroy J. Working with gardeners to identify potential invasive ornamental garden plants: testing a citizen science approach. Biol Invasions. 2018;20(11):3069–77. doi: 10.1007/s10530-018-1759-3.

[49]. Girmay M, Abebaw D, Bekele M. Distribution and impacts of invasive plant species in Gullele Botanical Garden. 2024. doi: 10.20944/preprints202405.0445.v1.

[50]. Zhou J, Tang Q, Zong D, Hu X, Wang B, Wang T. Drivers of Species Distribution and Niche Dynamics for Ornamental Plants Originating at Different Latitudes. Diversity. 2023;15(7). doi: 10.3390/d15070877.

[51]. Duncan P, Podest E, Esler KJ, Geerts S, Lyons C. Mapping Invasive Herbaceous Plant Species with Sentinel-2 Satellite Imagery: Echium plantagineum in a Mediterranean Shrubland as a Case Study. Geomatics. 2023;3(2):328–44. doi: 10.3390/geomatics3020018.

[52]. Süle G, et al. Escape from the garden: spreading, effects and traits of a new risky invasive ornamental plant (Gaillardia aristata Pursh). NeoBiota. 2023;83:43–69. doi: 10.3897/NEOBIOTA.83.97325.

[53]. Bondorina IA, Kabanov AV, Khokhlacheva JA. Features of the introduction of ornamental herbaceous plants native to the Russian Far East region in Laboratory of Ornamental Plants, at Main Botanical Garden of Russian Academy of Science. BIO Web Conf. 2021;38:2–5. doi: 10.1051/bioconf/20213800016.

[54]. Wavrek M, Heberling JM, Fei S, Kalisz S. Herbaceous invaders in temperate forests: a systematic review of their ecology and proposed mechanisms of invasion. Biol Invasions. 2017;19(11):3079–97. doi: 10.1007/s10530-017-1456-7.

[55]. Erickson E, Patch HM, Grozinger CM. Herbaceous perennial ornamental plants can support complex pollinator communities. Sci Rep. 2021;11(1):1–12. doi: 10.1038/s41598-021-95892-w.

[56]. Palareti G, et al. Comparison between different D-Dimer cutoff values to assess the individual risk of recurrent venous thromboembolism: Analysis of results obtained in the DULCIS study. Int J Lab Hematol. 2016;38(1):42–9. doi: 10.1111/ijlh.12426.

[57]. Cláudia A, Martini A, Hummel C. Invasive alien ornamental plants in Brazil: impact, origin, preferred habitats and projections. 2024;1–14. doi: 10.1590/1677-941X-ABB-2023-0192.

[58]. Li Y, et al. Problems and challenges of invasive ornamental plants and molecular tools to control their spread. J Crop Improv. 2006;17(1–2):279–301. doi: 10.1300/J411v17n01_11.

[59]. Ncangu BB, Aganze B, Ahana Mungu MI, Imani G. Invasive species Lantana camara (Verbenaceae) and its impact on herbaceous plants diversity in Bukavu (South Kivu province, D.R. Congo). Ann des Sci des Sci Appliquées. 2023;15(1):66–76.

[60]. Grzędzicka E, Reif J, Hanzelka J. Large invasive herbaceous plants decrease the taxonomic, functional and phylogenetic diversity of birds via their reproductive traits. Funct Ecol. 2024;(November 2023):2595–609. doi: 10.1111/1365-2435.14683.

[61]. Masters JA, Emery SM. Do multiple mechanisms drive the dominance of an invasive plant (Ranunculus ficaria, Ranunculaceae) along an urban stream? J Torrey Bot Soc. 2016;143(4):359–66. doi: 10.3159/TORREY-D-15-00020.1.

[62]. Nelson SB, et al. Patterns and mechanisms of invasive plant impacts on North American birds: a systematic review. Biol Invasions. 2017;19(5):1547–63. doi: 10.1007/s10530-017-1377-5.

[63]. Niemiera AX, Von Holle B. Invasive Plant Species and the Ornamental Horticulture Industry. Manag Invasive Weeds. 2008;167–87. doi: 10.1007/978-1-4020-9202-2_9.

[64]. Dehnen-Schmutz K, Touza J, Perrings C, Williamson M. Ornamental horticultural trade as pathway for invasions. BCPC Proc Introd Spread Invasive Species. 2005;(November 2014):7–12.

[65]. Wilson SB, Deng Z. Ornamental Invasive Plants in Florida With Research-founded Alternatives. Horttechnology. 2023;33(4):349–56. doi: 10.21273/HORTTECH05205-23.

[66]. Krokaitė E, et al. Relating Invasibility and Invasiveness: Case Study of Impatiens parviflora. Front Ecol Evol. 2022;10(April):1–17. doi: 10.3389/fevo.2022.845947.

[67]. Sesay REV, Sesay F, Azizi MI, Rahmani B. Invasive Species and Biodiversity: Mechanisms, Impacts, and Strategic Management for Ecological Preservation. Asian J Environ Ecol. 2024;23(9):82–95. doi: 10.9734/ajee/2024/v23i9600.

[68]. Mircea DM, et al. Responses of different invasive and non-invasive ornamental plants to water stress during seed germination and vegetative growth. Sci Rep. 2023;13(1):1–17. doi: 10.1038/s41598-023-40517-7.

[69]. Spicer ME, Radhamoni HVN, Duguid MC, Queenborough SA, Comita LS. Herbaceous plant diversity in forest ecosystems: patterns, mechanisms, and threats. Plant Ecol. 2022;223(2):117–29. doi: 10.1007/s11258-021-01202-9.

[70]. Zimmerman M, Peterson NA, Zimmerman MA. Beyond the Individual: Toward a Nomological Network of Organizational Empowerment. 2016;34(October 2004). doi: 10.1023/B.

[71]. Francini A, Romano D, Toscano S, Ferrante A. The problem being addressed in this study is the lack of comprehensive information on the status and diversity of ornamental plants in Bole sub city, Addis Ababa. While ornamental plants are an important component of urban landscapes and play a critical r. Earth (Switzerland). 2022;3(4):1258–74. doi: 10.3390/earth3040071.

[72]. Kato-Noguchi H. The Impact and Invasive Mechanisms of Pueraria montana var. lobata, One of the World's Worst Alien Species. Plants. 2023;12(17). doi: 10.3390/plants12173066.

[73]. Wilson SB, Freyre R, Knox GW, Deng Z. Characterizing the invasive potential of ornamental plants. Acta Hortic. 2012;937(September 2012):1183–92. doi: 10.17660/ActaHortic.2012.937.148.

[74]. Rani G, Kaur J, Kumar A, Yogalakshmi KN. Ecosystem Health and Dynamics: An Indicator of Global Climate Change. In: Singh P, Singh RP, Srivastava V, editors. Contemporary Environmental Issues and Challenges in Era of Climate Change. Singapore: Springer Singapore; 2020. p. 1–32. doi: 10.1007/978-981-32-9595-7_1.

[75]. Callaghan TV, et al. Effects of changes in climate on landscape and regional processes, and feedbacks to the climate system. Ambio. 2004;33(7):459–68. doi: 10.1579/0044-7447-33.7.459.

[76]. Chersich S, Rejšek K, Vranová V, Bordoni M, Meisina C. Climate change impacts on the Alpine ecosystem: An overview with focus on the soil - A review. J For Sci. 2015;61(11):496–514. doi: 10.17221/47/2015-JFS.

[77]. Odland A, Sundstøl SA, Bjerketvedt DK. Alpine lichen-dominated heaths: ecology, effects of reindeer grazing, and climate change. A review. 2018;30–50.

[78]. Wahren CH, Camac JS, Jarrad FC, Williams RJ, Papst WA, Hoffmann AA. Experimental warming and long-term vegetation dynamics in an alpine heathland. Aust J Bot. 2013;61(1):36–51. doi: 10.1071/BT12234.

[79]. Verrall B, Norman P, MacKey B, Fisher S, Dodd J. The impact of climate change and wildfire on decadal alpine vegetation dynamics. Aust J Bot. 2023;(June). doi: 10.1071/BT23002.

[80]. Grabherr G, Gottfried M, Pauli H. Climate Change Impacts in Alpine Environments. Geogr Compass. 2010;4:1133–53. doi: 10.1111/j.1749-8198.2010.00356.x.

[81]. Kullman L. Changes in alpine plant cover - Effects of climate warming. Sven Bot Tidskr. 2003;97:210–21.

[82]. Cannone N, Sgorbati S, Guglielmin M. Unexpected impacts of climate change on Alpine vegetation. Front Ecol Environ - Front ECOL Env. 2007;5:360–4. doi: 10.1890/1540-9295(2007)5[360:UIOCCO]2.0.CO;2.

[83]. Grabherr G. Alpine Vegetation Dynamics and Climate Change - a Synthesis of Long-Term Studies and Observations. 2003. p. 399–409. doi: 10.1007/978-3-642-18967-8_24.

[84]. Coll J, Bourke D, Hodd RL, Sheehy Skeffington M, Gormally M, Sweeney J. Projected climate change impacts on upland heaths in Ireland. Clim Res. 2016;69. doi: 10.3354/cr01408.

[85]. Aartsma P, Odland A, Reinhardt S, Renssen H. Drivers of soil temperature variation in alpine lichen heaths and shrub vegetation during the summer. Arctic, Antarct Alp Res. 2023;55. doi: 10.1080/15230430.2023.2209397.

[86]. Klanderud K. Climate change effects on species interactions in an alpine plant community. J Ecol. 2005;93(1):127–37. doi: 10.1111/J.1365-2745.2004.00944.X.

[87]. Slatyer R. Climate change impacts on Australia's alpine ecosystems. ANU Undergrad Res J. 2010;2(October). doi: 10.22459/aurj.02.2010.05.

[88]. Love J, Robb J, Drielsma MJ. Climate change impacts in the NSW and ACT Alpine region. 2019;(October). doi: 10.13140/RG.2.2.31496.85767.

[89]. Mallory CD, Boyce MS. Observed and predicted effects of climate change on Arctic caribou and reindeer. Environ Rev. 2018;26(1):13–25. doi: 10.1139/er-2017-0032.

[90]. Vanneste T, et al. Impact of climate change on alpine vegetation of mountain summits in Norway. Ecol Res. 2017;32(4):579–93. doi: 10.1007/s11284-017-1472-1.

[91]. Peringer A, Frank V, Snell RS. Climate change simulations in Alpine summer pastures suggest a disruption of current vegetation zonation. Glob Ecol Conserv. 2022;37(May):e02140. doi: 10.1016/j.gecco.2022.e02140.

[92]. Alatalo JM, Little CJ, Jägerbrand AK, Molau U. Vascular plant abundance and diversity in an alpine heath under observed and simulated global change. Sci Rep. 2015;5(May):1–11. doi: 10.1038/srep10197.

[93]. Winkler DE, Lubetkin KC, Carrell AA, Jabis MD, Yang Y, Kueppers LM. Responses of alpine plant communities to climate warming. 2019. doi: 10.1016/B978-0-12-813493-1.00013-2.

[94]. Acar C, Acar H, Eroğlu E. Evaluation of ornamental plant resources to urban biodiversity and cultural changing: A case study of residential landscapes in Trabzon city (Turkey). Build Environ. 2007;42(1):218–29. doi: 10.1016/j.buildenv.2005.08.030.

[95]. Akbarlou M, Mansouri Z. Book of abstracts 13th meeting vegetation databases Vegetation Databases and Ecological Restoration Federal Institute of Hydrology (BFG) in Keynote abstracts. 2014;24–6.

[96]. Buba T. Distribution and composition of herbaceous plants in response to arable cultivation and local topographical variation in the Nigerian northern Guinea Savannah. Int J Ecol Environ Sci. 2016;42(4):265–75.

[97]. Deka K. Conservation and Utilization of Horticultural Genetic Resources. 2019. doi: 10.1007/978-981-13-3669-0.

[98]. Long C, Chen Z, Zhou Y, Long B. The Role of Biodiversity and Plant Conservation for Ornamental Breeding. 2018. p. 1–12. doi: 10.1007/978-3-319-90698-0_1.

[99]. Lamei P, Attorre F, Testolin R, De Sanctis M, Turia R, Hitofumi A. Disturbance Impacts of Logging on Ground Herbaceous Plant Species Richness, Diversity, and Composition of Lowland Rainforest of Papua New Guinea: Herbaceous Diversity in Tropical Papua New Guinea. Case Stud Environ. 2021;5(1). doi: 10.1525/cse.2021.1517753.

[100]. Sandal Erzurumlu G, Erzurumlu DY. Evaluation of Outdoor Ornamental Plants from the Viewpoint of Urban Biodiversity and Cultural Change in Terrestrial Climate: The Case of Nigde City. Yuz Yil Univ J Agric Sci. 2021;31(4):825–37. doi: 10.29133/yyutbd.860641.

[101]. Atsbeha G, Demissew S, Woldu Z, Edwards S. Floristic composition of herbaceous flowering plant species in Lalay and Tahtay Michew Districts , Central Zone of Tigray, Ethiopia. African J Ecol Ecosyst. 2015;2(6):159–69.

[102]. Sievert G, Prendergast J. Butterfly Inventory and Assessment of the Effects of Fire and Grazing Managements on the Tallgrass Prairie National Preserve; An Initial Analysis. 2011;(December 2011). doi: 10.13140/RG.2.2.36821.50407.

[103]. Kavana PY, et al. Herbaceous plant species diversity in communal agro-pastoral and conservation areas in western Serengeti, Tanzania. Trop Grasslands-Forrajes Trop. 2019;7(5):502–18. doi: 10.17138/TGFT(7)502-518.

[104]. Solomou AD, Skoufogianni E, Giannoulis KD, Charvalas G, Danalatos NG. Effects of environmental factors on herbaceous plant diversity in an organic cultivation of sage (Salvia officinalis l.) in a typical mediterranean climate. Agric For. 2020;66(2):7–17. doi: 10.17707/AgricultForest.66.2.01.

[105]. Yanitskyi V. The impact of herbaceous plants on biodiversity and stability of pine plantations in Western Polissia. Plant Soil Sci. 2024;15(2):42–54. doi: 10.31548/plant2.2024.42.

[106]. Fikadu T. The Effects of Tree Species on Herbaceous Vegetation Composition , Distribution and Diversity in Eastern Oromia. 2022;10(January):1–14. doi: 10.37421/2332-2543.2022.10.4.

[107]. Shi L, Maruthaveeran S, Yusof MJM, Zhao J, Liu R. Exploring Herbaceous Plant Biodiversity Design in Chinese Rain Gardens: A Literature Review. Water (Switzerland). 2024;16(11). doi: 10.3390/w16111586.

[108]. Willie J, Tagg N, Lens L. Diversity and community composition of herbaceous plants in different habitat types in south-east Cameroon. Afr J Ecol. 2018;56(2):312–22. doi: 10.1111/aje.12454.

[109]. Agra H, Ne'eman G. Woody species as landscape modulators: Their effect on the herbaceous plants in a Mediterranean maquis. Plant Ecol. 2009;205(2):165–77. doi: 10.1007/s11258-009-9606-3.