

Long-term Ecological Impacts and Management Strategies of *Ageratina adenophora* Invasion in Yunnan Province

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Abstract. *Ageratina adenophora*, an invasive species introduced to China in the 1940s, has severely impacted the natural environment of Yunnan Province since the 1980s. This study primarily examines the botanical characteristics of *Ageratina adenophora* and reviews its invasion history in Yunnan. The plant's invasive success is attributed to its strong competitive ability, largely due to its production of allelopathic chemicals that suppress the growth of nearby plants. *Ageratina adenophora* alters soil composition and microbial diversity, which enhances its own growth, while its toxicity adversely affects livestock and wildlife. The species encroaches on ecological niches, reducing biodiversity and diminishing cattle productivity by creating monocultural dominance, potentially destabilizing ecosystems. This paper outlines some of the most effective strategies for managing *Ageratina adenophora* in Yunnan, including plant substitution, biological control, plant quarantine, mechanical eradication, and chemical control. These methods are essential for the sustainable development and ecological conservation of Yunnan Province.

Keywords: *Ageratina adenophora*, ecosystem, invasive plant, Yunnan Province.

1. Introduction

Ageratina adenophora, commonly known as sticky eupatorium [1], is an invasive species characterized by its robust root system, which enables asexual reproduction through transverse rhizomes. The plant's stems are purple or dark green, with minute hairs on the surface. Its leaves are opposite, oblong or cordate, and have serrated margins. The flowers, typically white or pale purple, are aggregated in umbels, and the small achenes containing seeds are equipped with feather-like appendages that facilitate wind dispersal [2].

Ageratina adenophora Since its introduction to China, *Ageratina adenophora* has proliferated extensively in provinces such as Guizhou, Yunnan, Sichuan, and Guangxi, threatening over 14 million hectares of land. The rapid spread of this species has caused significant damage to local flora and agricultural crops. In response, the Ministry of Agriculture has implemented various control measures, including biological control and the creation of buffer zones along key transit routes. Efforts are also

being made to develop low-toxicity herbicides and explore potential uses of *Ageratina adenophora* as fodder and fuel to reduce its environmental and economic impacts.

With global climate change, *Ageratina adenophora*'s suitable habitat may expand to higher latitudes or elevations, potentially invading new areas, threatening agricultural output and essential ecosystem services, including soil and water conservation, and nitrogen cycling. Charles and Dukes [3] have highlighted that invasive species can severely disrupt ecosystem services. The continued spread of *Ageratina adenophora* in Yunnan poses risks to both agricultural productivity and natural ecosystem health by altering key ecological functions.

Despite the growing threat, detailed analysis of the ecological implications of *Ageratina adenophora* in Yunnan, along with systematic prevention and control strategies, remains limited. This study employs a literature review approach to comprehensively assess the impact of *Ageratina adenophora* on Yunnan's ecosystem, particularly its effects on human livelihoods. Based on the findings, this paper proposes a range of prevention and control strategies aimed at mitigating the invasion's impacts and preserving the ecological balance in Yunnan.

2. Research background

2.1. Ecological conditions of Yunnan province

Yunnan, located on the Yunnan-Guizhou Plateau, is characterized by a mountainous terrain with deep valleys and rivers, forming a unique hydrological system. The province's maximum elevation is 6740 meters, while the lowest is 76.4 meters above sea level, resulting in a difference of 6663.6 meters between the northern and southern extremes. Due to its varied elevation and geographical position, Yunnan exhibits a wide range of climates, from tropical to temperate, which supports a rich diversity of ecosystems. Varied elevations and topographical features have resulted in distinct microclimates. The region encompasses a variety of ecosystems, including tropical rainforests, subtropical forests, temperate forests, alpine meadows, and wetlands, thereby offering a variety of habitats [4]. According to the 2024 China Crop Germplasm Resources Network, Yunnan is home to more than 15,000 species of higher plants, including 19,333 species from 3,084 genera and 440 families. This represents 6.4% of the global total of approximately 300,000 species, as well as 50.1% of China's documented species, which exceed 38,000.

2.2. History of *Ageratina adenophora* invasion in Yunnan

Immigrants initially brought *Ageratina adenophora* to Europe as an ornamental plant, which was later transported to Australia and southern Asia. It has now spread extensively across tropical and subtropical areas of the Americas, Asia, and Africa. During the 1990s, *Ageratina adenophora* spread from Yunnan to the southwestern provinces. *Ageratina adenophora* proliferates rapidly due to its remarkable resilience, reproductive ability, and potent allelopathic properties. During the 1990s, *Ageratina adenophora* spread from Yunnan to the southwestern provinces [5]. Currently, six locations in Guizhou and Xizang are home to *Ageratina adenophora* [6-7]. *Ageratina adenophora*'s probable distribution range encompasses all regions south of the Yangtze River. Without effective control, *Ageratina adenophora* could potentially spread throughout all regions south of the Yangtze River.

3. The impact of *Ageratina adenophora* invasion on the ecology of Yunnan

3.1. Changes in soil nutrient content

Ageratina adenophora significantly alters soil composition and microbial communities, impacting nutrient availability for local plants. *Ageratina adenophora* is recognized for its invasive capacity to exude allelopathic substances into the soil, modify the soil microclimate, and influence the nutrient composition of the soil. In 2009, Li Huina collected soil samples from Heilongtan Park, Kunming, Yunnan, with varying levels of *Ageratina adenophora* invasion. Samples were categorized into six types based on invasion levels, including monocultures and mixed native plant habitats. *Ageratina*

adenophora affects the soil environment, as demonstrated by assessing the concentrations of organic matter, total nitrogen, total phosphorus, total potassium, nitrate nitrogen, ammonia nitrogen, accessible phosphorus, and available potassium in soil samples from several locations. The soil selection adhered to NiuHongbang's 2007 experimental methodology regarding the impact of *Ageratina adenophora* on soil physicochemical characteristics [8]. Following experimentation, *Ageratina adenophora* significantly enhanced the organic matter and total nitrogen levels in the soil. *Ageratina adenophora* increased ammonia and nitrate nitrogen levels in the soil, with concentrations in heavily invaded areas being 5.9 times higher than those in local plant areas, measuring 53.00 mg/kg; the nitrate nitrogen content was 5.95 times higher, at 91.98 mg/kg [9]. Compared to indigenous flora, *Ageratina adenophora* exhibits a superior capacity for soil enrichment and can more effectively modify the soil environment to facilitate its own growth. This pertains to *Ageratina adenophora*'s capacity to alter soil microbial composition.

3.2. Alter the microbial composition of the soil

Upon entering the soil, bacteria decompose organic stuff and convert it into nutrients. The soil's nutrients and resident bacteria have changed. Li Huina subsequently conducted experiments on cultivable soil microbial species, reiterating the soil extraction and classification techniques utilized in previous studies [9]. Experimental results indicate that heavily invaded regions have a high abundance of soil fungus, actinomycetes, autotrophic nitrogen-fixing bacteria, and ammonia-oxidizing bacteria. The quantity of fungi in mixed plant ecosystems is 2.1 times greater, however marginally lower than in places with single native plants. The quantity of autotrophic nitrogen-fixing bacteria and ammonia-oxidizing bacteria in heavily invaded regions exceeds that in areas with solely native plants and those with mixed native plants, measuring 4.41×10^5 and 8.69×10^4 , respectively. The abundance of denitrifying bacteria diminishes with increasing invasion, recorded at 2.5×10^2 in severely invaded regions and 4.5×10^2 in moderately invaded areas, which is comparable to and marginally exceeds the quantity found in mixed native plant environments. The correlation coefficient between soil biota groups and accessible nutrients indicates that soil microorganisms significantly influence the production of nitrate nitrogen, ammonia nitrogen, available phosphorus, and available potassium. Actinomycetes had a substantial link with available potassium (correlation coefficient 0.689), but autotrophic nitrogen-fixing bacteria demonstrated a considerable correlation with in situ nitrogen (correlation value 0.683). The invasion of *Ageratina adenophora* outcompetes native plants in terms of soil nutrient enrichment. This suggests a strategy for the invasion and proliferation of *Ageratina adenophora*: rapidly and effectively acquiring nutrients by enhancing soil nutrients levels, especially in nutrient-deficient soils, to compete with indigenous flora for resources [9].

3.3. Suppression of adjacent plant growth and competition

3.3.1. Allelopathic effects

The allelopathic properties of *Ageratina adenophora* suppress the growth of neighboring plants by releasing toxins. These substances may modify root development and growth in plants. *Ageratina adenophora* emits chemical compounds through its stems, leaves, and roots, including loosestrife ketone and hydroxyloosestrife ketone, into the air or soil, which hinder the growth and development of adjacent plants. Research indicates that *Ageratina adenophora* extract significantly inhibits the seed germination of three prevalent plant species: barnyard grass, gray green quinoa, and amaranth. Following treatment with 1000 mg of *Ageratina adenophora* extract, the root tips of the three weed seedlings exhibited varying degrees of damage, including swelling, shrinkage, and deformation; the surface cells of the root tip were lost, and the inner cells were arranged in a disordered pattern. Administration of *Ageratina adenophora* extract can substantially diminish the quantity of root tip RBCs in three weed seedlings, provoke RBC mortality, markedly enhance the thickness of the RBC adhesive layer, and elevate PME activity. The findings indicate that *Ageratina adenophora* extract suppresses the formation of three varieties of root edge cells and triggers apoptosis in root tip edge cells, hence compromising the

protective mechanism of root edge cells against root tips, ultimately hindering root growth and development [10].

3.3.2. Resource competition.

Ageratina adenophora excels in resource competition, forming dense vegetation that occupies large areas and competes for water and nutrients. Its robust root system can penetrate deeply into the soil, compete for water and nutrients, and inhibit the root development of other plants. Furthermore, *Ageratina adenophora*'s leaves are relatively large, allowing it to efficiently capture sunlight, obstruct other plants, and affect their photosynthesis. *Ageratina adenophora*'s remarkable adaptability enables it to thrive in nutrient-deficient soil, enhancing its competitive advantage for resources [11], which subsequently impacts crop growth.

3.4. Affects animal health and survival

3.4.1. Impact on animal health.

Ageratina adenophora encroaches into natural grasslands, and due to its toxicity, many cattle are unable to feed enough. *Ageratina adenophora* can adversely affect an animal's liver, spleen, kidneys, and intestines. Wang Shu conducted an experiment to evaluate the detrimental effects of *Ageratina adenophora* on animals, employing Chengdu Ma sheep as participants. The sheep were categorized into two groups: a control group receiving 0% *Ageratina adenophora* powder and an experimental group receiving 40% *Ageratina adenophora* powder. Following a 90-day feeding period, serum and cecal contents from Ma sheep were taken to assess alterations in serum liver function indicators and gut microbiota. Ultimately, the Chengdu Ma sheep in the experimental group displayed clinical manifestations like mental fatigue, unstable posture, and total alopecia. *Ageratina adenophora* significantly influenced serum concentrations of aspartate transaminase, alkaline phosphatase, alanine aminotransferase, gamma-glutamyl transferase, and total cholesterol throughout the latter phases of the trial. The rise in these figures indicates that *Ageratina adenophora* has significantly impaired the liver function of Ma sheep. *Ageratina adenophora* impacts the species diversity and abundance of stomach microbiota in Ma sheep. Wang Shu's tests indicated that *Ageratina adenophora* elevated the relative abundance of Firmicutes while diminishing the relative richness of Bacteroidetes and Proteobacteria in the digestive tract of Ma sheep, leading to a disruption in overall metabolic energy [12]. This method illustrates that *Ageratina adenophora* is detrimental to certain cattle and wildlife. Due to the same dietary composition, the gut microbiota of many herbivorous species may be identical. This indicates that *Ageratina adenophora* may inflict intestinal damage in other herbivorous mammals.

3.4.2. *Ageratina adenophora* obliterates animal habitats.

The combined characteristics of herbaceous and shrubby *Ageratina adenophora* enable its invasion to dominate the local herbaceous plant ecological niche, leading to habitat loss for tiny fauna [13]. Moreover, the toxicity of *Ageratina adenophora* prevents herbivorous animals from consuming vegetation in densely affected areas, leading to a decline in biodiversity. Consequently, animal husbandry will face significant challenges in a habitat severely infested with *Ageratina adenophora*.

3.5. Altering the ecological configuration

Invasive species modify interspecies interactions to affect the energy flow and material cycle of ecosystems, potentially leading to ecological problems. System failure and operational decline. *Ageratina adenophora* is rapidly spreading across Yunnan Province. People typically regard *Ageratina adenophora* as a dominant species in its invaded regions, as it proliferates densely in contiguous areas and significantly disrupts the surrounding biological ecology. Researchers Fang Zenghong et al. found that when *Ageratina adenophora* invaded the understory, plant density, species richness index, species diversity index, and species evenness index all went down a lot. However, plant height, tiller count, and aboveground biomass all went up a lot. It quickly spreads from plant to plant thanks to its strong tillering,

high reproductive capacity, and wide range of propagation methods. It takes advantage of ecological niches and then beats out other herbs and shrubs by producing substances that are allelopathic. This leads to the formation of large-scale monocultures, significantly diminishing understory species diversity and adversely affecting forest ecosystems [14].

4. Prevention and Management

4.1. Ecological prevention and control measures

4.1.1. Plant-based substitution strategies.

The use of interspecies competition for substitution control has consistently been a significant focus on the prevention and management of invasive alien species within ecological frameworks. Multiple studies have shown that employing economic crops for substitution control is a crucial strategy for executing green prevention and management of invasive species [15]. Research by Lu et al. indicates that the perennial dicotyledonous plant *Pueraria lobata* possesses significant potential to substitute *Ageratina adenophora*. *Pueraria lobata* serves as both a traditional Chinese medicinal and a premium feed source. Lu et al. found that *Pueraria lobata* significantly enhanced surface coverage within one year, reducing *Ageratina adenophora* prevalence by 96% [16]. Even a minimal presence of *Ageratina adenophora* will be overshadowed by the vigorous growth of *Pueraria lobata*. The efficacy of plant management can reach 96.2%, while the control of dry weight can achieve 96.0%. In regions where *Ageratina adenophora* is detrimental, it can be systematically eradicated and replaced with economically advantageous species that exhibit more competitiveness than *Ageratina adenophora*. Currently, in Guanling autonomous county, Yunnan province, Huangzhucao and Baici are employed for vegetation management. Floral species and Sichuan pepper trees are employed to manage *Ageratina adenophora*. The Huangzhu grass exhibits remarkable environmental adaptability, characterized by rapid growth, vigorous stem and leaf development, and extensive coverage. It efficiently suppresses the growth and seed dispersal of *Ageratina adenophora*. In Shangguan Town, Guanling Autonomous County, the formerly prevalent *Ageratina adenophora* has been supplanted by 86,000 acres of Huangzhucao; furthermore, in regions where *Ageratina adenophora* invasion is pronounced, white loosestrife can thrive unimpeded and serve as a substitute for *Ageratina adenophora*. In Yexin Village, Guanling Autonomous County, the removal of purple grass and subsequent planting of white grass yielded rapid results. Data indicates that the prevention and control rate of *Ageratina adenophora* in the region is above 85%. The Sichuan pepper tree obstructs sunlight, leading to a decline or potential mortality of *Ageratina adenophora* owing to inadequate light, hence enhancing the prosperity of local residents. In Hongxing Village, Guanling Autonomous County, 3000 acres of Sichuan pepper trees have supplanted the *Ageratina adenophora* that had infested the region for over 20 years. In Guanling Autonomous County, Yunnan Province, notable progress has been made in substituting *Ageratina adenophora* with flora such as bamboo grass, white thorn flower, and Sichuan pepper tree. The swift growth traits of bamboo grass and its capacity to thrive in suboptimal soil conditions allow it to efficiently suppress the proliferation of purple loose grass. Nonetheless, the constraints of plant substitution include protracted growth cycles and reliance on appropriate climates, which must be thoroughly evaluated during the implementation phase.

4.1.2. Biological control methods

Ageratina adenophora's pollen can lead to allergic pneumonia, rhinitis, and even fatality in livestock, particularly horses. The biological toxicity of *Ageratina adenophora* prevents its direct use as feed, leading to the common practice of employing natural enemies to manage invasive species. The Zelan fruit fly, a parasitic insect, has shown potential in controlling *Ageratina adenophora*, though its current population size limits effectiveness. The Zelan fruit fly can be artificially cultivated and released in the distribution area of *Ageratina adenophora*, effectively controlling its spread and keeping the population density of invasive species below the level of ecological and economic harm. LI et al. confirmed that

the Zelan fruit fly has a significant impact on the growth and development of the *Ageratina adenophora* [17]. However, under the current parasitic intensity, the Zelan fruit fly has no significant effect on the *Ageratina adenophora* branches' diameter, number of flower branches, number of head-shaped flowers, or fruit setting. Because of the large difference in their numbers, the reproductive and dispersal abilities of Zelan fruit flies are weaker than those of *Ageratina adenophora*. Therefore, researchers should consider searching for local natural enemies for biological control. This approach can reduce the risk of introducing new natural enemies and facilitate the reproduction and release of local species. Furthermore, native organisms have a longer survival time in the local environment and pose less potential threat to the environment than invasive species, thereby reducing ecological threats. However, searching for species that have inhibitory effects on *Ageratina adenophora* would require significant time and financial resources.

4.2. Anthropogenic prevention and control

4.2.1. Enhance plant quarantine measures.

Ageratina adenophora is presently creating issues in southwestern China and certain provinces south of the Yangtze River. Enhancing biological quarantine and preventing transmission are effective strategies for managing the proliferation of *Ageratina adenophora* and mitigating its effects. *Ageratina adenophora* is primarily disseminated via inadvertent transport and transfer during human industrial and economic activities. Strengthening plant quarantine in affected areas and raising awareness of invasive species threats are crucial steps. In regions where *Ageratina adenophora* has not been introduced, it is essential to enhance vehicle inspections in areas already infested, promptly eliminate reproductive bodies of *Ageratina adenophora*, and obstruct transmission paths.

4.2.2. Mechanical eradication.

Manual or mechanical removal of *Ageratina adenophora* plants is presently one of the most effective methods for their control. Easily eradicated, *Ageratina adenophora* is a superficially rooted plant. When the water loss rate of *Ageratina adenophora* surpasses 35%, it forfeits its capacity to germinate. Post-rainy season, when soil moisture is conducive for excavation yet unfavorable for *Ageratina adenophora* germination, it is optimal to excavate during periods of enough sunlight to mitigate water loss and prevent germination, which results in mortality. Local forest management efforts can use it to eradicate *Ageratina adenophora*, which then undergoes central processing. The plants can be desiccated and sent to relevant enterprises for use as raw materials. Mechanical eradication is notably effective in small-scale invasion zones; nevertheless, it is costly and does not guarantee complete eradication in extensive *Ageratina adenophora* invasion areas. Therefore, researchers can incorporate chemical control to eradicate the region and ensure the sustained efficacy of prevention and control measures.

4.2.3. Chemical regulation.

Biological control does not exclude chemical control. Low-toxicity, environmentally benign herbicides, such as glyphosate and sulfometuron methyl, have been effective in controlling *Ageratina adenophora*, with efficiency rates exceeding 90%. Glyphosate, a premium herbicide deemed safe for humans and livestock, rapidly passivates in soil without adversely affecting it. Sulfometuron methyl is a slightly toxic herbicide that has neither carcinogenic nor mutagenic properties. This herbicide is suitable for use in forested and uncultivated areas, effectively reduce *Ageratina adenophora* with an efficiency rate exceeding 90%. During application, it is imperative to exercise caution to prevent the herbicide from dispersing and damaging neighboring plants. While herbicides like glyphosate are very good at killing *Ageratina adenophora*, researchers need to investigate how they might affect the environment, especially when it comes to how long they stay on the ground and how they affect the plants nearby. Additional investigation is required to ascertain its safety and long-term effects.

4.3. The method's superiority and limitations

The advantages of plant replacement encompass superior management capabilities and a significant capacity for substituting *Ageratina adenophora*, in addition to the fact that all chosen plants are indigenous to the region and will not inflict secondary harm on the local ecology. It is a laborious and challenging technique to ensure that the chosen species proliferates more rapidly than *Ageratina adenophora*. As a result, it is advisable to choose economically beneficial plants in order to encourage individuals to deliberately cultivate them, fostering reciprocal advantages for both the ecological environment and humanity. Biological control can directly diminish the proliferation of *Ageratina adenophora*, effectively suppressing it. Nonetheless, while selecting organisms, it is essential to ensure they will not adversely impact other species in the vicinity, necessitating extensive observation and research to identify appropriate creatures. Mechanical eradication is efficient for small-scale invasions but becomes cost-prohibitive for larger areas. Chemical control is the most straightforward method for addressing extensive infestations of *Ageratina adenophora*. Yunnan's biological ecosystem is complex, and following the eradication of *Ageratina adenophora*, indigenous species may inhabit the treated soil. This method is unsuitable for application in areas with intricate biological systems, as it may adversely affect the local ecology. It is only suitable for areas with significant *Ageratina adenophora* infestations. Lastly, getting rid of *Ageratina adenophora* requires using a variety of strategies that are tailored to the area's needs. These include biological control, physical control, plant control, and scientific pesticide application for successful overall management. It is essential to restrict the events that facilitate the spread of *Ageratina adenophora* through human activities.

5. Conclusion

In summary, the rich biodiversity and unique climate of Yunnan Province, along with the accelerated spread of *Ageratina adenophora* driven by global warming, present significant ecological challenges. Current research on *Ageratina adenophora* remains limited and lacks a systematic framework for addressing its ecological impact and sustainable management.

This research provides a detailed and systematic examination of the effects of *Ageratina adenophora* on the Yunnan ecosystem. The invasion significantly impacts soil nutrient composition, increasing total nitrogen by up to 11 times, ammonia nitrogen by 5.9 times, and nitrate nitrogen by 5.95 times. The microbial community composition is also affected, with an increase in ammonia-oxidizing bacteria by 4.41×10^5 in severely invaded areas. Meanwhile, denitrifying bacteria populations decrease, reaching as low as 2.5×10^2 in heavily invaded regions. These changes indicate a profound alteration in soil ecology, which can negatively affect local agriculture. *Ageratina adenophora* also inhibits root development in neighboring plants and disrupts their growth by triggering apoptosis in root tip cells, exacerbating agricultural losses.

Additionally, *Ageratina adenophora* has significant effects on animal health. It alters the gut microbiota in livestock, such as Ma sheep, by increasing the relative abundance of Firmicutes and reducing the relative abundance of Bacteroidetes and Proteobacteria, leading to metabolic disorders that impact livestock productivity. The invasion also disrupts ecosystem structure by reducing species richness, species diversity, and plant density, while promoting large-scale monocultures that degrade biodiversity. To manage the invasion, this paper suggests several methods, including the cultivation of kudzu vines as a plant substitution strategy and the use of fruit flies as a form of biological control. Mechanical eradication and enhanced plant quarantine measures are also recommended. Combining these methods with chemical control can significantly reduce the spread of *Ageratina adenophora*. This study lacks a thorough investigation into the ecological mechanisms behind *Ageratina adenophora*'s impacts and does not fully integrate prevention and control strategies tailored to local environmental conditions. Future research should focus on long-term ecological monitoring to better understand the invasion dynamics and to develop region-specific control measures. Strengthening public awareness, advancing scientific research, and enhancing biodiversity conservation efforts in Yunnan are critical steps in mitigating the long-term ecological and agricultural damage caused by *Ageratina adenophora*.

Acknowledgments

All the authors contributed equally and their names were listed in alphabetical order.

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