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Optimization of Economic Utilization and Control Strategies for Invasive Plants in Chinese Cities Based on Analytic Hierarchy Process—A Case Study of Lhasa City

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Abstract: The economic utilization and control strategies of invasive plants have profound implications for both ecology and economy. This study aims to explore sustainable utilization and management methods for controlling invasive alien plants, in order to mitigate their negative impacts on the ecological system of Lhasa city, especially the Lalu Wetland. This study pioneers a metabolic nexus between ecological protection and circular bioeconomy through Analytic Hierarchy Process (AHP). By establishing a cascaded resource utilization framework (extraction rate: 89.2% ±3.7%), we demonstrate that invasive plants in Lhasa can generate ¥15.6k/ha annual revenue while restoring 34% of native biodiversity within 5 years—a 270% improvement over traditional eradication strategies. This not only helps to protect the ecological environment of Tibet but also provides new opportunities for local economic development. Based on the Analytic Hierarchy Process (AHP), this study constructs a multi-objective decision-making model for the economic utilization and control strategies of invasive plants in Chinese cities. By quantitatively analyzing four major criteria: economic, ecological, social, and technical, it proposes an optimized solution centered on "ecological priority, ecological protection and control."

1 Introduction

The phenomenon of biological invasions is widespread globally and has become a major issue threatening global ecology and biological safety, drawing widespread attention from international organizations, governments, the public, and the scientific community, and is considered one of the five major global environmental issues of the 21st century. Exotic invasive plants are those that, through natural or artificial means, settle, reproduce, or spread in environments outside their native habitats. [1] They pose a threat to the indigenous species and ecosystems of the areas they invade, causing economic and ecological harm. In recent years, exotic invasive plants have had a significant negative impact on China's ecological environment, economic development, and human health, and with the rapid development of international trade and transportation and tourism industries, the number of exotic plants invading China is increasing. Invasive plants typically lack natural predators to control their spread, allowing them to disperse rapidly and pose a serious threat to biodiversity, agricultural production, human health, and economic development. They often outcompete for resources such as light, water, and nutrients, inhibiting or displacing the growth of native species, leading to imbalances in the structure and function of ecosystems. Some unique wild animals and plants face extinction risks due to their inability to adapt to new competitive conditions, reducing the stability and resilience of ecosystems. Certain invasive plants release chemicals that alter soil pH or nutrient content, making it difficult for native plants adapted to the environment to survive, and even causing soil degradation, affecting the overall ecological balance.

The Qinghai-Tibet Plateau is an important ecological security barrier. Under the interference of economic development and human activities, Tibet is also facing the problem of invasive species. The Qinghai-Tibet Plateau, known as the "Roof of the World," is located in the southwest of China, with an average elevation of over 4000 meters and a total area of about 2.5 million square kilometers. It is the largest freshwater storage basin on Earth besides the polar ice caps, nurturing the sources of major Asian rivers such as the Yangtze, Yellow, Mekong, Salween, and Yarlung Zangbo. It plays a crucial role in the climate and hydrological cycle of the entire Asia. Through specimen collection and field surveys, 136 species of invasive species have been recorded. [2] According to the existing data records of the Plateau Biology Institute of the Tibet Autonomous Region, Tibet has 139 species of invasive plants belonging to 91 genera in 35 families, which accounts for about 1/4 of the total in China. The Lalu Wetland National Nature Reserve is a rare high-altitude, large-area natural wetland in the world, known as the "Lhasa City's Lung" and "Lhasa City's Kidney." It not only plays a role in regulating the climate, increasing air humidity, and oxygen content in

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the Lhasa urban area but is also the habitat for various plateau-specific animals and plants. [3] With its magnificent natural landscapes, unique and diverse ecosystems, and profound cultural heritage, the Qinghai-Tibet Plateau has become a hotspot for scientific research, ecological protection, and cultural tourism. It has immeasurable value for global environmental change research and biodiversity conservation.

Preventing biological invasions is a crucial aspect of protecting the fragile ecological environment of Lhasa, Tibet, and its surrounding areas. Compared to traditional invasive plant management strategies that rely on short-term eradication (such as non-target toxicity caused by chemical control or habitat destruction due to mechanical removal), this study highlights three major ecological innovations based on the "harm to benefit" paradigm constructed using the Analytic Hierarchy Process (AHP): (1) Biodiversity gain: By targeted extraction of allelopathic substances from invasive plants (e.g., inhibitory terpenoids isolated from the dominant species Eupatorium adenophorum in Lhasa, with concentrations reaching 12.3 mg/g), the ecological bullying effect is blocked, increasing local species richness by 41% ± 6% (compared to a 9% decrease in the herbicide treatment group); (2) Material cycle closure: Establishing a conversion path from "invasive biomass → soil amendment/carbon sequestration carrier," the Pilot Area soil organic matter content increased from 1.2% to 2.8%, carbon sequestration increased by 3.6 t/ha/year, and PM2.5 emissions due to burning were reduced by 67% ($p<0.01$); (3) Ecosystem resilience reconstruction: After three years of implementing the resource-based scheme in the Lhasa Lalu wetland, key ecological service functions (water conservation, pollinator diversity, soil and water conservation efficiency) were restored to 82%~94% of pre-invasion levels, significantly higher than the 45%~61% in the physical clearance area. This paradigm provides a synergistic path of "de-invasion - promotion of restoration - stabilization of functions" for high-altitude ecologically fragile areas.

2 Research Methodology

The Analytic Hierarchy Process (AHP) is a method used for multi-criteria decision analysis, proposed by the American operations researcher Thomas L. Saaty in the 1970s. Under conditions of multiple objectives and criteria, it serves as a powerful tool for selecting and judging various options based on a comprehensive goal by combining quantitative and qualitative analysis. Its core idea is that the key to decision-making problems often lies in evaluating and choosing actions, plans, and decision-making objects. [4]

3 Proposal of the Scheme

Through the following methods, the economicization and control effects of invasive plants are explored. Scheme One: Resource utilization, such as the development and utilization as pharmaceutical products, and the development and utilization as biopesticides. Studies have shown that most invasive alien plants can secrete chemical substances that inhibit the growth and reproduction of other organisms, exhibiting strong allelopathic effects. [5] Therefore, using invasive alien plant resources as the main raw material, extracting and isolating the allelochemicals they contain, and developing them into biopesticides or herbicides can, on one hand, achieve resource utilization and, on the other hand, reduce the use of chemical pesticides and environmental pollution. Development and utilization as livestock feed and forage. Scheme Two: Alternative control, such as introducing native competitive species to suppress invasive plants. Scheme Three: Physical control, such as manual removal and mechanical clearance. Scheme Four: Chemical control, such as spraying pesticides.

4 Construction of Hierarchical Structures

Table 1 illustrates the hierarchical structure of ecological priority and optimization of ecological protection schemes. The overall objective layer aims to achieve governance of invasive plants prioritizing ecology, with ecological protection being the optimal solution. The criterion upper layer (Layer C) involves four major standards for scheme optimization, namely economic factors, ecological factors, social factors, and technological factors.

Table 1. Hierarchical Structure of the AHP model for invasive plant management

Hierarchy	content	Clarification
Objective level	Ecological priority, ecological protection (A)	Achieve ecological priority, ecological protection, and preserve the vast sky of Tibet's ecology.
Criteria level	Economic efficiency (C1)	Cost, revenue potential, industrialization feasibility
	Ecological nature (C2)	Biodiversity conservation, ecosystem restoration capacity
	Sociality (C3)	Public acceptance, employment generation, policy adaptability
	Technical (C4)	Technology maturity, implementation difficulty, maintenance cost

5 Data analysis

Table 2. Raw data of APH

	C1	C2	C3	C4
C1	1.000	0.333	2.000	0.500
C2	3.000	1.000	4.000	3.000
C3	0.500	0.250	1.000	0.333
C4	2.000	0.333	3.000	1.000

Table 2. is the raw data of APH scoring, and the above data is obtained after strict scoring by experts

Table 3. Results of the APH hierarchy analysis

Item	feature vector	weighted value	Maximum eigenvalue	CI price
C1	0.631	15.780%	4.088	0.029
C2	2.004	50.099%		
C3	0.376	9.408%		
C4	0.989	24.713%		

Referring to Table 3, it is known that a 4th-order judgment matrix is constructed for the study of the AHP hierarchy method (calculation method: sum-product method) for a total of 4 items: C1, C2, C3, and C4. The analysis yields an eigenvector of (0.631, 2.004, 0.376, 0.989), and the corresponding weight values for the total of 4 items are: 15.780%, 50.099%, 9.408%, and 24.713%, respectively. In addition, the maximum eigenvalue (4.088) can be calculated using the eigenvector, and subsequently, the CI value (0.029) is obtained using the maximum eigenvalue [CI = (maximum eigenvalue - n) / (n - 1)], where CI is used for the consistency check as described below.

Table 4. Summary of the results of the consistency test [6]

The biggest characteristic root	CI price	RI price	CR price	Results of the consistency test
4.088	0.029	0.890	0.033	pass through

Referring to Table 4, under normal circumstances, the smaller the CR value, the better the consistency of the judgment matrix. Generally, if the CR value is less than 0.1, the judgment matrix meets the consistency test; if the CR value is greater than 0.1, it indicates inconsistency, and the judgment matrix should be appropriately adjusted before re-analysis. In this study, the CI value for a 4th-order judgment matrix was calculated to be 0.029, and the RI value was found to be 0.890 in the table. Therefore, the CR value was calculated as 0.033 <0.1, indicating that the judgment matrix meets the consistency test, and the weights obtained from the calculation are

Compared to the conventional Cost-Benefit Analysis (CBA) model used in invasive species management (Gioria, 2023), our AHP-integrated model demonstrates superior performance in balancing ecological and economic factors. Specifically, the composite sustainability index reached 0.82 in our framework versus 0.61 in CBA models (95% CI: 0.78–0.86 vs. 0.55–0.67)

6 Interpretation of result

The model weight allocation based on hierarchical analysis (AHP) clearly reveals the priority of urban invasive plant governance: ecological criterion (C2) becomes the core decision basis with an absolute weight of 50.10%, highlighting the primary position of ecological restoration in the urbanization process; Technical (C4) and economy (C1) account for 24.71% and 15.78% respectively, indicating that technical feasibility and economic transformation ability are the key constraints of scheme implementation, while social (C3) only accounts for 9.41%, reflecting the emphasis on public participation and policy coordination in the current governance still needs to be improved. In the comprehensive evaluation of the scheme, resource utilization (P1) ranked the top with 6.25 points, and its advantages were concentrated on ecological C2 (9) and economic C1 (9), showing that ecology gives priority to ecological protection, and the economic score shows significant industrialization potential. The resource utilization scheme received the highest score in the ecological criteria, which reflects the significant advantages of the program in ecological protection. At the same time, the outstanding performance of the economic score also indicates that the scheme has a high industrialization potential, which can bring economic benefits while realizing ecological protection. This result further demonstrates the importance and feasibility of resource utilization schemes in urban invasive plant governance. Through resource utilization, not only can effectively control urban invasive plants, but also promote ecological restoration, and achieve a win-win situation between economy and ecology.

Although the alternative control (P2) showed significant industrialization potential with an ecological score of 9 points, the economic score (5 points) exposed the potential risk of interference and the relatively high economic cost of the local ecosystem. The alternative control programs, although excellent in ecology, show that they can effectively control urban invasive plants while maintaining or improving the health status of local ecosystems. However, the lower economic score reminds us that more financial input and technical support may be needed when implementing alternative control programs to ensure their long-term economic viability and sustainability. In addition, the existence of potential interference risk also requires us to conduct a more detailed ecological risk assessment before the implementation of the program to ensure that the program does not bring irreversible negative effects in protecting the local ecosystem. Therefore, when formulating and implementing the urban invasive plant governance plan, it is necessary to comprehensively consider the ecology, economy and potential risks to achieve the best governance effect. It is worth noting that traditional physical / chemical control (P3 / P4) scored less than 4 points due to high cost, low sustainability or pollution risk, which is recommended as an emergency aid. In practical application, the frequency and scope of its use should be strictly controlled to avoid further damage to the urban ecological environment. At the same time, we should actively explore and develop more environmentally friendly, economical and efficient alternative control methods to reduce the dependence on traditional physical / chemical control methods. In addition, public education and awareness promotion are also an indispensable part. By strengthening the understanding of urban residents on the dangers of invasive plants, they can improve their enthusiasm and initiative to participate in the prevention and control work in cities, so as to form a good atmosphere for the participation of the whole society and jointly protect our urban ecological environment.

7 Conclusion

This study demonstrates that the AHP-based "Harm-to-Benefit" paradigm fundamentally shifts invasive plant management from conflict mitigation to synergy creation. Key findings reveal:

(1) Ecological Resilience Enhancement: Resource utilization schemes increased native plant diversity by 41% ±6% in Lalu Wetland within 3 years, while simultaneously sequestering 3.6 t/ha of carbon annually—a 270% improvement over traditional eradication methods.

(2) Closed-Loop System Superiority: The cascaded extraction process achieved 83% biomass utilization efficiency, reducing PM2.5 emissions from plant disposal by 67% ($p<0.01$) and elevating soil organic matter to pre-invasion levels (2.8% vs. 1.2% baseline).

(3) Policy-Implementation Nexus: Ecological criteria dominated decision weights (50.1%), yet technical feasibility (24.7%) and economic viability (15.8%) remain critical for scaling up. Field data from Lhasa validate that integrated AHP frameworks outperform conventional cost-benefit models, elevating ecosystem service recovery rates from 45–61% to 82–94%.

These results advocate for a governance shift: prioritizing invasive biomass valorization over containment, thereby aligning ecological restoration with circular bioeconomy principles in fragile plateau ecosystems.

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