Survival Status, Challenges, and Conservation Strategies of Xinjiang Wild Apple (Malus sieversii): Postprint

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Abstract

Xinjiang wild apple (Malus sieversii) is the dominant species in the Tianshan wild fruit forests, exhibiting extremely rich genetic diversity and constituting an important component of the global apple gene pool. Since the 1960s, the distribution area of Xinjiang wild apple populations has declined sharply. However, the causes underlying this population decline remain unclear, and no effective conservation measures have been established.

This study, based on a comprehensive review of previous research and combined with field investigations, further analyzes and discusses the current distribution status of wild apples and the challenges they face, including insect pests, disturbances, and population regeneration difficulties.

The investigation reveals that the following problems persist in the conservation and research of Xinjiang wild apple: First, controversy remains regarding the origin and evolution of Xinjiang wild apple. Second, the distribution area of Xinjiang wild apple populations continues to contract, with the area in three counties being less than one-third of that recorded 60 years ago. Third, although the insect pest problem has been effectively controlled, a comprehensive pest prevention and monitoring system has not been fully established. Fourth, issues of excessive disturbance persist; while farmland reclamation and human logging have been somewhat controlled, overgrazing remains prevalent. Fifth, the problem of regeneration difficulty remains prominent, with existing research being at a preliminary stage and lacking in-depth investigation.

To address these existing problems, the following measures are recommended: utilize molecular biology and other advanced technologies to further investigate the origin and evolution of Xinjiang wild apple; establish a Xinjiang wild apple resource monitoring system, employing cutting-edge monitoring technologies to

timely and effectively track the current status of wild apple resources; develop a pest prevention and monitoring system to promptly and effectively monitor and control disease and pest outbreaks; establish Xinjiang wild apple protected areas, strengthening in-situ conservation and legal publicity to enhance local residents' awareness of endangered plant protection; conduct research on the regeneration mechanisms of Xinjiang wild apple, while simultaneously reinforcing ex-situ conservation measures.

Through these proposed solutions and recommendations, this study aims to provide a scientific reference for the effective conservation and management of Xinjiang wild apple.

Full Text

Survival Status, Problems, and Conservation Strategies of *Malus sieversii* in Xinjiang

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Abstract

Malus sieversii is a dominant species in the Tianshan wild fruit forests and possesses extremely rich genetic diversity, representing an important component of the world' s apple gene pool. Since the 1960s, the distribution area of *M. sieversii* populations has declined sharply. However, the causes of this population decline remain unclear, and no effective conservation measures have been established. Based on a comprehensive review of previous studies combined with field investigations, this paper further analyzes and discusses the current distribution status of wild apples and the challenges they face, including pest infestations, anthropogenic disturbances, and regeneration difficulties. Our analysis reveals five persistent problems in the conservation and research of *M. sieversii*: First, the origin and evolution of *M. sieversii* remain controversial. Second, the distribution area of *M. sieversii* populations continues to shrink, with three counties now having less than one-third of the area they had 60 years ago. Third, while pest problems have been effectively controlled, a comprehensive pest prevention

and monitoring system has not been fully established. Fourth, issues of excessive disturbance persist; although farmland reclamation and logging have been somewhat controlled, overgrazing remains a serious problem. Fifth, the difficulty of *M. sieversii* regeneration remains prominent, with existing research still in its preliminary stages and lacking in-depth investigation. To address these issues, we propose the following measures: utilize molecular biology techniques to further study the origin and evolution of *M. sieversii*; establish a resource monitoring system employing advanced technologies to effectively track the status of *M. sieversii* resources; develop pest prevention and monitoring systems for timely detection and control of disease and pest outbreaks; establish protected areas for *M. sieversii* to strengthen in-situ conservation and legal outreach, enhancing local residents' awareness of endangered plant protection; and conduct research on the regeneration mechanisms of *M. sieversii* while strengthening ex-situ conservation measures. These proposed solutions and recommendations aim to provide a reference for the scientific conservation and effective management of *M. sieversii*.

Keywords: endangered plant, population distribution, population regeneration, insect pests, human disturbance, conservation strategies

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Malus sieversii, also known as Sievers apple or Tianshan wild apple, constitutes an important component of the world' s apple gene pool and represents the progenitor of modern cultivated apples. It is classified as a Grade II nationally protected endangered plant in China and listed as "Vulnerable" by the International Union for Conservation of Nature (IUCN). As a dominant species in the Tianshan wild fruit forests, *M. sieversii* is naturally distributed across Central Asian countries including Kazakhstan and Kyrgyzstan, with its Chinese distribution limited to the Ili River Valley and Tacheng region of Xinjiang. The species exhibits rich population genetic diversity and plays a crucial role in maintaining regional ecosystem stability, soil and water conservation, and biodiversity. Through long-term evolutionary processes, it has developed excellent traits such as cold resistance, drought tolerance, and disease resistance. However, over recent decades, *M. sieversii* forests have suffered severe ecological damage and extreme difficulties in natural regeneration due to anthropogenic disturbances including illegal logging, forest clearing for agriculture, damage from the apple small borer (*Agrilus mali*), and grazing pressure. These factors have led to a sharp decline in natural population numbers and distribution area, severely impeding reproduction, accelerating the loss of genetic diversity, and depleting germplasm resources, making urgent conservation action imperative.

Despite the recognized importance of *M. sieversii* and numerous conservation efforts, the species remains critically endangered. The causes of population decline are still not well understood, and implemented conservation measures have not achieved effective protection outcomes. Although previous reviews have summarized resource status, ecological characteristics, genetic relationships with cultivated apples, genetic diversity, and conservation strategies, a decade has passed

since these syntheses. Critical questions remain: What persistent problems exist in current conservation and research efforts? What future research directions could enable more effective protection and utilization? This paper provides an updated comprehensive review covering the origin and evolution of *M. sieversii*, current conservation challenges, and strategies for improved protection and utilization. Based on field surveys and literature analysis, we systematically examine existing problems in *M. sieversii* conservation and research, propose targeted solutions and recommendations, and aim to provide a foundation for the scientific conservation and effective management of this endangered plant resource.

1.1 Origin and Evolution of *Malus sieversii*

The origin and evolution of *M. sieversii* have long been subjects of scholarly debate, with two main hypotheses. The first suggests that *M. sieversii* originated in the Tertiary period, survived geological transformations, and retreated to climatically favorable "refugia" during several Quaternary glaciation events, resulting in today' s patchy distribution of wild apple communities. The second hypothesis proposes that *M. sieversii* underwent multiple cycles of expansion and contraction across the Central Asian plains, including the Tianshan Mountains of China and Kazakhstan, with post-glacial migration occurring from west to east to form the current distribution pattern. Recent research supports both views to some extent. Habitat fragmentation has created three distinct genetic lineages: a Tacheng region lineage in China, a Tajikistan-Kazakhstan Dzungarian lineage, and an eastern lineage extending from China' s Ili region through Kazakhstan to Kyrgyzstan. Differentiation among these lineages was driven by increasing aridification in Central Asian mountains since the Late Miocene, with further range contraction during the Quaternary preserving the species in narrow, climatically favorable mountain refugia—supporting the first hypothesis. Conversely, Li et al. (2011) used molecular data to argue that during glacial periods, *M. sieversii* retreated to Central Asian plains, then post-glacially migrated along the Trans-Ili Alatau into the low mountains of the Ili region, reaching Gongliu and Xinyuan counties before continuing eastward and northward —partially supporting the second hypothesis. The key disagreement centers on whether *M. sieversii* completely disappeared from the Ili River Valley during glacial periods. Resolving this debate requires further analysis using palynology, fossil evidence, and genome sequencing technologies.

1.2 Dramatic Reduction of *Malus sieversii* Distribution Area in China

Malus sieversii naturally occurs across Central Asian regions including eastern Kazakhstan, the Dzungarian and Trans-Ili Alatau ranges, Zhambyl, Karatau, Kyrgyzstan' s Issyk-Kul and Talas Alatau ranges, Uzbekistan' s Fergana region, and Tajikistan. In China, it is concentrated in the Tianshan, Barluk, and Tarbagatay mountains at elevations of 1,000–1,800 m, with recent surveys documenting occurrences up to 2,023 m. The species is patchily distributed

across six counties: Xinyuan, Gongliu, Yining, and Huocheng in Ili Kazakh Autonomous Prefecture, and Tuoli and Emin in Tacheng region. Analysis of distribution trends over the past 60 years using R software reveals a dramatic decline in Xinjiang, with populations in Xinyuan, Gongliu, and Emin counties shrinking to less than one-third of their original area, while Huocheng, Tuoli, and Yining show less change, though current data for these counties remain incomplete [Figure 1: see original paper].

1.3 Persistent Pest Damage to *Malus sieversii*

Research indicates that *M. sieversii* suffers from multiple pests and diseases, with the apple small borer (*Agrilus mali*) and apple ermine moth (*Yponomeuta padella*) being the two major threats. In 2011, *A. mali* infested 3,866 hectares in Ili' s wild apple forests, affecting nearly 40% of the total area and killing over 600 hectares of fruit trees. Inadequate prevention, limited understanding of the pest' s life history, and scarcity of natural enemies led to rapid spread and sharp declines in fruit and seed production. In addition to *A. mali*, other pests from Lepidoptera, Coleoptera, and Hymenoptera orders inhabit healthy trees, feeding on leaves and causing tree mortality during outbreaks .

1.4 Ongoing Excessive Disturbance of *Malus sieversii*

Since the 1960s, excessive disturbance has caused soil erosion and landslides in some *M. sieversii* distribution areas. Field surveys from 2015–2020 confirm that over-interference remains a serious problem, including: (1) Farmland expansion—though somewhat controlled, forest clearing for agriculture persists in Gongliu and Xinyuan counties [Figure 2A: see original paper]; (2) Overgrazing—livestock browsing and trampling of seedlings and fruit consumption occurs throughout protected areas, severely affecting growth and reproduction in Huocheng, Gongliu, and Xinyuan counties [Figure 2B: see original paper]; (3) Tourism development—visitor access to scenic areas like Guozigou in Huocheng leads to seedling trampling and fruit picking; and (4) Proximity to cultivated apples—genetic erosion from nearby *Malus* ×*domestica* plantations reduces genetic diversity of wild populations [Figure 2C: see original paper].

1.5 Regeneration Difficulties in *Malus sieversii* Populations

Malus sieversii understories lack seedlings, with populations dominated by older individuals and few young ones, resulting in unstable or declining population structures that impede reproduction and natural regeneration. Current research reveals three main challenges: (1) Extreme seedling scarcity—while a 2007 survey in Gongliu and Xinyuan showed relatively stable age structures in intact populations, more recent studies indicate that even well-preserved Xinyuan populations have few young individuals and show declining trends. Investigations in Emin and Tuoli counties found regeneration lagging behind population aging, indicating more severe decline. (2) Poor seedling survival—continuous monitoring in

Xinyuan revealed that naturally germinated seedlings cannot survive until autumn, making natural regeneration extremely difficult. Successful regeneration requires suitable habitats for both seed germination and seedling establishment. (3) Absence from soil seed banks—a survey in Gongliu' s Mohor Township found no *M. sieversii* seeds in the soil seed bank, further limiting regeneration potential.

2.1 Investigating Origin and Evolution Using Molecular Biology Techniques

Researchers have employed molecular biology techniques to study plant origins, evolution, and migration through morphology, cytology, palynology, enzymology, and molecular markers. While some studies have addressed *M. sieversii* origin and evolution, data remain insufficient. We recommend strengthening international and domestic collaboration using advanced genomics methods to resolve these controversies. Phylogeographic analysis provides effective tools for exploring species' evolutionary history and modern distribution patterns. Molecular clocks and fossil evidence are primary methods for estimating origins and evolution, though plant fossils are often scarce and insufficient. Combining molecular clocks with fossil records offers more effective estimation of species' evolutionary timelines. Applying these techniques to *M. sieversii* research holds significant scientific value.

2.2 Integrating Remote Sensing, Ecology, and Molecular Biology to Investigate Distribution Decline

Despite conservation investments since the 1950s, including protected area establishment, in-situ and ex-situ conservation, pest control, and artificial regeneration, *M. sieversii* decline continues due to mountainous terrain, poor planning, excessive historical disturbance, and natural regeneration difficulties. We recommend: (1) Using drones and remote sensing for distribution monitoring —these technologies enable rapid, accurate identification and area calculation compared to traditional surveys; (2) Combining ecological methods to explore causes beyond human impacts, such as climate and land-use change reducing suitable habitats; and (3) Integrating molecular biology to investigate biological constraints like dispersal and propagation limitations.

2.3 Comprehensive Pest Management and Control

Pest control is an urgent task for *M. sieversii* forest restoration. Researchers have extensively studied *A. mali* biology, spatial distribution, natural enemies, and control effectiveness, providing theoretical foundations. Biological control using parasitoid wasps and trunk injection methods have proven effective. Studies have also examined relationships between pest density and stand factors, revealing significant negative correlations with altitude and slope. While progress has been made, we recommend: (1) Employing remote sensing, insect radar, ground sensor networks, and GIS for systematic monitoring and prevention; (2)

Strengthening research on pest mechanisms, particularly responses to global warming; and (3) Preventing invasion of foreign pests like fire blight, which severely threatens both wild and cultivated apples.

2.4 Effective Protection Measures Against Excessive Disturbance

Human impacts have caused persistent population decline, reduced numbers, simplified structure, and increasing endangerment. To reduce over-interference, we recommend: (1) Establishing ecological research stations to integrate Tianshan wild fruit forests into national ecological monitoring networks, implementing strict protection regulations including closure measures in heavily disturbed areas, and enforcing laws against grazing, deforestation, construction, improper grafting, and excessive tourism development with dedicated management personnel; and (2) Strengthening legal outreach to enhance local residents' conservation awareness, particularly in mountainous areas where legal understanding is limited.

2.5 Comprehensive Investigation of Regeneration Difficulties

Seedling recruitment and population regeneration critically affect Tianshan wild fruit forest community structure. Literature shows severe regeneration barriers across multiple counties. Despite national and regional support for measures like returning farmland to forest, enclosure fencing, seed propagation, artificial tending, root sprouting, and artificial pollination, obstacles persist. We recommend: (1) Enhancing research on regeneration mechanisms—studies show overgrazing, seedling harvesting for fodder, and fruit collection reduce seedlings, while heterospecific soils may facilitate regeneration and conspecific soils may inhibit it. Systematic research from seed production to seedling establishment is needed to identify key limiting factors. (2) Conducting long-term continuous monitoring of regeneration status across multiple populations, examining microhabitat effects on seedling growth and mortality to identify critical regeneration stages. (3) Utilizing modern biotechnology and artificial measures to promote natural regeneration, including artificial seeding, planting, grafting, and tissue culture methods that have established effective propagation systems.

3.1 Establishing a Resource Monitoring System

Malus sieversii faces numerous survival and reproduction challenges. While conservation research has employed molecular biology, ecology, remote sensing, pest control, and artificial regeneration, these efforts remain preliminary with insufficient investigation of endangerment mechanisms. Based on previous experience, we recommend improving distribution information through continued community surveys and remote sensing technologies to establish an information monitoring network. Real-time monitoring of growing environments can prevent human damage and identify other threats. A comprehensive monitoring system would enhance supervision, provide dynamic information on resource and

habitat changes, improve endangered species evaluation systems, and achieve effective protection.

3.2 Advancing Ex-Situ Conservation Research

Research on in-situ conservation, ex-situ conservation, and artificial propagation has expanded population numbers, providing better conditions for future studies. We recommend integrating in-situ, ex-situ, and reintroduction approaches with long-term monitoring to understand age structure and population dynamics of ex-situ populations. Investigating functional leaf traits, ecological stoichiometry, and nutrient resorption efficiency in relation to environmental factors like light and soil moisture would enable comprehensive adaptability assessment. Examining reproductive success through flowering, fruiting, seed morphology, and germination rates would determine offspring fitness differences and evaluate ex-situ conservation success, providing theoretical foundations for future efforts.

3.3 Establishing *Malus sieversii* Protected Areas

Scientific conservation and sustainable population development remain challenging. We recommend establishing dedicated *M. sieversii* protected areas in the Tianshan wild fruit forest region to strengthen in-situ conservation. While existing reserves protect other species, none specifically target wild *M. sieversii* populations. A dedicated reserve would minimize human destruction and external interference through strict protection regulations, maximizing conservation effectiveness and gradually restoring the ecological environment and biodiversity of wild apple forests.

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