

Pinus massoniana seeding practices for forest restoration in China

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Abstract

Previous afforestation effort, much of which was accomplished with aerial seeding, restored *Pinus massoniana* Lamb. forests across more than 4 million ha of barren lands and difficult mountainous terrain in Ganzhou, Jiangxi Province, China. This manuscript provides a review of literature reporting the factors that led to forest and site degradation, conventional practices and techniques used to widely establish forest cover of *P. massoniana*, and post-sowing and plantation management practices used to encourage development and growth of restored *P. massoniana* forests. Factors known to impede successful seeding of *P. massoniana* include poor seed quality, harsh soil and site conditions such as soil erosion and droughty soil, unpredictable and extreme weather or climatic events including drought, frost, or excessive rainfall, and insufficient site preparation or plantation maintenance. Procuring high-quality seed, conducting thorough site assessments, and implementing practices that effectively mitigate factors that limit seed germination, seedling establishment, and tree growth are key to successful *P. massoniana* seeding.

Keywords

Mason’s pine, direct seeding, aerial seeding

Contents

1	The region	55
1.1	Physiographic region and climate	55
1.2	The forest	56
2	Deforestation of degradation of restoration sites	57
2.1	Site degradation	57
2.2	Seed, seedling, and tree damaging agents	58
3	Mitigating impacts for seeding	58
3.1	Site preparation	58
3.2	Damage prevention	59
4	Seed procurement and preparation	60
4.1	Collection	60
4.2	Handling	60
4.3	Storage and stratification	60
4.4	Plantation establishment	61
5	Post-sowing practices and plantation maintenance	62

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6	Successful seeding	63
6.1	Defining success	63
6.2	Limiting factors and risks	65
6.3	Key elements that contribute to success	65
7	Acknowledgements	65
8	References	66

1 The region

Ganzhou, the largest administrative region in Jiangxi Province, China, has a warm and humid subtropical climate, creating favorable conditions for the growth of trees and forests (Figure 1). Historically, it was an area very rich in forest vegetation, but due to wars and over-harvesting, its native forest has been seriously degraded and reduced. By the early 1980s, about 6.8 million ha of forests suffered extensive environmental degradation and severe soil erosion. To effectively improve the ecology and environment of the region, Ganzhou carried out the Greening Gannan Action from 1985 to 1994. In barren lands and forestland of difficult terrain conditions, more than 4 million ha of *Pinus massoniana* Lamb. forests were created through afforestation with aerial seeding and planting seedlings (Pan et al. 2019). Forest cover in the region has increased to 76.2%, which has played an important role in improving local ecological and environmental conditions, effectively curbing land degradation, and reducing soil erosion.

1.1 Physiographic region and climate

Ganzhou is located between 24° 29' and 27° 09' N latitudes and 113° 54' and 116° 38' E longitudes. With a latitudinal distance of 295 kilometers and a longitudinal distance of 219 km, the region has a land area of 39,400 sq km, accounting for 23.6 % of the total land area of Jiangxi Province (Figure 1).

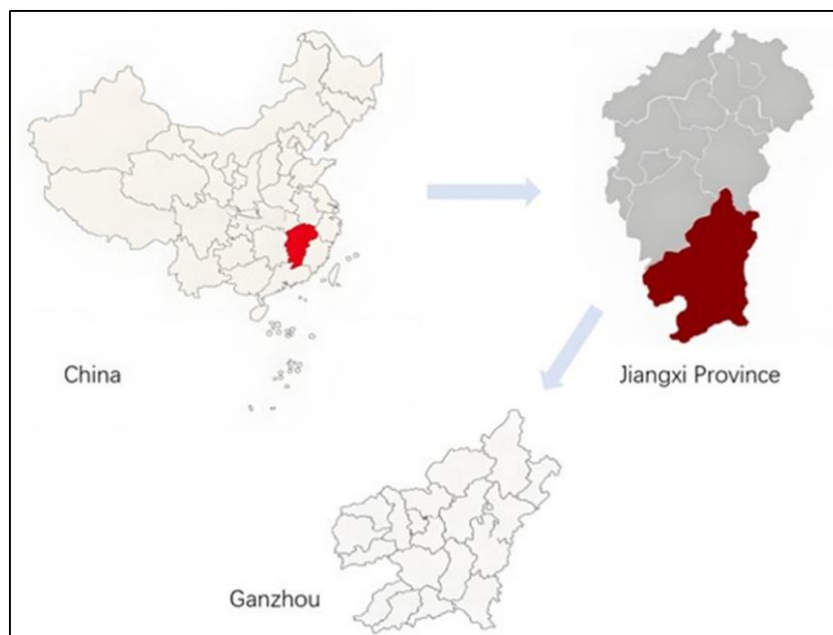


Figure 1. The location of Ganzhou in the Jiangxi Province of China.

Ganzhou is located on the northern edge of the southern subtropical zone and the southern edge of the central subtropical zone. The subtropical hilly and mountainous humid monsoon climate prevails, with precipitation concentrated in spring and summer, and the region experiencing four distinct seasons. The average annual temperature is 18.9 °C, the average daily temperature in the warmest month is 38.6 °C, the average daily temperature in the coolest month is -7.9 °C, the average annual rainfall is 1526 to 1700 mm, and the average annual frost-free period is 282 to 293 days. According to IPCC (2023), average global temperatures are likely to rise by more than 1.5 °C above pre-industrial levels by 2050, likely resulting in an increase in the frequency and magnitude of extreme events, such as extremely high temperatures and heavy rainfall events.

A variety of soils occur in Ganzhou. Primary soil parent materials are granite, purple shale, slate, sandstone, limestone, gneiss, and Quaternary red clay. Based on the USDA classification system (Soil Survey Staff 2022), the main soils in the region are Ultisols, which are derived from weathered red sandstone and mudstone.

1.2 The forest

P. massoniana (Masson's pine, horsetail pine) is the primary overstory species of forests created through afforestation in Ganzhou. It can tolerate infertile soil and drought and grows on clay, sand, gravel ridges and slopes, and in exposed crevices in rocks. The species grows best in acidic to slightly acidic soil (pH 4.5–6.5). It grows poorly on waterlogged sites and is intolerant of salts and alkalinity in calcareous soils.

The understory vegetation of *P. massoniana* forests is relatively rich with understory shrubs including *Glochidion puberum* (L.) Hutch., *Loropetalum chinense* (R.Br.) Oliv., *Lespedeza bicolor* Turcz., *Rhododendron simsii* Planch., *Eurya japonica* Thunberg, *Phyllanthus urinaria* L., *Symplocos tanakana* Nakai, and *Gardenia jasminoides* J. Ellis. Other understory vegetation mainly includes *Dicranopteris dichotoma* (Thunb.) Bernh., *Imperata cylindrica* (L.) P. Beauv., *Miscanthus floridulus* (Labill.) Warb. ex K. Schum. & Lauterb., *Agropyron cristatum* (L.) Gaertn., *Ischaemum ciliare* Retz., *Paspalum orbiculare* Forst., *Poa annua* L., *Eriachne pallescens* R. Br., *Carex parva* Nees, and *Pteridium aquilinum* (L.) Kuhn.

The region is dominated by young forests, mostly ranging from 16 to 33 years old. The average diameter at breast height (DBH) ranges from 7.6 cm to 19.0 cm, the average dominant height ranges from 7.4 m to 18.9 m, and the density ranges from 331 to 5039 stems ha⁻¹ (Cao et al. 2018). Characteristics that favor the natural regeneration of *P. massoniana* include abundant seed production, ease of dispersal, and resistance to stress and some anthropogenic disturbance. In contrast, constraints to seedling establishment include environmental requirements of the species, competition, animal damage, disease and insect pests, and some anthropogenic factors, e.g., soil degradation. For example, people often excessively cut or clear *P. massoniana* forests to obtain wood or expand agricultural land. This impairs the ecology of the provenance and degrades the soil environment favorable to *P. massoniana* thereby hindering its natural renewal.

2 Deforestation or degradation of restoration sites

2.1 Site degradation

Soils, topography, and climate predispose forest sites of the Ganzhou region to degradation following certain disturbances (Figure 2). The Ultisols in Ganzhou are characterized by low organic matter content, poor soil fertility (Zhong et al. 1998), and subsoils high in sand and coarse fragments. These factors result in poor physiochemical properties that impede vegetative recovery after disturbance. Further, soil micromorphological analysis indicates that soil development is slowing as the process of iron mineralization and argillic horizon formation are gradually weakening, alteration of feldspar and mica is diminishing, and detrital weathering is intensifying (Cheng et al. 2006). Relative to topography, the terrain in the Ganzhou region is mainly composed of low mountains and hills. Where areas of sun-exposed, windward slopes occur, there is heightened potential for surface runoff and sediment transport creating highly erodible topographic conditions. Finally, the subtropical climate of the region brings high temperatures and abundant rainfall. The distribution of annual precipitation is highest in the spring and summer (70% of annual precipitation), with typhoon-induced rainstorms of high erosivity being common. This climatic pattern exacerbates severe soil erosion and degradation in the region. Together, these factors create a harsh environment for the establishment and development of *P. massoniana* forests.

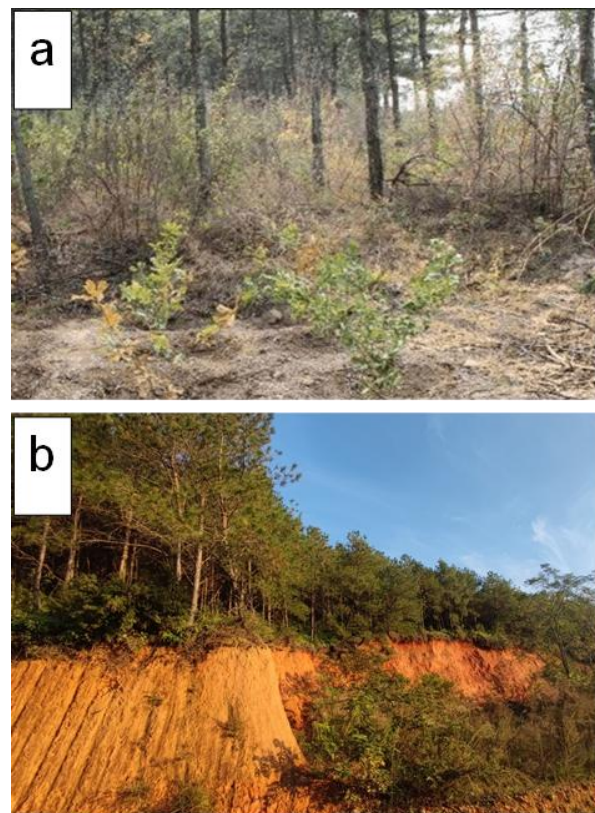


Figure 2. Degraded site (a) and soil erosion (b) in *P. massoniana* afforestation areas of Ganzhou. (Photo credits: (a) Qiao Liu, (b) FangChao Wang).

2.2 Seed, seedling, and tree damaging agents

Several diseases can impact the establishment and survival of *P. massoniana* seedlings and trees. Damping-off is a common disease caused primarily by the fungi *Fusarium oxysporum* and *F. verticillioides*. Damage occurs during seed germination near the soil surface such that the shoot may fail to emerge from the soil and die due to rot of the apical meristem or other soft tissues. Leaf blight (pathogen *Cercoseptoria pini-densiflorae*.) is common during the seedling phase, prevalent from August to October, and spreading during periods of high rain. Mortality occurs if most needles are diseased. Sphaeropsis blight (*Sphaeropsis sapinea*) can cause damping-off of seedlings or a foliar disease of larger plants (Huang 2020). Pine rust (*Cronartium quercuum*) can be harmful to established trees, creating cankers that weaken stems. Avoiding the establishment of pine-oak (*Quercus* spp. L.) mixtures when restoring forests can reduce the incidence of this disease (Liu 2021). The pinewood nematode disease (*Bursaphelenchus xylophilus*) often causes high mortality in infected trees (Kim et al. 2020). The disease is vectored by a beetle (*Monochamus alternatus*) and is commonly observed under hot and dry climatic conditions.

Animal damage to *P. massoniana* seed and seedlings mainly includes herbivory, trampling of seedlings, and other indirect damage. Rodents, e.g., squirrels (Family Sciuridae) and voles (Subfamily Arvicolinae), and birds, e.g., the Oriental magpie (*Pica serica*), often consume seed, significantly reducing its availability for germination. Large animals such as wild boar (*Sus scrofa*) and deer (Family Cervidae) can damage seedlings by browsing on the young needles, digging up the roots, or inhibiting seedling growth by destroying soil structure through trampling. In addition, gnawing by mice and rats (Family Muridae) may damage the seed coat of seed, making it easier for pathogens to infect and indirectly increasing the risk of disease.

3 Mitigating impacts for seeding

3.1 Site preparation

As seeding is conducted mostly by aerial means, site preparation is very necessary. Clearing the site of weedy vegetation is typically the first practice. Lawnmowers or brush cutters are used along the main pathways of the site for removal of herbaceous plants and small shrubs. Tractors and/or chainsaws may be needed to clear larger shrubs or dense vegetation. After vegetation is cleared, soil is loosened or tilled to prepare the seedbed. Tillers or plows are used to loosen the surface layer, especially in hardened or barren soil areas. The typical loosening depth is 10–15 cm, which enhances soil aeration and water retention. In addition, for areas with steeper slopes, bulldozers or excavators can be used to create small ditches or terraces that help control soil erosion and retain moisture. Modifying the slope through terracing can prevent seed from being washed away. Finally, aerial applications of fertilizers (such as nitrogen, phosphorus, potassium, or slow-release fertilizers), applied with helicopters or drones, can be used to improve site fertility (Chen 2022).

3.2 Damage prevention

To prevent the occurrence of disease, it is necessary to ensure that *P. massoniana* seeds are sourced from healthy origins, avoiding seed contaminated with pathogens. Additionally, necessary seed disinfection treatments should be carried out, such as soaking seed in a 0.5% potassium permanganate solution for 2 hours or spraying seed with a 3.0% formalin solution and then rinsing. Avoiding sowing densities that overcrowd seedlings is beneficial because appropriate sowing densities help maintain good air circulation around seedlings and reduces proliferation of certain pathogens. Overly dense plantations tend to trap moisture that favors the occurrence of mold and fungal diseases. In the case of severe diseases, applications of low-toxicity pesticides, such as fungicides, may be appropriate for limiting impacts. However, excessive reliance on chemical control of pathogens should be avoided, and integrated methods, including biological control and physical control, should be considered to reduce environmental pollution and to minimize negative impacts on the ecosystem. Further, regular disease monitoring should be implemented at the afforestation site, observing tree growth, leaf color, and any abnormalities in tree bark to detect potential disease risks early. Monitoring equipment, such as temperature and humidity sensors, can also be deployed to collect soil and climate data to predict and prevent possible disease outbreaks.

When selecting seed, it is important to choose *P. massoniana* varieties with strong disease resistance. Selecting superior seed sources with disease resistance can substantially limit damage caused by pathogens. Also, fertilization can promote healthy tree growth and enhance resistance to pathogens. However, excessive nitrogen fertilizer may cause trees to grow too quickly, making them more susceptible to pest damage, so fertilization should be based on soil conditions relative to the needs of the trees. Ensuring good soil drainage to prevent waterlogging is also important for minimizing damage by pathogens. Some pest prevention can be gained from the use of natural predators and other beneficial organisms. For example, releasing natural predators (such as ladybugs (Family Coccinellidae) or predatory mites (Class Arachnida)) can help control pest populations. Additionally, establishing pest-resistant plants among *P. massoniana* can disrupt the spread of pests, reduce pest occurrence, and enhance the ecological stability of the forest.

Preventing animal damage on the forest restoration site has been accomplished with fencing and trapping. Fencing prevents entry of larger animals potentially damaging to the regeneration, while live traps, such as cage traps set with appropriate bait, can be established near fencing to capture smaller animals not deterred by fences. Additionally, measures to reduce animal habitat and food sources around the restoration area can be used to minimize animal damage. For example, clearing surrounding brush, decaying wood, weeds, and leaf piles can help reduce rodent habitat and the level of their presence in the afforestation area. Moreover, planting aromatic or animal-repelling plants around the *P. massoniana* forest, such as rosemary (*Salvia rosmarinus* Spenn.), mint (*Mentha* spp. L.), or lavender (*Lavandula* spp. L.), can serve as natural deterrents. These plants, through their scent or unpleasant taste, can discourage animal use of the area. The use of noise-generating devices (such as ultrasonic animal repellents) or light-based devices (such as flashing lights or mirrors) can also help scare animals away or effectively prevent animals from entering the restoration area, especially during the early stages of sowing and establishment.

4 Seed procurement and preparation

4.1 Collection

Ensuring genetic diversity of the seed source is key to enhancing the success rate of *P. massoniana* seeding. Therefore, in seeding projects in Ganzhou, the selection and management of seed sources should be an important consideration to ensure the use of high-quality seeds that are suited to local environmental conditions (Qin 2017). *P. massoniana* seed is typically collected from well-performing natural stands or orchards across the range targeted for seeding. The best time for seed collection is from mid-November to early December, with a preference for cones from trees that exhibit good growth and form. Cones harvested for their seed are usually yellow-brown or chestnut-brown and show good seed production.

4.2 Handling

Removing seed from *P. massoniana* cones is a several step process. First, the cones are screened to remove those that are broken, diseased, or infested with pests. After screening, they are sprinkled with lime and covered with straw to retain heat and moisture. Generally, a thin, even layer of lime (about 100–150 g m⁻²) is sprinkled over the cones. The cones are turned every other day and sprayed with warm water (50 to 60 °C) for about 10 days (Lai 2019). Lastly, cones are spread on a concrete pad in the sun or heated in a ventilated room to encourage the release of the seed. Seeds that separate from cones are collected on a regular basis and prepared for storage.

Testing seed viability and quality are crucial steps for ensuring successful afforestation (Dong et al. 2019). The seed should be full, free from insect infestation, disease, and mold, and have a glossy seed coat that smells of pine resin. The kernel should be milky white, opaque, elastic, and not oily. Embryos should be bright white with more oil than the kernel; poorly developed or embryos from old seed are discolored and lack oil or appear hard, rotten, molded, or powdery. Tetrazolium chloride staining can be used as an indicator of viability—full staining of cut seed indicates viability. Quality can also be indexed by the compression method. In this technique, seeds are boiled in water for 10 minutes and then squeezed between two glass slides. White pulp squeezed out of the seed indicates good quality, while the release of water or bubbles indicates poor quality. Another test involves sliding seed across the palm of the hand with thumb and fingers of the other hand; a crisp, “rustling” sound indicates good water content (10–11%) and quality seed.

4.3 Storage and stratification

Seed separated from cones should be placed in water to remove debris and filter out bad seed; good seed will sink, and bad seed often will float. *P. massoniana* seed should be stored at 8% moisture content under controlled temperature (0 to 5 °C) and relative humidity (60% or less) (Xia 2019). Seed should be stored in moisture-resistant bags that allow for some gas exchange. The storage area should be well-ventilated to ensure adequate airing. *P. massoniana* seeds are typically stored for up to 1 year but can be stored for 2 years if adequately dried and sealed in moisture-tight plastic bags.

4.4 Plantation establishment

Aerial seeding is a quick, efficient, and low-cost method for sowing seed on afforestation sites. This method is especially suitable for seeding large, remote, and mountainous areas that are difficult to access and traverse. The area to be seeded should be a contiguous area large enough for the operation of the aircraft, i.e., helicopters or drones. Agricultural (fixed-wing planes or helicopters) aircraft were mainly used to aerially seed most of the early afforestation projects, while today some aerial seeding is being conducted with drones. Terrain and clearance should meet the operational requirements of the selected aircraft. Areas appropriate for aerial seeding of *P. massoniana* are generally hills and mountains with elevations of 300 to 800 m and slopes of less than 35°. Sites preferably are of deep, acidic red soils with good drainage and a site index of ≥ 16 m at base age 50 years (Zhao 2021).

In Ganzhou, aerial seeding of *P. massoniana* is typically conducted using helicopters or drones flying at a height of 50 to 100 m to ensure broad coverage of the area and minimize the impact of wind speed variation. Depending on the terrain and equipment used, about 30 to 80 ha can be seeded per hour. Given the hilly and mountainous terrain of Ganzhou, aerial seeding is an effective method for reaching remote and steep areas that are difficult to access. During the seeding process, low wind speeds are required, ideally between 3 to 5 m sec⁻¹, to prevent seed from dispersing unevenly or being blown off course. Before seeding, a terrain survey and weather assessment are necessary to ensure optimal timing and equipment settings for the seeding operation, which will improve seeding efficiency and seedling establishment rates.

Aerial seeding should be conducted between late February and early March (late winter to early spring). Because of the subtropical monsoon climate at Ganzhou, the temperature and rainfall in spring provide new germinants with a long establishment period before the hot and dry season arrives.

It is often difficult to control initial seedling density when using aerial seeding, but densities that are too high may be reduced with tending treatments after stand establishment if the area is accessible. Under normal circumstances, the seeding rate for aerially sown *P. massoniana* is 4–6 kg ha⁻¹. Densities between 3300 to 3600 stems ha⁻¹ meet establishment objectives for small- to medium-diameter timber at a rotation length of 30–40 years, densities between 3000 to 3300 stems ha⁻¹ meet objectives for large-diameter timber at a rotation length of 40–50 years, and densities of 1500 to 1650 stems ha⁻¹ meet objectives for very large diameter timber at a rotation length of 50–60 years (Zhang 2023).

Establishing mixed-species plantations is an effective approach for enhancing the sustainability of *P. massoniana* forests. By introducing other tree species into *P. massoniana* stands, ecological diversity and stability of the forest can be improved, reducing the risks of pests and diseases that affect monocultures, and promoting soil health and water cycle improvements. For example, native evergreen species like *Quercus variabilis* Blume are highly plastic and thrive in acidic or mildly acidic soils. When established in mixed plantings with *P. massoniana*, gains are observed in forest biodiversity, soil structure, and soil water retention capacity. Two other tree species, *P. tabuliformis* Carr. and *Robinia pseudoacacia* L., are drought-resistant and are not highly demanding of soil resources. They are often used in mixed planting with *P. massoniana* to enhance stand stability and disaster resilience. Mixed-species forests of these species

contribute to soil fertility, increase forest resilience, and improve carbon storage capacity. With careful species selection and planting design, mixed-species plantations can also effectively reduce the risk of forest fires, maintain biodiversity, and increase the economic value of the forest. Therefore, promoting mixed-species plantations is crucial for the long-term sustainable management of *P. massoniana* forests.

5 Post-sowing practices and plantation maintenance

Post-sowing management practices can be used on seeded sites to improve germination, seedling survival and growth, and early canopy closure. Water and nutrient management are particularly crucial. Seeded areas generally lack irrigation systems and rely on natural precipitation for stand establishment. During droughty periods, supplementation of rainfall deficits can be helpful if possible. From November to April of the following year, natural precipitation is often insufficient to meet the growth needs of seedlings, so irrigation should be conducted during this period. If the *P. massoniana* seeding area is large and includes many high slopes or hard-to-reach areas, aerial irrigation is an effective watering method. By using helicopters or drones equipped with water tanks, water can be evenly sprayed across the forest area.

Because aerially seeded sites are often infertile and seldom receive intensive site preparation, it is important to broadcast fertilizer before sowing. Applying nitrogen, phosphorus, and potassium fertilizers aerially, especially in slow-release formulations, can ensure a relatively long-term nutrient supply during the rapid growth phase of seedlings. Additional fertilization can be applied later in the rotation if deemed necessary for stand growth. Regular mechanical or chemical weeding may be required to ensure that weeds do not outcompete seedlings. Typically, large-scale weeding operations are conducted using lawnmowers or cultivators. In cases of heavy weed competition, selective herbicides can be used.

Regular inspections are necessary to detect and address pest and pathogen issues promptly. Some diseases, such as Sphaeropsis blight, can be prevented or controlled by using fungicides such as carbendazim (Huang 2020). Aerial drones can be used for large-scale pesticide applications.

Several other tending or management practices may be implemented as the stand develops. Pruning is practiced to remove dead, diseased, and overcrowded branches. Soil loosening is practiced to improve aeration and enhance root development. This is usually done before the growing season, once or twice a year, depending on the rooting depth of the trees, typically at a depth of 5–10 cm. For remote and steep sites that have been aerially seeded, soil loosening is generally more challenging due to the terrain and transportation constraints, which limit the use of machinery (Figure 3). On these sites, large-scale soil loosening is typically not done unless the terrain is relatively flat, and small equipment can be used. In practice, these remote areas often rely more on natural precipitation and subsequent maintenance measures, such as fertilization, irrigation, and weed control. Stand thinning is practiced when seedlings grow to a certain density in young and intermediate-aged stands. Trees that are poorly growing, affected by pests or diseases, or are overly dense are selectively thinned to ensure the remaining trees are healthy and disease-free. In large-scale forest areas, mechanical equipment (such as harvesters and tractors) can be used to improve efficiency, especially in flat areas. However, on steep slopes or areas with difficult

access, manual thinning may be relied upon, which, although less efficient, can be effective in complex terrain.

6 Successful seeding

6.1 Defining success

Several key indicators can be considered to evaluate the success of *P. massoniana* seeding operations for forest establishment: germination rate, initial seedling establishment and plantation stocking, target species ratio, the early growth and development rate of seedlings and saplings, and seedling health (Xie 2023). These indicators, measured in plots established in the restoration area, index different aspects of plantation establishment, from seed germination to seedling growth and survival. The following paragraphs expand on each specific evaluation criteria.

Seed should germinate within a reasonable time after sowing, e.g., 2 weeks. Generally, seed germination should occur no later than 3 to 4 weeks after sowing. If germination is significantly delayed, the practitioner should review the suitability of the seed treatment methods, reassess seed quality, or determine if unsuitable environmental conditions have prevailed on the site since sowing. Delayed germination but with a germination rate greater than 60 % indicates satisfactory seed treatment and quality.

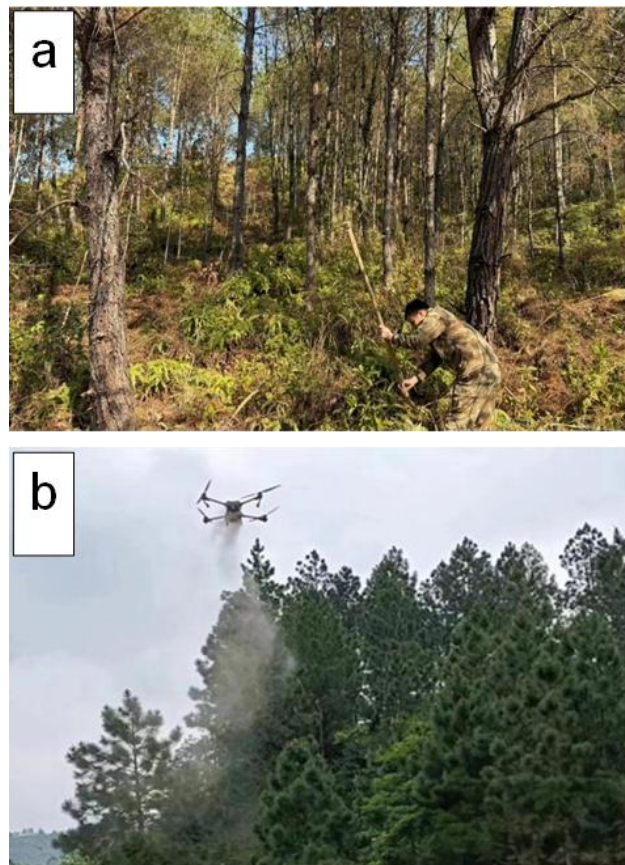


Figure 3. Soil loosening (a) and pest control (b) at *P. massoniana* afforestation sites. (Photo credits: FangChao Wang).

Initial stocking of seeded *P. massoniana* plantations should range from 1500 to 3600 seedlings ha⁻¹, which has been determined to be optimal for avoiding under-utilization of site resources and excessive resource competition among individuals. Along with this level of early stocking, seedling survival of 80% or greater for the first 2 years is considered adequate for plantation success. This survival rate would indicate that seed quality, plantation establishment practices, and growing conditions were conducive to stand establishment (Wu 2018, Figure 4).

Additionally, *P. massoniana* should dominate 70 to 80% of total stem density of the planting area. Several native species often naturally regenerate on seeded sites. Maintaining the targeted species ratio not only enhances the survival rate of *P. massoniana* but also contributes to ecosystem stability.

Seedlings should achieve an expected height and stem diameter within a specific growth period. One-year-old seedlings should reach a height of at least 20 to 30 cm and a basal diameter of 0.5 cm or more. Such growth would indicate sufficient nutrient and environmental conditions for *P. massoniana* success in the seeded area. Moreover, the majority of established *P. massoniana* seedlings should demonstrate consistent growth that favors desired stand development.

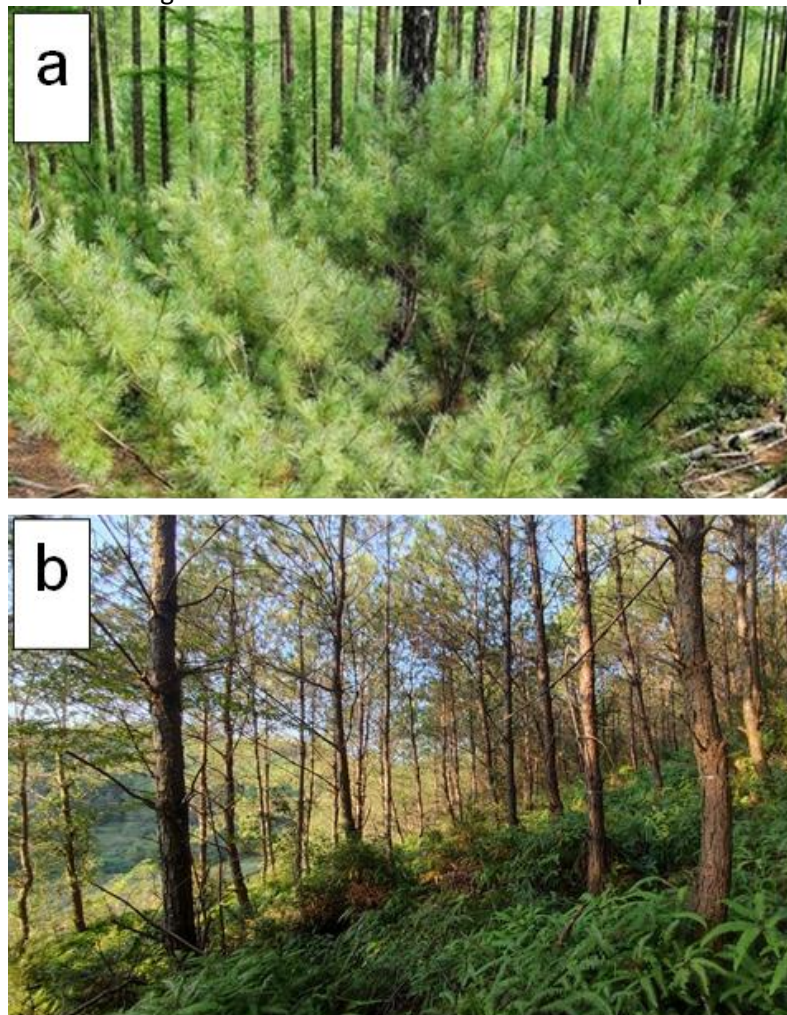


Figure 4. *P. massoniana* seedlings (a) and mature plantation (b) established through aerial seeding. (Photo credits: (a) FangChao Wang, (b) Qiao Liu).

6.2 Limiting factors and risks

To implement successful restoration of *P. massoniana* through seeding, it is important to consider factors that can limit application or add risk to seeding programs. Several factors can impact the success rate and broader application of seeding operations across the landscape. Seed quality is fundamental to success. Factors that lead to poor seed quality, such as low viability, improper storage, or inadequate seed pretreatment, can result in low germination and poor seedling health. Additionally, using seed from a limited genetic pool can reduce resilience to environmental stresses and increase susceptibility to pests and disease. Harsh site conditions that arise from various soil and site factors can hinder seed germination and seedling establishment. Soil factors limiting germination and seedling growth include soil erosion, soil degradation, poor soil drainage, droughty soil, low soil fertility, inappropriate soil pH, or unsuitable soil texture. Insufficient site preparation or plantation maintenance, such as weeding and protection from pests, pathogens, or animal damage, can result in high seedling mortality and poor growth. Finally, unpredictable, extreme weather or climatic events such as drought, frost, or excessive rainfall can negatively affect seedling survival and growth. Many seeding projects focus primarily on initial planting and survival rates, while neglecting subsequent long-term monitoring. Long-term data can help identify issues for adjustment of the management plan. Thus, proper planning with consideration for the factors that impede successful restoration is essential.

6.3 Key elements that contribute to success

Successful afforestation with seeding involves many biological, silvicultural, economic, and policy factors that must be integrated into the application. Key elements that foster successful seeding of *P. massoniana* to restore sustainable forests in Ganzhou include: 1) using seed of local provenance from high-quality sources that will ensure good germination and early seedling growth; 2) selecting seed sources of appropriate genetic diversity adapted to site conditions and climate in the region; 3) applying effective seed treatments such as surface sterilization and stratification to improve seed germination rate and seedling survival (Lan 2021); 4) conducting a thorough site assessment and implementing necessary site preparation such as weed control, drainage, and etc., to provide conditions conducive to germination and early seedling growth; 5) determining appropriate plantation density and intercropping plants according to ecological and economic objectives to maximize land use efficiency and tree growth space; 6) Post-sowing practices such as irrigation, fertilization, weeding, pest and disease control, and stand management (e.g., pruning, soil loosening, and thinning) are essential for ensuring seedling survival, growth, and the long-term health of *P. massoniana* plantations. Finally, regular maintenance and monitoring help effectively address challenges like nutrient deficiencies, weed competition, and pest issues (Xi et al. 2014).

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CAUTION

Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or wildlife if they are not handled or applied properly. Use all herbicides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and their containers.

8 References

- Cao M, Pan P, Ouyang XZ, Zang H, Ning JK, Guo LL, Li Y (2018) Relationships between the composition and diversity of understory vegetation and environmental factors in aerially seeded *Pinus massoniana* plantations. *Chin J Ecol* 37(1):1–8. [In Chinese]
- Chen X (2022) Planting technology and cultivation management of Masson pine. *J Agric Catastrophology* 12(6):170–174. [In Chinese]
- Cheng DB, Cai C, Zuo CQ (2006) Advances in research of soil degradation by erosion. *Res Soil Water Conserv* 13(5):252–254. [In Chinese]
- Ding YB (2012) Occurrence of common pests and diseases of Masson pine and their control measures. *Anhui Agric Bull* 18(6):97–98. [In Chinese]
- Dong LJ, Wu W, Lian X (2019) Analysis of the cultivation technology of horse-tailed pine seedlings. *Farmers Staff* 7:102. [In Chinese]
- Dou X, Deng Q, Li M, Wang W, Zhang Q, Cheng X (2013) Reforestation of *Pinus massoniana* alters soil organic carbon and nitrogen dynamics in eroded soil in south China. *Ecol Eng* 52:154–160. <https://doi.org/10.1016/j.ecoleng.2012.12.099>
- Huang H (2020) Introduction to the planting and pest control technology of *Pinus massoniana*. *South China Agric* 14(18):76–77. [In Chinese]
- Huang X, Huang C, Teng M, Zhou Z, Wang P (2020) Net primary productivity of *Pinus massoniana* dependence on climate, soil and forest characteristics. *Forests* 11(4):404. <https://doi.org/10.3390/f11040404>
- Intergovernmental Panel on Climate Change (IPCC) (2023). *Climate change 2021: the physical science basis. Working Group I contribution to the sixth assessment report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK. <https://doi.org/10.1017/9781009157896>
- Kim BN, Kim JH, Ahn JY, Kim S, Cho B-K, Kim Y-H, Min J (2020) A short review of the pinewood nematode, *Bursaphelenchus xylophilus*. *Toxicol Environ Health Sci* 12:297–304. <https://doi.org/10.1007/s13530-020-00068-0>
- Lai X (2019) Interpretation of technical points of cultivation and planting of *Pinus massoniana*. *J Green Sci Technol* 7:227–228. [In Chinese]
- Lan H (2021) An analysis of the technical points and popularization and application of the afforestation of *Pinus massoniana*. *South China Agric* 15(05):113–114. [In Chinese]
- Li D (2015) Vegetation technology and economic benefit of Masson Pine. *For Sci Technol Inf* 4:33–35. [In Chinese]

- Li M, Li H, Ding X, Wang L, Wang X, Chen F (2022) The detection of pine wilt disease: A literature review. *Int J Mol Sci* 23(18):10797. <https://doi.org/10.3390/ijms231810797>
- Li QM (2023) Study on the prevention and control of common diseases and insect pests of *Pinus massoniana*. *Guangdong Canye* 57(05):63–65. [In Chinese] <https://doi.org/10.3969/j.issn.2095-1205.2023.05.20>.
- Li X, Liu Q, Chen Y, Hu L, Yang F (2008) Aboveground biomass of three conifers in the Qianyanzhou plantation, Jiangxi Province, China. *Front For China* 3:16–23. <https://doi.org/10.1007/s11461-008-0007-x>
- Liu L (2021) Common diseases and insect pests of Masson pine and afforestation control measures. *J Agric Catastropholgy* 11(12):15–16. [In Chinese]
- Lou Q, Chen H, Ding G, An N (2022) Effects of afforestation density on understory vegetation and soil properties in Masson pine plantations. *West For Sci* 51(05):139–145. [In Chinese] <https://doi.org/10.16473/j.cnki.xblykx1972.2022.05.020>
- Pan P, Sun Y, Ouyang X, Zang H, Rao J, Ning J (2019) Factors affecting spatial variation in vegetation carbon density in *Pinus massoniana* Lamb. forest in subtropical China. *Forests* 10(10): 880. <https://doi.org/10.3390/f10100880>
- Qin GF (2017) Masson pine seed garden. China Forestry Publishing House, Beijing, China, pp 89–92.
- Qin Y (2022) Exploration of planting technology and cultivation management points of Masson pine. *J Green Sci Technol* 1:50–52. [In Chinese]
- Soil Survey Staff (2022) Keys to Soil Taxonomy, 13th ed. USDA Natural Resources Conservation Service, Washington, DC, USA.
- Wu Y, Hu S, Li H (2018) Silvicultural technology of *Pinus massoniana*. *Mod Agric Sci Technol* 6:55. [In Chinese]
- Wu Y (2019) Practical cultivation techniques of Masson pine. *For Ecol* 6:39–40. [In Chinese] <https://doi.org/10.13552/j.cnki.lyyst.2019.06.018>.
- Xi W, Wang F, Shi P, Dai E, Anoruo AO, Bi H, Li W (2014) Challenges to sustainable development in China: a review of six large-scale forest restoration and land conservation programs. *J Sustain For* 33(5):435–453. <https://doi.org/10.1080/10549811.2014.899503>
- Xia Z (2019) Analyzing the cultivation technology and pest management of ponytail pine seedlings. *Flowers* 12: 254–255. [In Chinese]
- Xie H (2023) Key points of high-yield cultivation and management methods of *Pinus massoniana*. *Special Econ Animals and Plants* 3:137–139. [In Chinese]
- Zhang HB (2023) Exploration on management of seedling afforestation of *Pinus massoniana*. *Agric of Henan* 23:39–41. [In Chinese]
- Zhao JJ (2021) Technical points and measures of young forest nurturing in the afforestation of *Pinus massoniana*. *Rural Sci Technol* 12(28):85–87. [In Chinese]
- Zhao L (2020) Occurrence and control of common pine diseases. *J Agric Catastropholgy* 10(05):23–24. [In Chinese]
- Zhao X (2017) A review of technology concerning the aerial seeding afforestation in China. *Shaanxi For Sci Technol* 5:90–94. [In Chinese]
- Zhong J, Guo QR, Luo BS, Tan J, Huang XL, Zhuo MN (1998) Study on the physical degradation and mechanism of laterite soil on sloping land—III. analysis of the mechanism of soil physical degradation. *Trop Subtrop Soil Sci* 7(2):166–171. [In Chinese] <https://doi.org/10.16258/j.cnki.1674-5906.1998.02.015>