

Adaptive Mechanisms of Tree Seedlings to Adapt to Stress—Second Edition

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Tree seedlings represent a critical bottleneck in forest regeneration. This vulnerable life stage is highly sensitive to environmental fluctuations. In recent decades, climate change and land degradation have intensified stressors—such as prolonged droughts, heat waves, soil salinization, pollution, and nutrient losses—that directly threaten seedling survival and growth. For example, the increasing frequency and severity of droughts under warming climates have been linked to dramatic declines in seedling emergence and survival. At the same time, habitat fragmentation and shifting disturbance regimes expose seedlings to novel biotic pressures and microclimate extremes. Understanding how seedlings respond physiologically and behaviorally to these stresses is therefore essential for predicting future forest dynamics and guiding restoration efforts.

Building upon the success of the first volume, this second edition of this Special Issue, “Adaptive Mechanisms of Tree Seedlings to Adapt to Stress—Second Edition” continues to collect innovative research addressing the complex responses and strategies employed by seedlings to cope with various environmental pressures. This compilation includes eleven original research articles covering a broad spectrum of species, stress factors, ecological contexts, and physiological mechanisms. The key messages of each study are synthesized into three main aspects and summarized according to different tree species or key ecological indicators, as outlined below.



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1. Adaptation to Nutrient and Environmental Stresses

Masson pine (*Pinus massoniana*): Yang and Wang [1] found that high phosphorus (P) fertilization significantly promoted root growth and branching of seedlings, but also caused substantial consumption of nitrogen and carbon resources, leading to a marked decline in stem and leaf N/P and C/P ratios and thereby exacerbating nitrogen limitation. P supplementation alleviates growth restriction under low-P stress, but excessive P supply may trigger new nutrient constraints.

Chinese fir (*Cunninghamia lanceolata*): Wan et al. [2] analyzed differences in growth and biomass allocation among six provenances of Chinese fir, showing clear variation in adaptive strategies. For instance, one provenance (located in Fujian Province) exhibited a more balanced root/shoot allocation, supporting stable growth and efficient water and nutrient uptake, whereas a weaker provenance (located in Zhejiang Province) displayed a higher root/shoot ratio, indicating growth limitation. This finding suggests that breeding should prioritize genotypes with balanced root allocation and strong absorptive capacity.

***Quercus longispica*:** Tu et al. [3] investigated germination and seedling adaptations of *Q. longispica* in the subalpine Himalayas and revealed multiple strategies for stress avoidance.

Polyembryony and rapid germination enabled embryos to escape parasitism and predation. Rapid elongation of cotyledonary petioles pushed the epicotyl into the soil, ensuring efficient transport of water and nutrients from the cotyledons to the roots. This process helped seedlings withstand drought, cold, and fire. In addition, post-germination epicotyl dormancy, regulated by temperature, prevented non-hardy seedlings from sprouting during winter. These combined traits secured successful regeneration in harsh environments.

Manchurian walnut (*Juglans mandshurica*): Cui et al. [4] compared regeneration patterns across habitats (from forest edge to interior) and found that seedling growth and regeneration were most vigorous at the forest edge, where the regeneration index reached 1.0, but declined significantly toward the interior. Moreover, the abundance of other shrubs and trees in edge habitats showed a significant negative correlation with walnut seedling numbers. The results indicate that habitat heterogeneity—especially forest edge environments—plays a critical role in walnut regeneration and should be prioritized in conservation and restoration efforts.

Leaf Si and Ca stoichiometry along elevation gradient: Chen et al. [5] examined leaf silicon and calcium contents along elevational gradients in subtropical forests of China. The results showed that with increasing elevation, leaf Si content and Si/Ca ratio decreased significantly, whereas Ca content increased markedly. Structural equation modeling further revealed that Si and Ca stoichiometric traits were highly conserved among closely related species, and phylogenetic lineage exerted a stronger influence on Si/Ca distribution than local environmental factors. This suggests that evolutionary history imposes strong constraints on mineral nutrient allocation.

Interactive effects of elevated CO₂ and drought: Brisebois and Major [6] studied the effects of elevated CO₂ (800 ppm) and drought on morphological and growth allocation traits of four Betulaceae species (two *Alnus* spp. and two *Betula* spp.) in greenhouse experiments. They found that *Alnus* species exhibited substantial growth enhancement under elevated CO₂, while *Betula* species showed stable or slightly reduced responses. Growth was suppressed by drought in all species, but elevated CO₂ significantly mitigated drought effects in *Alnus*, doubling stem dry mass, whereas *Betula* showed only slight improvement. Overall, *Alnus* species demonstrated stronger carbon sequestration potential and resilience under combined elevated CO₂ and drought stress.

2. Stress Tolerance Mechanisms

White mulberry (*Morus alba*): Xu et al. [7] systematically analyzed physiological and biochemical responses of mulberry seedlings under different NaCl concentrations (0–300 mmol/L). The results confirmed that salt tolerance involved three major processes: first, osmotic adjustment through accumulation of soluble sugars, proteins, and proline; second, ion homeostasis by retaining Na⁺ mainly in roots while maintaining high K⁺/Na⁺ ratios in leaves; and third, activation of antioxidant enzymes such as superoxide dismutase (SOD) and peroxidase under salt-induced oxidative stress. These coordinated mechanisms enabled mulberry seedlings to reach peak tolerance under moderate salinity.

Populus: Chen et al. [8] studied the effects of foliar application of glycine betaine at different concentrations on salt tolerance of hybrid poplar (*Populus deltoides* × *P. euramericana*). They found that approximately 15 mmol/L glycine betaine (GB) application significantly alleviated salt-induced damage to chlorophyll and growth, while enhancing peroxidase (POD) and SOD activities. This indicates that exogenous GB acts as a compatible solute to strengthen antioxidant defense against salt-induced oxidative stress, providing a practical approach for poplar cultivation in saline soils.

3. Genetic Variation and Cultivation Management

Silver birch (*Betula pendula*): Sirgedaite-Šežienė et al. [9] investigated enzymatic and non-enzymatic antioxidant activity across seven half-sib families of silver birch and found significant genotype-specific differences. Across two growing seasons, most antioxidant indices increased significantly in the second year (e.g., SOD activity rose by 15–243%, and total phenol content increased by 46–189%). These findings indicate that genotype strongly influences antioxidant capacity, providing a theoretical basis for selecting stress-tolerant families.

Macadamia (*Macadamia integrifolia*): Yang et al. [10] evaluated the stability of 11 commonly used reference genes under various stresses and tissues in macadamia. Results showed that Actin (ACT) was the most stable across most conditions (cold, salt, PEG osmotic, and hormone treatments), while other genes showed condition-specific stability: EF1 β under GA and high-temperature stress, UBC under ethephon treatment, and CYP in root samples. This study provides reliable internal reference genes for future expression analyses in macadamia.

Black locust (*Robinia pseudoacacia*): Drăghici et al. [11] compared the effects of different provenances, substrates, and watering regimes on container seedling growth. Germination rates varied significantly by provenance, with the Bucharest provenance achieving the highest germination rate of 73.7%. Under adequate watering, seedlings mainly increased in height, whereas under water deficit, they exhibited stem thickening. Substrate physico-chemical properties also significantly affected survival, with the lowest rates observed in sandy, high-pH mineral substrates and low-pH peat substrates. These results suggest that matching provenance with appropriate substrates and irrigation strategies is essential for improving germination and seedling quality.

4. Conclusions

Together, the papers in this Special Issue illuminate the remarkable diversity and complexity of seedling responses to stress. They not only deepen our understanding of physiological, biochemical, genetic, and ecological mechanisms but also offer practical insights for forest management, breeding, and restoration efforts under global change.

We extend our sincere thanks to the contributing authors for sharing their outstanding work and to the reviewers whose feedback improved the quality of these contributions. We hope this collection will inspire further research into seedling adaptation and foster collaborative approaches to forest resilience.

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