



Figure 1 *Paris polyphylla* plants in their natural habitat and exposed aboveground and belowground (Adopted from Rawat et al., 2023)

3.2 Limitations of *Paris* spp. propagation technologies

Current propagation technologies for *Paris* spp. have made clear progress, but each major route still carries practical limitations. Traditional rhizome cutting is widely used because the species grows slowly and clonal propagation can bypass seed dormancy, yet the method has low multiplication efficiency because axillary meristems are limited, and cutting can sharply reduce net rhizome yield (Wang et al., 2021). Rhizome injury also creates phytosanitary problems: cut segments are susceptible to insects, disease, and rotting, causing substantial yield losses during multiplication (Wang et al., 2023). Even when rhizome splitting works, propagation rates are variable rather than uniformly high. In one three-year study, sprouted shoot buds averaged 49.33% from cut rhizomes and 75% from group rhizome fragmentation, which is useful for conservation but still indicates incomplete and method-dependent conversion efficiency. Other patented or nursery-based methods improve latent-bud induction or avoid direct rhizome damage, but these are still technique-specific optimizations rather than evidence of a universally standardized propagation system.

In vitro propagation and hormone-based regulation offer promising alternatives, but they also show that successful multiplication depends on highly specific developmental stages, explant types, and culture conditions. Tissue culture protocols have reported strong outcomes, including 80% shoot response and 94.4% greenhouse establishment under optimized BAP and NAA conditions, while other systems achieved bud germination within 6-8 days, multiplication factors above 5, rooting rates above 90%, and transplant survival above 90% (Puwein and Thomas, 2022). Somatic embryogenesis can further increase scale, producing an average of 63 somatic embryos per gram of callus in six weeks and shortening plantlet production by 12~15 months (Wang et al., 2023). However, these gains depend on precise regulation of medium composition, photoperiod, sucrose concentration, temperature, plant growth regulators, and rhizome developmental stage, indicating that the technology remains sensitive and not yet simple for broad field deployment (Kumar et al., 2025). Hormone-based rhizome induction shows similar conditionality: GA₃ can break dormancy within two weeks and induce polyapical shoots at 100%, with 7.2 apical shoots per treated rhizome, but this is still a controlled treatment protocol rather than a low-input routine practice for all germplasm types and planting settings (Wang et al., 2021).

3.3 Genetic background and quality evaluation deficiencies of artificial germplasm

A major constraint in artificial germplasm development is the incomplete understanding and control of genetic background. The genus has strong interspecific hybridization capacity, and unintended hybridization between *P.*