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Distribution, Population Structure, Regeneration Limitations, and Conservation Measures for Cunninghamia konishii Hayata in Pu Mat National Park, Vietnam

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Abstract
Cunninghamia konishii Hayata, a rare conifer belonging to the family Taxodiaceae, is known from only four isolated subpopulations within Pu Mat National Park (Khe Bu, Khe Tun, Khe Ngoa, and Pu Nhong), collectively covering approximately 7,167 hectares—equivalent to just 0.008% of the park's total area. The species occurs at elevations ranging from 960 to 1,500 meters on yellow feralit soils and typically forms clustered stands on steep slopes (35–45° inclination). Field surveys recorded mature individuals with diameters at breast height (DBH) ranging from 80 to 160 cm and heights between 30 and 50 meters, with some trees exceeding 60 meters. However, regeneration is critically limited, with seedlings found only in canopy gaps and along ravines, indicating serious recruitment failure. This study examines the species' current distribution, population structure, and ecological constraints, and proposes integrated in-situ and ex-situ conservation strategies aimed at improving natural regeneration and enhancing the long-term viability of this endangered conifer.
Keywords: *Cunninghamia konishii Hayata; Taxodiaceae; distribution; regeneration; Pu Mat National Park; conservation*

1.INTRODUCTION

Cunninghamia konishii Hayata is a narrowly distributed conifer species belonging to the family Cupressaceae (formerly classified under Taxodiaceae). In Vietnam, its presence has been recorded in only a few mountainous areas of Nghe An Province, including Pu Hoat, Pu Mat, Pu Den Den, and Pu Xai Leng. The species is currently categorized as Vulnerable in the 2007 edition of the Vietnam Red Data Book [1].

In addition to its ecological significance, C. konishii possesses rare and valuable essential oils with applications in daily life and scientific research [3]. Economically, the species is also noteworthy. Its wood is highly valued for its durability, resistance to termites, and attractive grain, making it desirable for handicrafts and household uses. As a result, C. konishii has faced increasing pressures from logging and overexploitation. Notably, in comparison to Fokienia hodginsii, another economically important conifer, C. konishii commands an export price approximately 15–20% higher.

Recent botanical surveys have confirmed the presence of C. konishii in specific areas within Pu Mat National Park—one of Vietnam's largest and most biodiverse protected areas. Despite its ecological and economic importance, scientific data on the species remain limited, particularly regarding its distribution, population structure, ecological characteristics, and regeneration dynamics.

Given its highly restricted range and mounting anthropogenic threats, a comprehensive assessment of C. konishii is urgently needed to inform effective conservation and management strategies. This study aims to evaluate the current status and ecological characteristics of C. konishii in Pu Mat National Park. The findings are expected to provide critical insights to support evidence-based conservation planning. Preliminary results of this research were presented at the International Scientific Conference held at Rajabhat Mahasarakham University, Thailand, in 2018 [4].

3. MATERIALS AND METHODS

3.1. Research Subject

The subject of this study is Cunninghamia konishii Hayata, a coniferous species belonging to the family Cupressaceae (formerly classified under Taxodiaceae).

3.2. Research Objectives

This study was conducted with the following specific objectives:

- To investigate the distribution of Cunninghamia konishii within Pu Mat National Park;
- To assess key ecological characteristics of C. konishii in its natural habitats;
- To examine the reproductive traits and regeneration patterns of C. konishii;

- To propose appropriate conservation strategies for C. konishii in Pu Mat National Park.

3.3. RESEARCH METHODS

Literature Review

A comprehensive review of national and international literature was carried out to synthesize existing knowledge on the distribution, ecology, and conservation of Cunninghamia konishii.

Line Transect Survey Method

Using existing forest land data and updated forest resource maps, preliminary transects were established to determine the current distribution of C. konishii within Pu Mat National Park. Survey routes were selected based on topographic features and insights from previous studies. Four main transects were established as follows:

- Route 1: From Khe Tun to Khe Ca
- Route 2: From Khe Bu to Khe Ngoa
- Route 3: Upstream area of Khe Thoi
- Route 4: Pu Nhong area

3.4. Data Collection

At each location where Cunninghamia konishii individuals were identified along the transects, three standard sample plots were established using conventional forestry survey techniques. Each plot measured 2,000 m² (40 m × 50 m). Within these plots, data were collected on species presence, ecological parameters, and indicators of natural regeneration.

4. RESULTS

4.1. Distribution Characteristics of Cunninghamia konishii

In Pu Mat National Park, Cunninghamia konishii exhibits a highly restricted and discontinuous distribution, often forming nearly pure stands. The species is primarily found at elevations ranging from 900 to 1,500 meters above sea level, predominantly in closed-canopy, evergreen, mixed broadleaf–coniferous subtropical forests.

Table 1. Distribution and basic metrics of Cunninghamia konishii populations in Pumat National Park

Area	Elevation (m	Slope (degrees)	Number of Individuals	DBH (cm)	Height (m)
Upstream Khe Thơi	1.050	40 - 42	650	96,20	31,80
Khe Ca – Khe Tun	960	35 - 38	70	154,90	46,60
Upstream Khe Ngoã	1.350	40 - 45	23	82,19	30,63
Pù Nhông	1.200	40 - 43	25	90,00	34,25

Field measurements confirm that C. konishii individuals are generally large, with diameters at breast height (DBH) ranging from 80 to 160 cm and heights between 30 and 50 meters. Some exceptional individuals have DBH values of 450–500 cm and heights exceeding 60 meters. The species is typically found on steep slopes (35°–45°) in complex, rugged terrain, frequently along stream banks and within ravines, especially in upstream areas. The highest population density was observed in the upper reaches of Khe Thơi, where more than 650 individuals were recorded—significantly outnumbering populations in Khe Ca–Khe Tun, upper Khe Ngoã, and Pù Nhông.

Figure 01: A population of Cunninghamia konishii (Source: https://tienphong.vn/ngam-co-thu-sa-mu-dau-hon-2000-tuoi-trong-loi-rung-gia-duoc-cong-nhan-la-cay-di-san-viet-nam-post1602316.tpo)

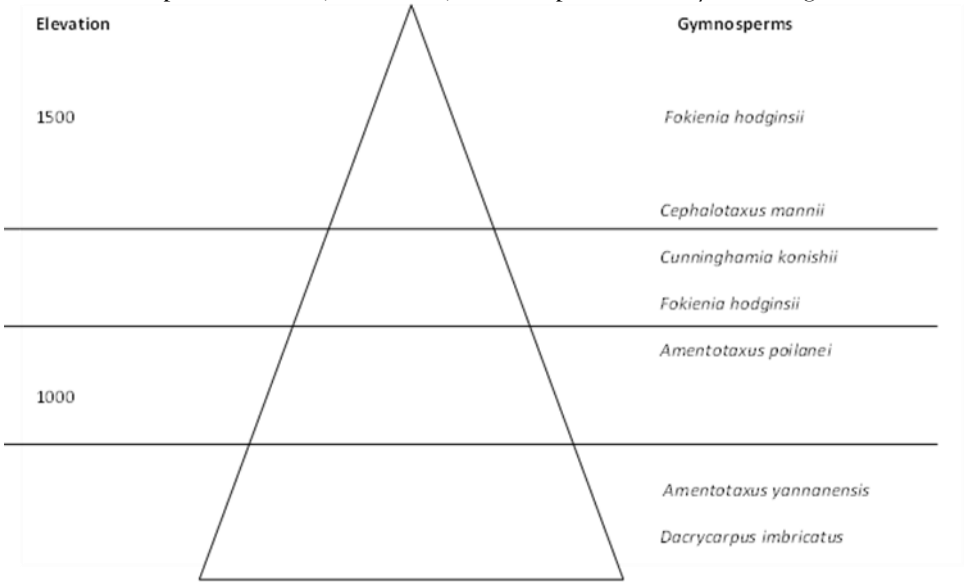
Geographical and Altitudinal Distribution: Beyond Pu Mat National Park, C. konishii has been recorded in northern and central Taiwan, China (Fujian), northern Laos, and several northern provinces of Vietnam, including Son La, Ha Giang, Thanh Hoa, and Nghe An. In Vietnam, the species is primarily distributed at elevations above 1,000 meters. Reports from Laos indicate its presence at 900–2,200 meters, while in China it is found at 1,300–2,000 meters, and in Taiwan, at 1,300–2,800 meters [5,6].

Table 2. Area coverage of Cunninghamia konishii subpopulations in Pu Mat National Park

TT	Area	Subzone Codes	Area (ha)	Notes
1	Upstream Khe Thơi	787; 794	5,513	
2	Khe Ca – Khe Tun	795; 798	1,039	
3	Upstream Khe Ngoã	835	0,325	
4	Pù Nhông	813	0,289	
Total			7,167	

4.2. Comparative Distribution of Cunninghamia konishii and Other Gymnosperm Species at High Elevations in Pu Mat National Park

To better contextualize the distribution of Cunninghamia konishii, a comparative analysis was conducted with other gymnosperm species that occur at high elevations within Pu Mat National Park. This analysis was based on prior research, field data, and the present study's findings.



From this analysis, a distribution profile and elevation map of selected gymnosperm species were developed. The data indicate that C. konishii tends to occupy higher elevations than most other gymnosperms in the park, typically inhabiting remote, steep, and rugged mountainous terrain. This

narrow elevational range highlights the species' ecological specialization and potential susceptibility to habitat fragmentation and climate change.

Most individuals of C. konishii are found at elevations between 1,000 and 1,500 meters—representing a transitional zone between closed-canopy, broad-leaved evergreen rainforests and subtropical evergreen forests. This range overlaps with the elevational distributions of Cephalotaxus mannii and Amentotaxus poilanei, and partially overlaps with Fokienia hodginsii. However, F. hodginsii typically occurs at slightly higher elevations within the park.

4.3. Ecological Characteristics of Cunninghamia konishii

4.3.1. Elevation and Topography

Cunninghamia konishii primarily inhabits closed-canopy, evergreen forests composed of mixed broadleaved and coniferous species at elevations ranging from 960 to 1,500 meters above sea level. The species is most frequently found on steep slopes (ranging from 38° to 45°) in areas with highly dissected and rugged terrain. Within these zones, it is typically distributed from the base of ravines up to mid-slope trench areas.

The habitats occupied by C. konishii are characterized by steep, rocky, and often near-vertical slopes, covered with largely undisturbed primary forest. This complex topography likely limits the species' spatial distribution by restricting opportunities for population expansion. Additionally, these physical conditions significantly hinder regeneration: seedlings struggle to establish on steep slopes and are often washed away by surface runoff into areas with poor soil stability or unsuitable conditions for growth. In the rare cases where seedlings do survive, they tend to grow in clumps, leading to a strongly aggregated distribution pattern.

4.3.2. Tree Layer Structure

Structure and Density of the Tree Layer

Field surveys were conducted at three standard sample plots (40 m × 50 m each) in distinct localities where C. konishii populations were identified. Data on species composition and tree density were collected to characterize the structure of the forest's tree layer. The results are summarized below using dominance formulas that indicate the relative presence of tree species in each area:

Area	Species Composition Formula
Khe Thơi.	2,64Smd + 2,11Gie + 1,48Tra + 1,35Com + 1,20Mn + 0,97Re +1,45LK
Khe Tun – Khe Ca.	1,82Gie + 1,81 Sa mu dầu + 1,62Re + 1,21Tra + 1,06Mn + 0,99Com + 0,51Gi + 1,84 LK
Khe Ngoã	1,89Gi + 15,68Tra + 14,58Smd + 1,43Vu + 0,90Com + 0,59Chr + 2,40LK

In the Khe Thơi plot, Cunninghamia konishii clearly dominates the canopy layer, exhibiting the highest population density and growth performance. This dominance gradually decreases in the Khe Ca – Khe Tun and Khe Ngõa plots, reflecting the overall distribution pattern of C. konishii in Pu Mat National Park. These findings suggest that Khe Thơi represents the most favorable ecological niche for the species.

Several associated species were also frequently recorded in C. konishii habitats, including ramie (Boehmeria nivea), red tangerine (Citrus reticulata), and Mac Nieng (Calocedrus macrolepis). Their consistent co-occurrence may indicate ecological relationships, although further studies are needed to clarify these potential associations—potentially through analysis of species association indices or relative dominance values.

Table 04: Growth quotient of Cunninghamia konishii in three study areas

Area	N (trees/ha)	$\bar{X}$D1.3 (cm)	$\bar{X}$Hvn (m)	N(%)	ΣG (m²/ha)	G%
Khe Thơi.	25	96,20	31,80	4,95	18,16	39,19
Khe Tun – Khe Ca.	20	154,90	46,60	3,42	37,67	57,08
Khe Ngõa	20	82,19	30,63	4,17	10,61	27,40

📌 **Notes:**

- **N (trees/ha):** Density of Cunninghamia konishii individuals per hectare.

- ***X*D1.3 (cm):** Mean diameter at breast height (DBH), measured at 1.3 meters above ground.
- ***X*Hvn (m):** Mean total tree height (from base to top).
- **ΣG (m²/ha):** Total basal area of all C. konishii individuals per hectare.

Figure 02: This tree has a measured trunk circumference of 23.7 meters and a diameter of 5.5 meters. It is considered the largest known Cunninghamia konishii tree in Vietnam to date.

4.3.3. Growth Characteristics

The average growth quotient of Cunninghamia konishii is relatively high, indicating that most individuals within the surveyed populations are mature trees. However, a notable absence of younger individuals points to a serious regeneration issue. The lack of seedlings and saplings is atypical for a stable forest ecosystem and underscores a critical problem that necessitates further ecological and conservation research.

4.3.4. Sub-Canopy Structure

In most locations where Cunninghamia konishii occurs, the forest remains largely undisturbed. Canopy closure ranges from 0.70 to 0.80, and the forest exhibits vertical stratification into three distinct layers:

- **Emergent Layer (A1):**

This layer includes trees reaching heights of approximately 27 meters, such as Cunninghamia konishii and Manglietia insignis. It represents about 15%–20% of total individuals and is composed of scattered, well-distributed trees.

- **Main Canopy Layer (A2):**

The dominant stratum, with trees ranging from 15 to 25 meters in height, comprises 55%–60% of the total tree population. Dominant species include Cinnamomum spp., Lithocarpus elegans, Machilus trijuga, Endiandra hainanensis, Syzygium spp., and Mischocarpus pentapetalus.

- **Understory Layer (A3):**

This layer consists of trees below 15 meters in height, primarily small trees and woody species such as Pandanus spp., Sarcopteryx spp., Camellia spp. (wild tea), and young rattan shoots.

The shrub and herbaceous layers are relatively sparse and mostly composed of species like Tectaria brachiata, Pentaphragma spp., Begonia spp., Melastoma eberhardtii, and Ludwigia octovalvis.

4.3.5. Soil and Climate Characteristics

Soil

The habitats of Cunninghamia konishii are dominated by yellow or yellowish ferralitic soils formed on sedimentary and metamorphic rocks. These soils are coarse in texture, often shallow, and associated with rocky or fragmented terrain, which can impede root establishment and seedling development.

The species typically grows on soils derived from weathered granite or other silicate rocks, particularly deep and well-drained soils such as loamy clay or sandy loam. Suitable soil types include yellow-red soils over shale (ferralic acrisols), humus-rich gray soils over shale (humic acrisols), and humus-rich yellow-red soils. Topographic (elevation, slope) and edaphic (soil texture) conditions are key environmental factors affecting the growth of this species.

Temperature

Ambient temperatures in the high-altitude habitats of Cunninghamia konishii are generally 2–3°C lower than in adjacent lowland areas. Diurnal and seasonal temperature fluctuations are pronounced.

Climate

Cunninghamia konishii thrives in temperate and humid climates, well-adapted to tropical monsoon conditions. It typically experiences an average annual temperature of 13–19°C and annual rainfall exceeding 1,500 mm, reaching up to 4,000 mm in some localities. However, the species is vulnerable to prolonged exposure to temperatures below –4°C.

Precipitation and Humidity

Annual precipitation in its distribution areas ranges from 1,700 to 2,000 mm, with highly seasonal rainfall. The rainy season begins earlier and ends sooner than in lowland regions. Areas are notably affected by the Lao wind (Foehn effect), producing two distinct climatic seasons. Humidity is high during the rainy season but drops significantly in the dry season, particularly under the influence of Lao winds, increasing evapotranspiration pressure on vegetation.

Light Intensity

The species is mainly found from ravine bases to mid-slope areas, where steep topography reduces direct sunlight. Consequently, light intensity under the canopy is generally low, which may impact seedling development and photosynthetic performance.

4.4. Reproductive Characteristics

Field surveys revealed several distinctive features in the reproductive biology of Cunninghamia konishii. Notably, seeds do not readily disperse upon cone dehiscence; instead, they often remain attached to the cone scales after falling to the ground. Under favorable environmental conditions, germination can occur directly from the fallen cone—a rare phenomenon among gymnosperms and a distinctive reproductive trait of this species. This trait likely contributes to the species' clumped distribution patterns.

Seedlings of C. konishii were commonly observed in canopy gaps, forest openings, and disturbed areas such as landslides, indicating a high light requirement during early developmental stages. In contrast, natural regeneration was rarely observed under closed-canopy conditions due to insufficient light availability.

Overall, C. konishii exhibits poor regeneration capacity in its natural habitat. Regeneration primarily occurs via seed germination, with very few juvenile individuals observed across survey plots. Seedling survival is low, and successful recruitment into mature size classes is limited. These factors represent significant ecological constraints and pose major challenges for in-situ conservation and long-term population viability.

4.5. Conservation Strategies for Cunninghamia konishii in Pù Mát National Park

To ensure the survival and recovery of the endangered Cunninghamia konishii, a comprehensive conservation strategy integrating both in-situ and ex-situ approaches is essential.

4.5.1 In-situ Conservation

- Delineate and formally designate conservation sub-zones within Pù Mát National Park where extant populations of C. konishii are concentrated.
- Enhance the monitoring capacity of local forest protection agencies through training and increased patrolling.
- Engage local communities, border guard units, and local authorities in participatory forest protection initiatives.
- Establish anonymous community reporting systems (e.g., suggestion boxes) to detect and deter illegal logging or forest encroachment.
- Promote conservation awareness by developing and disseminating community-based forest protection agreements and customary conservation conventions.
- Facilitate natural regeneration by selectively thinning understory vegetation to increase light penetration under the forest canopy, thereby improving seedling establishment conditions.
- Collect mature cones from natural populations and sow seeds in ecologically suitable adjacent areas to facilitate local population expansion.

4.5.2 Ex-situ Conservation

- Initiate propagation programs using both sexual (seed-based) and asexual (clonal) techniques to produce healthy seedlings for restoration.
- Establish experimental plantations in areas with ecological conditions analogous to the species' natural habitat.
- Conduct further ecological research on C. konishii, particularly in the Sa Mù Mountain area, to refine site selection criteria and optimize the success of ex-situ conservation interventions

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

The findings of this study confirm that Cunninghamia konishii is a rare and highly localized conifer species in Vietnam, with a fragmented distribution limited to four main sub-areas within Pù Mát National

Park: Khe Thơi, Khe Tun, Khe Ngoa, and Pù Nhông. The total area of occupancy is estimated at approximately 7,167 hectares, accounting for a mere 0.008% of the park's overall area. These populations are confined to high-elevation zones ranging from 960 to 1,500 meters above sea level, often on steep slopes of 38°–45°, which present significant ecological challenges for regeneration and survival.

The species primarily occurs on light yellow feralit soils developed from sedimentary and metamorphic substrates, characterized by coarse texture, low fertility, and poor water-holding capacity. Despite these marginal edaphic conditions, C. konishii persists under a temperate, humid microclimate influenced by the northeast monsoon and the dry Lao winds, which contribute to high annual temperature variability and a clear seasonality in precipitation.

Ecologically, C. konishii displays poor natural regeneration. Although viable seeds are produced and occasionally germinate in situ, particularly under favorable light conditions such as canopy gaps or landslide-prone areas, seedling survival and recruitment into mature cohorts remain extremely limited. The absence of saplings and juveniles under closed canopies highlights the species' strong light dependence during early life stages and raises concerns about the sustainability of current populations under natural conditions.

The reproductive biology of C. konishii also reveals an unusual mechanism among gymnosperms, wherein seeds germinate directly from fallen cones on the forest floor—a trait that may increase the likelihood of clumped seedling establishment but does not compensate for overall low recruitment rates. Collectively, these findings underscore the species' vulnerability to both environmental pressures and anthropogenic disturbances, reinforcing the need for targeted conservation actions.

5.2. Recommendations

Given its extremely limited distribution, small population size, and constrained regeneration potential, Cunninghamia konishii should be formally classified as an endangered species in Vietnam and incorporated into national and international conservation priority lists (e.g., IUCN Red List). To ensure the long-term survival of this species, the following integrated and multi-level conservation strategies are recommended:

a) In-depth ecological research:

- Future studies should focus on the species' reproductive ecology, seed dispersal mechanisms, seedling survival rates, and habitat requirements, especially light and soil conditions necessary for successful establishment.
- Monitoring genetic diversity across populations is critical for understanding inbreeding risks and informing conservation breeding programs.

b) In-situ conservation:

- Immediate steps should be taken to designate core conservation zones within Pù Mát National Park where C. konishii populations are concentrated.
- Forest protection measures must be strengthened, including regular patrolling, the installation of early warning systems for illegal logging, and the empowerment of local communities in participatory forest management.
- Habitat management interventions, such as selective thinning of the understory and canopy gap creation, should be piloted to improve light availability for natural regeneration.
- Enrichment planting with locally sourced seedlings in degraded or marginal habitats should be considered to stabilize declining populations.

c) Ex-situ conservation and propagation:

- Establish propagation programs using both clonal and sexual reproduction techniques in botanical gardens and nurseries.
- Develop pilot plantations in ecologically analogous areas to serve as genetic reservoirs and potential sites for population reinforcement or reintroduction.
- Maintain a seed bank and establish long-term living collections of genetically representative individuals.

d) Policy and capacity-building:

- Develop a species-specific conservation action plan that integrates with the park's management plan and national biodiversity strategies.
- Allocate funding and technical resources for long-term research and conservation implementation.
- Enhance local capacity through training programs for rangers, researchers, and community stakeholders.

e) Public awareness and education:

- Raise awareness about the ecological value and endangered status of C. konishii through community-based environmental education programs, ecotourism initiatives, and school curricula in buffer zone areas.

In conclusion, safeguarding Cunninghamia konishii requires a proactive, science-based, and community-inclusive conservation approach. The species serves not only as an important component of the montane forest ecosystem in North Central Vietnam but also as a flagship for the conservation of other narrowly distributed taxa in the Annamite region.

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