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**A STUDY ON VASCULAR PLANT DIVERSITY AND PROPOSED
CONSERVATION MEASURES IN KIM HY NATURE RESERVE,
THAI NGUYEN PROVINCE**

SUMMARY OF DOCTORAL DISSERTATION IN BIOLOGY

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List of the author's published works related to the doctoral dissertation:

1. Van Hai Do, Thu Thuy Nguyen, Hong Quang Bui, Thi Hoan Duong, Ritesh Kumar, Choudhary & Yunfei Deng, 2025, Notes on the genus *Thunbergia* (Acanthaceae) in Vietnam, *Phytotaxa*, 697 (3), pp. 255–264.
2. Do Van Hai, Nguyen Thu Thuy, Zheli Lin, Yunfei Deng, 2023, *Strobilanthes spathulatibracteata*, a new species of Acanthaceae from northern Vietnam, *Phytotaxa*, 597(2), pp. 184-192.
3. N. T. Thuy, S. Zeng, D. V. Hai, D. T. Hoan, Z. Lin, & Y. Deng, 2022, *Sporoxeia vietnamensis* (Melastomataceae), a new species from northern Vietnam, *Phytotaxa*, 558(3), pp. 283-290.
4. Z. Lin, N. T. Thuy, D. V. Hai & Y. Deng, 2022, New records of the genus *Rungia* (Acanthaceae) from Vietnam, *Thai Forest Bulletin (Botany)*, 50(2), pp. 100-103.
5. Nguyen Thu Thuy, Do Van Hai, Duong Thi Hoan, Zheli Lin, Yunfei Deng, 2022, A newly recorded species *Strobilanthes lamiifolia* (Nees) T. Anderson (Acanthaceae) for the flora of Vietnam, *Academia Journal of Biology*, 44(3), pp. 1-9.

Introduction

1. Rationale of the dissertation

Vietnam, located in the tropical monsoon climatic region, possesses highly favorable conditions for the development of diverse biological organisms, resulting in rich ecosystems and high biodiversity. However, biodiversity worldwide is increasingly threatened by human activities that negatively impact and degrade natural ecosystems. At present, biodiversity conservation has become a key global strategy and action program, with strong support from international organizations in biodiversity assessment, conservation, and sustainable development. Kim Hy Nature Reserve, Thai Nguyen Province, plays a particularly important role in the conservation of biodiversity and limestone forest ecosystems. The reserve preserves valuable genetic resources of several rare and endemic plant species threatened with extinction, such as *Keteleeria davidiana* (Bertrand) Beissn, which is currently found only in Kim Hy, and *Pseudotsuga sinensis* var. *brevifolia* (W.C.Cheng & L.K.Fu) Farjon & Silba, which now occurs in only four northern mountainous provinces of Vietnam. Preliminary surveys indicate that Kim Hy Nature Reserve has great potential in terms of biodiversity, especially vascular plant diversity and limestone forest ecosystems. However, existing studies remain limited and are mainly confined to preliminary inventories serving management and planning purposes. Therefore, this doctoral dissertation is entitled “*A study on vascular plant diversity and proposed conservation measures in Kim Hy Nature Reserve, Thai Nguyen Province*”.

2. Research objectives

To comprehensively assess the diversity of vascular plants in Kim Hy Nature Reserve, Thai Nguyen Province, as a scientific basis for proposing appropriate conservation measures.

3. Research contents

3.1. Content 1: Taxonomic identification and updating of the vascular

plant checklist in Kim Hy Nature Reserve

To comprehensively and systematically update the checklist of vascular plant species in Kim Hy Nature Reserve, Thai Nguyen Province, up to the time of the present study.

3.2. Content 2: Assessment of vascular plant diversity in Kim Hy Nature Reserve

- Diversity at higher taxonomic levels, including divisions, classes, families, and genera;
- Diversity of plant life forms;
- Diversity of phytogeographical elements;
- Diversity of plant use values;
- Diversity of endangered, rare, and precious genetic resources.

3.3. Content 3: Proposed conservation and development measures for plant diversity in Kim Hy Nature Reserve

4. Scientific and practical significance

- *Scientific significance*: To update, supplement, and systematize information on the diversity of vascular plants in the Kim Hy Nature Reserve, thereby providing a reliable data source that serves as a reference basis and supports related studies;

+ To assess the level of diversity across taxonomic ranks (division, class, family, genus, and species), life forms, phytogeographical elements, and the utilization values of plant species.

+To compile a checklist and distribution maps of endangered, rare, and valuable plant species, and to propose solutions for the conservation and development of vascular plant diversity in the Kim Hy Nature Reserve.

- *Practical significance*: The results of this study provide the Management Board of Kim Hy Nature Reserve and scientists with a scientific basis for proposing and developing comprehensive conservation strategies, promoting sustainable use of existing plant resources for socio-economic development, and setting conservation priorities for rare and

valuable plant species in the area.

5. New contributions of the dissertation

+ Co-described and co-published two new species to science *Sporoxeia vietnamensis* D.V.Hai, Z.L.Lin & S.Jin Zeng (Melastomataceae) and *Strobilanthes spathulatibracteata* D.V. Hai, Z.L. Lin & Y.F. Deng (Acanthaceae).

+ Co-published two newly recorded to the flora of Vietnam *Rungia sinothailandica* Z.L.Lin & Y.F.Deng and *Strobilanthes lamiifolia* (Nees) T. Anderson (Acanthaceae).

+ The checklist of vascular plants in Kim Hy Nature Reserve was updated to include 1,446 vascular plant species belonging to 779 genera and 182 families of six vascular plant divisions.

+ A total of 485 vascular plant species were newly added to the flora of Kim Hy Nature Reserve.

+ Compiled a comprehensive inventory of threatened, rare, valuable, and endemic species, and established conservation priority rankings based on the integration of multiple conservation data sources.

+ Provided further evidence confirming that Kim Hy Nature Reserve represents a hotspot of vascular plant diversity within the limestone ecosystems of northeastern Vietnam, with high significance for plant conservation and genetic resources (a checklist comprising 1,446 vascular plant species; including 75 species listed in the *Vietnam Red Data Book* (2024) (3 Critically Endangered (CR), 33 Endangered (EN), 39 Vulnerable (VU)); 97 species regulated under Circular No. 85/2025/TT-BNNMT (5 in Group IA, 92 in Group IIA); 76 species included in CITES (3 in Appendix I, 73 in Appendix II); 69 species endemic to Vietnam; and 17 species assessed by the IUCN Red List (2024) (3 CR, 7 EN, 7 VU).

6. Structure of the dissertation

The dissertation comprises 150 pages, including 64 tables, 25 figures, and 60 pages of photographs.

The structure of the dissertation is as follows: Introduction (3 pages); Chapter 1. Overview (34 pages); Chapter 2. Research objects and methods (9 pages); Chapter 3. Results and discussion (86 pages); Conclusions and recommendations (2 pages); List of publications related to the dissertation (1 page); References (15 pages); and Appendices.

Chapter 1. Overview

1.1. Studies on plant diversity worldwide

1.1.1. Biodiversity

Plants play a fundamental role in sustaining life and maintaining ecosystem stability on Earth, serving as primary producers in most food chains and providing essential ecosystem services. Recognizing their importance, the international community has promoted the integration of biodiversity conservation and sustainable development since the late twentieth century, as reflected in the Convention on Biological Diversity (1992) and the Global Strategy for Plant Conservation (2002). More recently, the Madrid Declaration (2024) has reaffirmed the central role of plants in ensuring a sustainable future for humanity.

1.1.2. Studies on taxonomic composition of plant floras

Plant taxonomy has progressed from artificial, morphology-based systems to evolutionary classifications. From early contributions by Theophrastus, Ray, Tournefort, and Linnaeus, the discipline advanced through integrative approaches developed by Hutchinson, Brummitt, and Takhtajan. In the twenty-first century, DNA-based systems such as APG IV have become standard for angiosperm classification, while major Asian floras (e.g., *Flora of China*, *Flora of Thailand*) provide key references for floristic studies in Vietnam.

1.1.3. Studies on life-form diversity

Raunkiaer (1934) classified plant life forms into five groups based on the position of perennating buds. Life-form spectra reflect ecological conditions, with Phanerophytes dominating humid tropical rainforests, while

Hemicryptophytes and Cryptophytes prevail in high-mountain regions. Climate change has been shown to reduce life-form diversity, particularly impacting Phanerophytes in Southeast Asian tropical forests.

1.1.4. Studies on phytogeographical elements and endemism

Rosauer et al. (2009) proposed phylogenetic endemism to identify spatial concentrations of evolutionary history. Lee et al. (2009) documented 104 Korean endemic plant species using SEM-based seed morphology, while Georgioui and Delipetrou (2010) reported that endemic species constitute 15.6% of Greece's flora, spanning 242 genera in 56 families.

1.1.5. Studies on endangered and rare plant species

The IUCN Red List (since 1994) uses criteria based on population decline, distribution, and population size to assess extinction risk, classifying species from EX to NT. It currently includes over 166,000 species, with more than 46,000 threatened, including over 16,000 plant species. Regional assessments further highlight the global decline in plant diversity.

1.2. Studies on plant diversity in Vietnam

1.2.1. Taxonomic studies of the flora

Plant taxonomic research in Vietnam began with *Flora Cochinchinensis* (João de Loureiro) and was later developed through major works such as *Flore générale de l'Indo-Chine*, subsequently consolidated as The Flora of Cambodia, Laos, and Vietnam. National publications, including *An illustrated flora of Viet Nam*, *Checklist of Plant Species of Vietnam*, and *Flora of Vietnam*, have recorded over 11,500 vascular plant species, providing a scientific basis for the classification and identification of the Vietnamese flora. In addition, studies on plant use values and resource potential: PROSEA project, *Useful Plants of Vietnam*, *Non-timber Forest Products of Vietnam*, *Dictionary of Medicinal Plants of Vietnam*, and *Checklist of Medicinal Plants of Vietnam* have highlighted the important roles of plants in economic development, medicine, ecology, and biodiversity conservation.

1.2.2. Studies on life-form diversity

In Vietnam, studies on plant life forms have mainly applied Raunkiaer's (1934) classification system with five basic life-form groups. From early research by Pócs Tamás (1965) in northern Vietnam to subsequent studies in regions such as Sa Pa – Phan Si Pan, Lam Son (Hoa Binh), Pu Hoat (Nghe An), Phia Oac – Phia Den (Cao Bang), and the Western Nghe An Biosphere Reserve, life-form spectra consistently indicate the dominance of phanerophytes, reflecting the ecological characteristics of humid tropical and mountainous vegetation in Vietnam..

1.2.3. Studies on phytogeographical elements and endemism

The phytogeographical composition of Vietnam's flora has been widely studied. Gagnepain (1944) recognized five major floristic groups in Indochina, dominated by Sino-Chinese and Sino-Himalayan elements. Later works by Lê Trần Chân, Thái Văn Trùng, and Nguyễn Nghĩa Thìn refined this framework, highlighting Vietnamese–Indochinese endemism and the roles of tropical and temperate migration routes, which together reflect the high diversity and complex origin of the Vietnamese flora.

1.2.4. Studies on endangered and rare plant species

In Vietnam, endangered plant conservation is supported by scientific research, national Red Lists, and legal frameworks. Major works, including studies on conifers, the Vietnam Red Data Book (2007, 2024), and the Red List of Medicinal Plants (2019), apply IUCN criteria and show an increasing number of threatened species. Legal instruments such as Circular No. 85/2025/TT-BNNMT and CITES Notification No. 25/TB-CTVN (2023) provide a formal basis for the protection, management, and sustainable use of rare plant species.

1.3. Botanical studies in Kim Hy Nature Reserve

According to Decision No. 630/QĐ-UBND (10 May 2017), Kim Hy Nature Reserve covers an area of 15,715.02 ha, currently located in Van Lang, Con Minh, and Vinh Thong communes, Thai Nguyen Province. The

reserve represents the mountainous ecosystems of northern Vietnam, is influenced by a tropical monsoon climate with cold winters, and lies on the eastern flank of the Himalayas-an important global biodiversity center. Numerous studies have addressed plant diversity and conservation of rare species in the area, particularly the *Keteleeria davidiana* (Bertrand) Beissn., whose remaining populations consist of very few mature individuals. In addition, Kim Hy Nature Reserve is the type locality of a plant species new to science, *Elatostema kimhyense* Y.G. Wei & V.T. Do, described in 2017.

1.4. Natural and socio-economic conditions of Kim Hy Nature Reserve

1.4.1. Natural conditions of Kim Hy Nature Reserve

1.4.1.1. Geographical location

Kim Hy Nature Reserve is located in a limestone mountainous area along the boundary between Van Lang, Con Minh, and Vinh Thong communes, Thai Nguyen Province. The reserve lies between 22°07'30"–22°16'20" N latitude and 105°50'50"–106°03'50" E longitude

1.4.1.2. Topography

Kim Hy Nature Reserve comprises low and middle mountains within the Ngan Son arc, characterized by highly dissected, diverse, and complex terrain. The landscape includes both limestone mountains and non-limestone (soil) mountains, forming two clearly distinct geomorphological zones.

1.4.1.3. Climate

The study area is characterized by a subtropical mid-mountain climate, with two distinct seasons annually.

1.4.1.4. Hydrology

There are no major rivers within the study area; stream water rapidly infiltrates into deep subterranean systems due to karst processes.

1.4.1.5. Geology and soil

- Geology: The geological substrate of the study area is of sedimentary origin, formed under the general orogenic processes of northeastern Vietnam.
- Soils: The main soil types include humic feralit soils on mid-mountain

sandstones, feralit soils developed on limestone weathering products, colluvial valley soils, and soils on limestone mountains.

1.4.2. Socio-economic conditions of Kim Hy Nature Reserve

1.4.2.1. Population, ethnicity, and labor

The study area is mainly inhabited by the Tay (58.3%), Dao (17.3%), and Nung (14.1) ethnic groups. The labor force includes 7,688 people (62.5% of the population), with a balanced gender structure and a predominance of unskilled labor.

1.4.2.2. Economy and livelihoods

The main economic activities include crop cultivation, livestock farming, forestry production, and tourism and trade services, with agriculture and forestry playing a dominant role in local livelihoods.

1.4.2.3. Social conditions

Education and training, public healthcare services, and cultural, information, and sports activities have continued to receive attention and development in line with national policies.

Chapter 2. Research objects and methods

2.1. Research objects and scope

- The research focuses on vascular plant species in the Kim Hy Nature Reserve, Thai Nguyen Province
- The study was conducted over a four-year period, 8/2021 – 8/2025

2.2. Research methods

2.2.1. Literature-based method

Relevant documents concerning the study area were compiled, and both published and unpublished materials on plant diversity in Kim Hy Nature Reserve were reviewed and synthesized.

2.2.2. Methods for studying plant diversity

Plant collection, classification, assessment, and identification were conducted following the plant research methodology proposed by Nguyen Nghia Thin (2007).

2.2.3. Data processing methods

- Species identification and updating of the plant checklist were carried out using standard floristic references, including *An illustrated flora of Viet Nam*, *Checklist of Plant Species of Vietnam* (I–III), *Flora of Cambodia, Laos and Vietnam*, and the *Flora of Vietnam*,...

- The plant checklist was compiled following an evolutionary classification framework. Vascular plant divisions were arranged according to evolutionary trends. For Angiosperms (Magnoliophyta), taxa were divided into Liliopsida and Magnoliopsida and arranged in alphabetical order; family-level classification followed the APG IV system, while ferns followed PPG I and gymnosperms followed GPG. The remaining vascular plant divisions were organized consistently in alphabetical order.

- Analysis of taxonomic diversity of vascular plants at the levels of division, class, family, and genus.

- Assessment of phytogeographical elements and life-form diversity based on the established floristic checklist, following the approach of Nguyễn Nghĩa Thìn (2007).

- Analysis of the diversity of plant use values based on specialized references on plant resources and medicinal plants.

- Assessment of plant genetic resources of conservation concern, including rare and threatened species, according to the Vietnam Red Data Book (2024), CITES Vietnam (2023), Circular No. 85/2025/TT-BNNMT, and the IUCN Red List (2024).

Chapter 3. Results and discussion

3.1. Updated checklist of vascular plants in Kim Hy Nature Reserve

The checklist of vascular plants in Kim Hy Nature Reserve was compiled based on field surveys combined with previously published data and arranged according to an evolutionary sequence. Flowering plants were classified into two classes, Monocotyledons and Dicotyledons; taxonomic circumscription followed the APG IV system for angiosperms, the PPG I

system for ferns, and an A–B–C order for the remaining plant divisions. The results recorded 1,446 species and infraspecific taxa, belonging to 779 genera, 182 families, and 6 divisions. Each taxon is documented with its scientific name, Vietnamese name, life form, phytogeographical element, use value, conservation status, and voucher information.

+ Among them, two species were newly described to science, namely *Sporoxeia vietnamensis* D.V. Hai, Z.L. Lin & S. Jin Zeng (Melastomataceae) and *Strobilanthes spathulatibracteata* D.V. Hai, Z.L. Lin & Y.F. Deng (Acanthaceae).

+ In addition, two species were newly recorded for the flora of Vietnam, including *Rungia sinothailandica* Z.L. Lin & Y.F. Deng and *Strobilanthes lamiifolia* (Nees) T. Anderson (Acanthaceae).

Furthermore, 485 vascular plant species, representing 312 genera and 100 families, were newly added to the flora of Kim Hy Nature Reserve based on specimens collected and examined during the present study, significantly enriching knowledge of the plant diversity of the study area.

3.2. Floristic diversity of Kim Hy Nature Reserve

3.2.1. Diversity at the division level

The study recorded a total of 1,446 species and infraspecific taxa, belonging to 779 genera and 182 families of six divisions of vascular plants in the study area:

Psilotophyta: 1 taxon, 1 genus, 1 family;

Lycopodiophyta: 13 taxa, 4 genera, 2 families;

Equisetophyta: 1 taxon, 1 genus, 1 family;

Polypodiophyta: 101 taxa, 40 genera, 16 families;

Pinophyta: 11 taxa, 8 genera, 5 families;

Magnoliophyta: 1,319 taxa, 725 genera, 157 families.

A comparison of the floristic composition at the division level indicates that Magnoliophyta overwhelmingly dominates the vascular flora of Kim Hy Nature Reserve, accounting for 91.22% of the total taxa, which represents

13.44% of the vascular plant flora of Vietnam. Polypodiophyta ranks second with 6.98% of the taxa, corresponding to 15.10% of the national fern flora. The remaining divisions (Psilotophyta, Lycopodiophyta, Equisetophyta, and Pinophyta) contribute only marginal proportions and play a secondary role in the overall floristic structure of the study area.

The distribution of vascular plant species among divisions in Kim Hy Nature Reserve is markedly uneven, with Magnoliophyta exhibiting overwhelming dominance. Within this division, Magnoliopsida constitutes the principal component, representing over 80% of the families, genera, and species of angiosperms, and approximately three quarters of the total vascular flora of the study area. In contrast, Liliopsida is considerably less represented. The predominance of dicotyledonous taxa conforms to De Candolle's climatic rule, highlighting the strong influence of tropical monsoon conditions on the floristic structure of Kim Hy Nature Reserve.

3.2.2. Diversity at the family level

Among the 182 vascular plant families recorded in Kim Hy Nature Reserve, 42 families are represented by a single species, 40 families by two species, 12 families by three species, 46 families by 4–10 species, and 42 families by more than 10 species. This pattern reflects the floristic specificity of the reserve, characterized by the presence of numerous taxa typical of tropical seasonal evergreen forests on low-elevation limestone terrain. A total of 42 families contain more than 10 species. Among them, the 11 most species-rich families (each comprising more than 28 species) include Orchidaceae (74 species), Fabaceae (70 species), Rubiaceae (58 species), Lamiaceae (50 species), Asteraceae (42 species), and Euphorbiaceae (39 species). Although the ten most species-rich families account for only 5.49% of the total number of families in the study area, they contribute as many as 462 species, representing 31.92% of the total vascular plant flora. This indicates a strong concentration of species diversity within a limited number of characteristic tropical families, a pattern commonly observed in humid

tropical floras.

3.2.3. Diversity at the genus level

The vascular flora of Kim Hy Nature Reserve comprises 779 genera, exhibiting a concentrated taxonomic structure where the 10 most genus-rich families (5.49% of total) account for 34.65% of all genera. *Ficus* is the most species-rich genus (27 species), followed by *Begonia* and *Ardisia* (11 species each), with the prevalence of *Begonia* underscoring the ecological importance of karst habitats. Conversely, the flora is characterized by a high proportion of species-poor taxa, including 488 monotypic and 153 oligospecific (two-species) genera. This pronounced disparity indicates a heterogeneous structure, where the loss of low-diversity genera poses a significant threat to higher-level taxonomic diversity and the overall ecological stability of the reserve.

3.1.4. Life-form spectrum of the vascular flora of Kim Hy Nature Reserve

The life-form spectrum of the vascular flora in Kim Hy Nature Reserve, Thai Nguyen Province, is expressed as follows:

$SB = 81,67 \text{ Ph} + 5,33 \text{ Hm} + 4,98 \text{ Cr} + 4,50 \text{ Ch} + 3,53 \text{ Th}$. According to this spectrum, phanerophytes (Ph) constitute the dominant life-form group, accounting for 81.67% of the total number of species. Within this group, several subcategories are recognized: microphanerophytes (Mi; 2–8 m in height) represent 17.36%, mesophanerophytes (Me; 8–25 m) 12.66%, lianas (Lp) 12.59%, and parasitic or hemiparasitic phanerophytes (Pp) account for a very small proportion (1.04%). The pronounced dominance of phanerophytes reflects the humid tropical monsoon climate and the predominance of low- to mid-elevation forest vegetation in Kim Hy Nature Reserve. The life-form spectrum of phanerophytes can be further expressed as: $\text{Ph} = 17,36 \text{ Mi} + 12,66 \text{ Me} + 12,59 \text{ Lp} + 18,46 \text{ Na} + 6,78 \text{ Ep} + 5,05 \text{ Mg} + 7,75 \text{ Hp} + 1,04 \text{ Pp}$. This distribution indicates a high structural diversity of woody life forms, with nanophanerophytes (Na) playing a particularly

prominent role, thereby contributing significantly to the ecological character and vegetation structure of the vascular flora of the reserve.

3.2.5. Diversity of phytogeographical elements of the vascular flora of Kim Hy Nature Reserve

3.2.5.1. Phytogeographical composition of the vascular flora of Kim Hy Nature Reserve

The vascular flora of Kim Hy Nature Reserve belongs predominantly to the tropical floristic region of mainland Southeast Asia and shows strong affinities with the Indochinese–South Chinese floristic region, which represents the largest phytogeographical element with 303 species (20.95%). The flora is also strongly influenced by the mainland Southeast Asian region, particularly the eastern Himalayan tropical element, comprising 150 species (10.37%). Two additional major tropical components are the Indochinese–Malesian element and the Asian tropical element, represented by 135 species (9.34%) and 133 species (9.20%), respectively. In addition to the dominant tropical elements, the presence of temperate elements, including the Northern temperate element (10 species) and the East Asian element (57 species), reflects the combined effects of the region’s distinctive natural conditions. The low- to mid-elevation mountainous terrain, characterized by steep slopes and altitudinal differentiation, creates cool and humid microhabitats that facilitate the persistence and local establishment of temperate and subtropical taxa. Moreover, the humid tropical monsoon climate with a pronounced cool winter and high seasonal temperature amplitude provides favorable conditions for species originating from cooler climatic regions. The cosmopolitan element, comprising 49 species (3.39%), further indicates the widespread distribution and ecological adaptability of certain plant taxa within the flora of Kim Hy Nature Reserve.

3.2.5.2. Diversity of Vietnamese endemic taxa

Vietnamese endemic taxa account for 69 species, representing 4.77% of the total vascular flora of Kim Hy Nature Reserve. This relatively high

proportion can be explained by the long geological history of the remnant limestone (karst) massifs and the ancient isolation of many plant lineages within unique habitats characterized by specialized ecological conditions. All 69 endemic species belong to the angiosperms (Magnoliophyta). Within this group, the class Magnoliopsida is dominant, comprising 56 species (81.16% of the endemic flora), which are distributed across 38 plant families. The occurrence of a substantial number of endemic species highlights the floristic uniqueness of Kim Hy Nature Reserve and represents an important indicator for biodiversity conservation planning and priority-setting in the region.

3.2.6. Diversity of use values of the vascular flora of Kim Hy Nature Reserve

The vascular flora of Kim Hy Nature Reserve exhibits high diversity and significant potential for sustainable use, with 1,122 species (belonging to 680 genera and 175 families) documented for their utility. A total of 1,853 use instances were recorded, indicating that many taxa provide multiple benefits. Medicinal plants constitute the largest group, comprising 867 species (representing 59.96% of the total flora). This is followed by timber species (18.46%), ornamental plants (10.86%), and edible species (9.34%), while resin-producing plants represent the smallest category (0.69%). These findings underscore the considerable value of the region's plant resources for conservation and sustainable development.

3.2.6.1. Edible plants: The edible plant group comprises 135 species belonging to 107 genera and 58 families, representing two vascular plant divisions, Magnoliophyta and Polypodiophyta. The family Asteraceae is the most species-rich among edible plants, with 16 species, accounting for 1.10% of the total number of species recorded in the vascular flora of Kim Hy Nature Reserve;

3.2.6.2. Timber plants: Timber-producing plants in Kim Hy Nature Reserve comprise 267 species, accounting for 18.46% of the total vascular plant species, indicating a considerable potential of forest resources in the

study area. The most species-rich families of plants include Fabaceae, Lauraceae, Euphorbiaceae, Fagaceae, and Meliaceae, with Fabaceae (24 species) and Lauraceae (22 species) being particularly dominant. A total of 171 genera of timber plants were recorded, of which approximately 70% are represented by a single species;

3.2.6.3. *Fibre plants*: Fibre-producing plants in Kim Hy Nature Reserve comprise 51 species, accounting for 3.53% of the total vascular flora. The family Malvaceae is the most species-rich, with 12 fibre-yielding species, while the genus *Calamus* (Arecaceae) is the most diverse at the generic level, represented by three species;

3.2.6.4. *Essential oil plants*: A total of 64 species of essential oil-producing plants were recorded in Kim Hy Nature Reserve, representing 4.43% of the total vascular plant species. Lamiaceae is the most species-rich family (12 species), while the most representative genera include *Piper*, *Magnolia*, *Cinnamomum*, and *Alpinia*, each represented by four species;

3.2.6.5. *Poisonous plants*: A total of 24 poisonous plant species were recorded in Kim Hy Nature Reserve, accounting for 1.66% of the total vascular flora. Fabaceae is the most species-rich family, represented by five species. The genera *Strychnos*, *Engelhardia*, and *Dendrocnide* are each represented by two species. Several poisonous species were documented, notably members of *Dendrocnide*, which are continuously distributed across limestone mountainous terrain;

3.2.6.6. *Ornamental plants*: The ornamental plant group in Kim Hy Nature Reserve comprises 157 species belonging to 113 genera and 51 families, indicating a high level of taxonomic diversity. Orchidaceae is the most species-rich family, with 38 species. *Dendrobium* is the most diverse genus (nine species). Most genera are represented by a single species, reflecting a high degree of species richness and taxonomic dispersion;

3.2.6.7. *Fodder plants*: A total of 38 plant species used as fodder were recorded, belonging to 32 genera and 12 families. Fabaceae is the most

species-rich family, with 10 species, followed by Poaceae with eight species. The genus *Cyperus* is the most diverse, represented by four species;

3.2.6.8. Fruit plants: The fruit plant group comprises 104 species belonging to 65 genera and 36 families within Kim Hy Nature Reserve. Moraceae is the most species-rich family, represented by 14 species, followed by Phyllanthaceae and Rutaceae with eight species each. The genera *Ficus* and *Syzygium* are the most diverse, each represented by five species, indicating a high level of fruit plant diversity in the study area;

3.2.6.9. Oil-bearing plants: A total of 37 oil-bearing plant species were recorded, belonging to 28 genera and 18 families. Euphorbiaceae is the most species-rich family, with 11 species. The genus *Litsea* is the most diverse, represented by four species. The predominance of genera and families represented by a single oil-bearing species highlights the taxonomic diversity of this functional group;

3.2.6.10. Tannin-producing plants: The tannin-producing plant group includes 31 species belonging to 23 genera and 12 families. These species are commonly used in tanning, textile dyeing, and food preservation. Fabaceae is the most species-rich family, with nine species, while *Castanopsis* is the most diverse genus, represented by four species;

3.2.6.11. Medicinal plants: The medicinal plant group recorded in Kim Hy Nature Reserve comprises 867 species belonging to 567 genera and 160 families, indicating an exceptionally rich medicinal plant resource. Fabaceae is the most species-rich family, represented by 44 medicinal species. At the generic level, *Ficus* is the most diverse, with 15 medicinal species. A total of 1,606 medicinal use records were documented, with the recorded species being used to treat 50 different disease categories. Many species exhibit multiple medicinal uses, reflecting their high practical value and underscoring the significant conservation importance and sustainable utilization potential of medicinal plant resources in the reserve.

3.2.7. Diversity of threatened, rare, endemic and valuable genetic

resources

The flora of Kim Hy Nature Reserve is not only rich in species composition but also of high conservation and utilization significance. A total of 219 threatened, rare, endemic and valuable plant species with varying levels of extinction risk were recorded, belonging to 151 genera and 52 families. These taxa account for 15.14% of the total species, 19.38% of genera, and 39.01% of families of the vascular flora in the study area. Many species are concurrently listed under multiple conservation frameworks, including the *Vietnam Red Data Book* (2024), the *IUCN Red List* (2024), Circular No. 85/2025/TT-BNNMT, and *CITES* (2023). Notable examples include *Paphiopedilum emersonii* Koop. & P.J. Cribb, *Paphiopedilum helenae* Aver., and *Paphiopedilum malipoense* S.C. Chen & Z.H. Tsi.

+ A total of 75 plant species recorded in Kim Hy Nature Reserve are classified as threatened in the *Vietnam Red Data Book* (2024), representing 5.18% of the total flora of the reserve and 12.15% of all vascular plant species listed nationally. These include 3 species categorized as Critically Endangered (CR), 33 as Endangered (EN), and 39 as Vulnerable (VU).

+ According to Circular No. 85/2025/TT-BNNMT, 97 plant species occurring in the reserve are subject to legal protection, accounting for 6.70% of the total flora. Among them, 5 species are listed under Group IA (strictly prohibited from commercial exploitation), while 92 species belong to Group IIA (restricted from commercial use).

+ According to Notification No. 25/TB-CTVN dated 17 February 2023 issued by the Vietnam CITES Management Authority, a total of 76 plant species recorded in Kim Hy Nature Reserve are listed in the Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Of these, three species are included in Appendix I (CITES I), comprising taxa threatened with extinction that are or may be affected by international trade; trade in specimens of these species is subject to the strictest regulations and is permitted only under exceptional

circumstances. The remaining 73 species are listed in Appendix II (CITES II), which includes species not necessarily threatened with extinction at present but that may become so unless trade is strictly controlled to prevent utilization being incompatible with their survival.

+ According to the IUCN Red List (2024), 17 plant species recorded in Kim Hy Nature Reserve have been assessed at the global level, accounting for 1.17% of the total flora of the area. Among these, three species are classified as Critically Endangered (CR), seven species as Endangered (EN), and seven species as Vulnerable (VU).

+ In addition, 69 plant species recorded in Kim Hy Nature Reserve are endemic to Vietnam but are not currently included in the Vietnam Red Data Book (2024), Circular No. 85/2025/TT-BNNMT, or the CITES Appendices (2023). These endemic taxa represent an important but under-recognized component of the regional flora.

Collectively, data on threatened, protected, and endemic plant species provide a critical scientific basis for in situ conservation planning and biodiversity management in Kim Hy Nature Reserve.

3.3. Drivers of decline and conservation measures for plant diversity in Kim Hy Nature Reserve

3.3.1. Threats to plant diversity in Kim Hy Nature Reserve

The decline of plant biodiversity generally results from three main groups of factors: natural processes, anthropogenic disturbances, and intrinsic biological limitations of species. Among these, human-induced impacts represent the dominant driver, operating at a rapid pace and remaining amenable to management intervention. Activities such as illegal mining, land-use conversion, free grazing, and the unsustainable extraction of timber and non-timber forest products exert substantial pressure on plant communities in Kim Hy Nature Reserve. Understanding these drivers provides a critical scientific basis for proposing appropriate conservation strategies for the area.

- Direct drivers: Plant diversity decline in Kim Hy Nature Reserve is primarily driven by direct human disturbances affecting coniferous forests and mixed forests on limestone mountains. Illegal mining, timber harvesting, and the exploitation of non-timber forest products have resulted in habitat degradation, disruption of forest structure, and reduced natural regeneration, particularly for lithophytic and limestone-specialist plant groups. In addition, forest encroachment for agricultural expansion, uncontrolled livestock grazing, and the persistent risk of forest fires continue to impose significant pressure on plant diversity and conservation efforts within the reserve.

- Indirect drivers: Indirect pressures on plant biodiversity in Kim Hy are closely associated with socio-economic conditions and management constraints. High poverty rates, limited employment opportunities, and shortages of arable land have increased local dependence on forest resources for livelihoods. Community awareness and technical capacity remain limited, while buffer-zone agriculture is characterized by low productivity and poorly adapted alternative livelihood models. Furthermore, low financial incentives under forest protection contracts, insufficient ranger staffing, and the large area under management have reduced the overall effectiveness of forest protection and biodiversity management.

3.3.2. Proposed conservation measures for plant biodiversity in Kim Hy Nature Reserve

3.3.2.1. Mitigating the drivers of biodiversity loss: Based on the analysis of both direct and indirect drivers of plant biodiversity decline in Kim Hy Nature Reserve, a set of conservation measures has been proposed. These measures aim to address the underlying causes of biodiversity loss and to enhance the effectiveness of plant conservation in the reserve.

Table 3.39. Proposed measures to mitigate the drivers of plant biodiversity decline in Kim Hy Nature Reserve

No.	Drivers of biodiversity loss	Proposed mitigation measures
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<i>I</i>	<i>Direct drivers</i>	
1	Illegal mineral extraction	- Strengthen inspection, enforcement, and confiscation/destruction of mining equipment; establish remote monitoring systems using satellite imagery; promote alternative livelihoods for local communities.
2	Illegal logging	- Increase the capacity of forest rangers and community-based forest protection groups; identify and regularly monitor logging hotspots; enhance legal awareness through village-level outreach.
3	Illegal harvesting of non-timber forest products	- Develop models for cultivating native medicinal plants in buffer zones and under forest canopies; establish sustainable harvesting quotas and regulations; expand OCOP products and geographical indication schemes; monitor species populations after harvesting.
4	Encroachment of forest land for agricultural and forestry production	- Review and strictly handle cases of illegal land encroachment; plan concentrated plantation zones; diversify tree species used in reforestation and afforestation programs.
5	- Free grazing of livestock; - Forest fires	- Designate specific grazing areas and support stall-fed livestock systems. - Establish local fire response teams; upgrade fire warning signage and conduct community-based fire prevention training.
<i>II</i>	<i>Indirect drivers</i>	
6	Lack of employment opportunities, limited arable land, high poverty rates	- Develop sustainable livelihoods (medicinal plant cultivation, ecotourism, handicrafts); expand planned production areas; provide credit access and vocational training.
7	Limited awareness of biodiversity conservation	- Disseminate conservation laws and regulations in local ethnic languages; integrate conservation education into village meetings and community activities;
8	Low agricultural productivity	- Promote native food crops, fruit trees, and vegetables with high economic value; apply intercropping and intensive farming to

		improve land-use efficiency; provide technical support and market linkages; develop agroforestry models.
9	Policy and management constraints	- Increase payments for forest environmental services; improve forest protection contracts; strengthen ranger staffing; apply modern technologies (satellite monitoring, camera traps); enhance coordination among local authorities, forest rangers, and communities.

3.3.2.2 Proposal for species conservation prioritization based on integrated datasets

Conservation priorities were established by integrating data from the Vietnam Red Data Book (2024), Circular No. 85/2025/TT-BNNMT, CITES (2023), Vietnamese endemic species, and the IUCN Red List (2024). Priority ranking followed a hierarchical order, with the Vietnam Red Data Book assigned the highest priority, followed by Circular No. 85/2025/TT-BNNMT, CITES, Vietnamese endemics, and the IUCN Red List. Based on this framework, 219 plant species were ranked into 24 priority levels, providing a scientific basis for species-focused conservation planning in Kim Hy Nature Reserve.

3.3.2.3. Conservation and development under an “integrated and rational approach: Plant species with utilitarian values are closely linked to multiple sectors, including agriculture, medicine, industry, food, cosmetics, construction, and tourism. Conservation strategies should therefore follow an integrated and rational approach, balancing biodiversity conservation with sustainable use and local livelihood development”.

3.3.2.4. Integrated application of in situ and ex situ conservation for threatened plant species

+ In situ conservation represents the core strategy for maintaining and restoring populations of threatened, rare, and valuable plant species within their natural habitats, thereby preserving ecological and evolutionary processes. Based on assessments of species status and distribution in Kim

Hy Nature Reserve, conservation targets were identified and prioritized. Key measures include strict protection of critical populations and habitats; ecological and regeneration studies of threatened species; establishment of long-term monitoring plots; collection and management of reproductive materials to reinforce populations; and habitat restoration using native species through appropriate silvicultural practices. In addition, complementary approaches such as quasi in situ conservation, seed orchards, plant micro-reserves, and the application of GIS and remote sensing to identify suitable habitats can support reintroduction and range expansion. In situ conservation is regarded as the most effective and sustainable approach and should be flexibly complemented by other conservation strategies when necessary.

+ Ex situ conservation refers to the conservation of plant species outside their natural habitats through storage and propagation in botanical gardens, nurseries, seed banks, gene banks, or via tissue culture. Ex-situ conservation plays an important role in safeguarding threatened species and supporting population recovery. Major ex situ measures include the establishment of seed banks under controlled drying and cold-storage conditions; cryopreservation of seeds, tissues, embryos, and pollen at ultra-low temperatures; and in vitro tissue and cell culture for the conservation and propagation of species with poor natural regeneration or small populations. Ex situ conservation offers advantages in terms of cost efficiency, space requirements, and long-term preservation of genetic diversity. However, it cannot replace in situ conservation and should be applied as a complementary approach to enhance overall plant conservation effectiveness, particularly for threatened, rare, and endangered species.

Conclusions and recommendations

1. Conclusions

1. The checklist of vascular plant species of Kim Hy Nature Reserve, Thai Nguyen Province, has been updated. Specifically:

+ A total of 1,446 vascular plant species and infraspecific taxa, belonging to 779 genera, 182 families, and 6 divisions of vascular plants, were recorded.

+ A total of 485 vascular plant species were newly added to the flora of Kim Hy Nature Reserve.

+ Co-described and co-published two new species to science *Sporoxeia vietnamensis* D.V.Hai, Z.L.Lin & S.Jin Zeng (Melastomataceae) and *Strobilanthes spathulatibracteata* D.V. Hai, Z.L. Lin & Y.F. Deng (Acanthaceae).

+ Co-published two newly recorded to the flora of Vietnam *Rungia sinothailandica* Z.L.Lin & Y.F.Deng and *Strobilanthes lamiifolia* (Nees) T. Anderson (Acanthaceae).

2. The diversity of vascular flora in Kim Hy Nature Reserve, Thai Nguyen Province was assessed:

+ Life forms were identified for all 1,446 species, and the biological spectrum of the vascular flora was established as:

$$SB = 81,67\%Ph + 5,33\%Hm + 4,98\%Cr + 4,50\%Ch + 3,53\%Th$$

+ Phytogeographical elements were determined for all 1,446 species, belonging to 16 geographical element groups.

+ A total of 1,122 plant species, representing 680 genera and 175 families, were identified as having resource and use values.

+ A checklist and distribution maps of threatened, rare, and valuable plant species were compiled, comprising 219 threatened species and infraspecific taxa belonging to 52 families and 151 genera, including (75 species listed in the *Vietnam Red Data Book (2024)*; 17 species in the *IUCN Red List (2024)*; 97 species regulated under *Circular No. 85/2025/TT-BNNMT*, and 76 species included in the *CITES Appendices (2023)*).

3. Proposed solutions for plant diversity conservation:

+ A priority-ranking framework comprising 137 priority levels was developed for species conservation based on the integration of five datasets:

the *Vietnam Red Data Book (2024)*, *Circular No. 85/2025/TT-BNNMT*, *CITES (2023)*, *the list of Vietnamese endemic species*, and *the IUCN Red List (2024)*. Accordingly, 219 species were classified into 24 priority groups (levels 1–24);

- + Conservation strategies based on an “integrated and rational approach” were proposed;

- + A balanced combination of in situ and ex situ conservation was recommended for threatened, rare, and valuable plant species in Kim Hy Nature Reserve.

4. Five publications related to the dissertation were co-authored, including three SCIE-indexed papers, one Scopus-indexed paper, and one national journal article recognized by the State Council for Professorship.

2. Recommendations

Further research and policy refinement are needed, together with concrete actions to implement forest protection and development solutions for Kim Hy Nature Reserve.

Develop and implement conservation and monitoring plans for plant species requiring urgent protection, giving priority first to CR species, followed by EN and VU species, and species listed in Groups IA and IIA and the CITES Appendices, according to the conservation priority ranking established from the assessment results based on the *Vietnam Red Data Book (2024)*, *Circular No. 85/2025/TT-BNNMT*, *CITES (2023)*, and *the IUCN Red List (2024)*.