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Quantitative Ethnobotany and Species Use Patterns in Ngao Model Forest, Northern Thailand

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Abstract

Understanding how ecological dominance aligns with culturally and economically valued plant use is critical for participatory forest management. This study integrated vegetation structure and ethnobotanical valuation to assess angiosperm importance across three forest strata (Mixed Deciduous Forest (MDF), Dry Dipterocarp Forest site 1 (DDF1), and Dry Dipterocarp Forest site 2 (DDF2)) within the Ngao Model Forest, Northern Thailand. Fifteen 10 × 10 m vegetation plots (five per forest stratum) were surveyed to calculate the Importance Value Index (IVI), and 198 semi-structured interviews were conducted to derive the Use Value Index (UVI) and a standardized Socio-Economic Value Index (SEVI). A total of 112 angiosperm species were recorded across forest types, with strong structural dominance by dipterocarps in DDF sites and greater compositional heterogeneity in MDF. Spearman rank correlation analysis supported the working hypothesis that ecological dominance is only weakly associated with cultural and socio-economic importance. IVI showed weak but significant positive correlations with UVI ($\rho = 0.288$, $p < 0.05$) and SEVI ($\rho = 0.300$, $p < 0.05$), indicating partial but limited alignment between structural abundance and livelihood value. Several species with moderate or low IVI exhibited disproportionately high UVI and SEVI scores, reflecting their importance in food, medicinal, and commercial use categories. Conversely, certain canopy dominants showed limited ethnobotanical significance. These findings demonstrate that ecological abundance alone is an insufficient proxy for community-defined species value. Integrating structural, cultural, and socio-economic indices provides a more comprehensive framework for identifying priority species in community-managed forest systems. The IVI–UVI–SEVI comparative approach offers practical insights for model forest governance by distinguishing ecological dominants, multipurpose livelihood species, and culturally significant taxa occurring outside forest interiors. This multidimensional valuation framework strengthens participatory forest management and biodiversity prioritization in heterogeneous tropical landscapes.

Keywords: ethnobotany; community forestry; model forest; northern Thailand; Important Value Index; Socio-Economic Value Index; Use Value Index

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1. Introduction

Forests provide a wide range of ecological functions and socio-economic benefits, supporting biodiversity conservation, climate regulation, and rural livelihoods. In tropical regions, forest-dependent communities rely heavily on plant resources for food, medicine, construction materials, and cultural practices, making the integration of ecological and

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social dimensions essential for sustainable forest management. Conventional forest inventories typically emphasize structural attributes such as species composition, dominance, and basal area, often summarized through indices such as the Importance Value Index (IVI) [1]. While these metrics are fundamental for understanding forest structure, they do not necessarily reflect how local communities value or utilize plant species.

Ethnobotanical research has consistently shown that species with limited ecological dominance may hold high cultural or livelihood importance, whereas structurally dominant species may be infrequently used [2,3]. Quantitative ethnobotany has therefore developed indices such as the (UVI) to capture the frequency and diversity of plant use based on local knowledge [4,5]. More recent approaches emphasize composite socio-economic indices that integrate multiple dimensions of use, preference, and cultural relevance to better reflect human–forest interactions [6]. These approaches recognize that traditional ecological knowledge shapes species valuation beyond abundance alone and is embedded in long-term observation, experimentation, and intergenerational transmission [7,8].

In Southeast Asia, and particularly in Thailand, ethnobotanical knowledge remains central to community forestry systems, where local users actively manage and extract forest resources under formal and informal governance arrangements [9,10]. Previous studies in northern Thailand have documented rich ethnobotanical knowledge associated with Dry Dipterocarp Forest (DDF) and Mixed Deciduous Forest (MDF), highlighting the importance of food, medicinal, and multipurpose species for household subsistence and cultural identity [10,11]. However, many existing studies focus either on floristic composition or on qualitative descriptions of plant use, with limited integration of quantitative ecological indices and socio-economic valuation within a single analytical framework.

Model Forests provide an important platform for examining such integrated relationships, as they are designed to balance ecological sustainability with community livelihoods through participatory management. The Ngao Model Forest in Lampang Province encompasses multiple forest types and is embedded within a landscape where communities maintain long-standing relationships with forest resources. Despite its relevance, empirical assessments linking forest structure with ethnobotanical importance within a model forest context remain limited. In particular, the extent to which ecological dominance corresponds with socio-economic importance has not been quantitatively examined.

Discrepancies between species recorded in ecological plots and those reported as important by local communities are well documented in ethnobotanical literature. These mismatches may arise from spatial heterogeneity, seasonal availability, selective protection, enrichment planting, or long-term management practices that are not captured by standard inventory methods [3,6]. Species maintained through repeated harvesting or cultural preference may be locally significant despite low representation in forest plots. Such species may function as culturally important resources, exerting disproportionate influence on livelihoods and management priorities relative to their ecological abundance [12].

Against this background, this study integrates ecological inventory data with ethnobotanical information to examine angiosperm utilization patterns in the Ngao Model Forest. Ecological importance was quantified using the IVI derived from vegetation structure, while socio-economic importance was assessed using the Use Value Index (UVI) and a standardized Socio-Economic Value Index (SEVI) derived from key informant interviews. By comparing these indices across forest types, the study evaluates whether ecological dominance corresponds with socio-economic valuation and identifies species that are culturally significant despite low structural representation.

The specific objectives of this study are to:

- Document species composition and family-level patterns across MDF and DDF types within the Ngao Model Forest;

- Quantify species importance using IVI, UVI, and SEVI;
- Assess the relationship between ecological dominance and socio-economic importance of angiosperm species.

The working hypothesis is that IVI is weakly correlated with UVI and SEVI, indicating that structurally dominant species are not necessarily the most socio-economically important to local communities. By empirically testing this hypothesis, the study contributes to a more integrated understanding of forest value that combines ecological structure with culturally embedded plant use, supporting more inclusive and context-sensitive forest management strategies.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Ngao Model Forest, Lampang Province, Northern Thailand (18°46′ N, 99°59′ E), a designated pilot site under Thailand's Model Forest Program managed collaboratively by the Royal Forest Department (RFD) and local communities (Figure 1). The Ngao Model Forest covers approximately 61,000 ha and includes mixed deciduous forest (MDF), dry dipterocarp forest (DDF), and patches of dry evergreen forest at elevations ranging from 200 to 1100 m a.s.l. Mean annual precipitation is approximately 1080 mm and mean annual temperature is 26 °C.

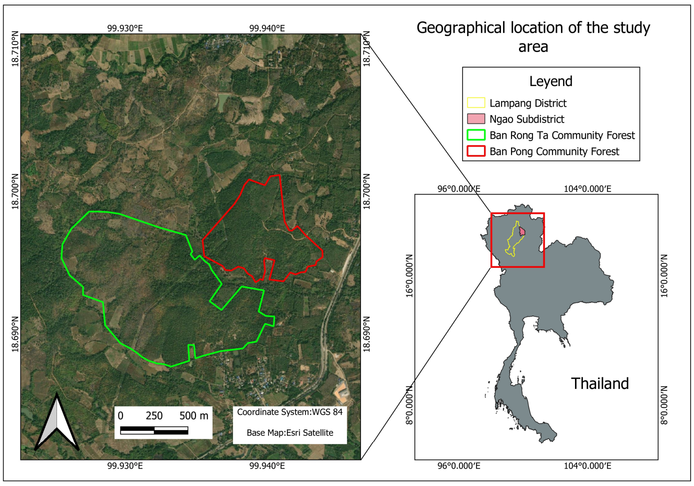

Figure 1. Map of the Study Area in Ban Pong and Ban Rong Ta, Lampang Province, Thailand.

Two communities—Ban Pong and Ban Rong Ta—were selected due to their active participation in community forest governance and differing forest-use patterns. Ban Pong households rely primarily on non-timber forest products (NTFPs) and small-scale agriculture, while Ban Rong Ta households combine forest-based extraction with mixed forest–farm livelihoods.

2.2. Research Design Overview

This study integrates ecological vegetation inventory with ethnobotanical and socio-economic data to evaluate relationships among ecological dominance (IVI), cultural use (UVI), and livelihood importance (SEVI).

Data collection comprised:

1. Vegetation sampling for structural analysis and IVI calculation.
2. Ethnobotanical interviews for UVI and SEVI calculation.
3. Statistical analysis of relationships among indices.

2.3. Vegetation Sampling and Ecological Data Collection

2.3.1. Sampling Design

A stratified purposive sampling design was employed to assess vegetation structure within actively utilized forest zones. To ensure spatial alignment between ecological sampling and areas of active resource use, plots were systematically positioned along line transects following established NTFP collection pathways. This deliberate spatial targeting ensures that ecological data and ethnobotanical data were derived from the exact same forest zones, enabling a robust comparison between ecological structure and cultural importance.

Three transect lines, one for each forest site, and five temporary plots within each transect were established to properly capture vegetation within each forest site. A total of 15 sample plots (10 × 10 m) were established and allocated equally, five per forest site, across three distinct forest sites:

- Mixed Deciduous Forest (MDF).
- Dry Dipterocarp Forest site 1 (DDF1; Ban Pong).
- Dry Dipterocarp Forest site 2 (DDF2; Ban Rong Ta).

Plots were positioned along line transects within areas actively used for forest resource collection to ensure spatial alignment between ecological and ethnobotanical data. Each transect measured approximately 100 m, with plots placed at regular intervals [13,14].

Within each plot in each transect, all woody angiosperm species meeting the minimum diameter threshold (DBH $\geq$ 10 cm) were recorded. Diameter at breast height (DBH) was measured at 1.3 m above ground level and applied exclusively to woody species, following standard forest inventory protocols [15,16]. Non-woody angiosperms, including herbs, climbers, and shrubs below the DBH threshold, were documented using presence–absence records and abundance count where applicable, to complement structural data from woody vegetation [17].

2.3.2. Vegetation Measurements

Special attention was given to regeneration status, with seedlings and saplings recorded separately to assess the sustainability of plant resource use. Regeneration data are widely recognized as critical indicators of population viability, as they reflect whether heavily utilized species are being naturally replenished or are at risk of decline due to over-harvesting or management pressure [18–20]. Vegetation data collection therefore provided a quantitative ecological foundation for linking species-level abundance and dominance with ethnobotanical importance and socio-economic use indices, enabling an integrated assessment of ecological availability and cultural utilization patterns [21–23].

Taxonomic identifications were verified using authoritative floristic references including Flora of Thailand and online databases (Plants of the World Online, International Plant Names Index), with family classification following the Angiosperm Phylogeny Group IV (2016) system [24,25]. All voucher specimens (Table S1) are maintained at the Faculty of Forestry, Kasetsart University herbarium (KUFFH) and Khon Kaen University herbarium (KKU).

2.3.3. Voucher Specimens

Voucher specimens were selectively collected for angiosperm species requiring taxonomic verification, including species not confidently identifiable in the field, understory and sub-canopy species, uncommon taxa, and species lacking previous herbarium documentation from the region. Well-known canopy dominants with distinctive morphological characters were identified using field characters and verified with regional floras (Flora of

Thailand, regional monographs) without requiring physical voucher collection, following standard vegetation ecology practice [22,23].

2.4. Ethnobotanical Data Collection

2.4.1. Sample Size Determination

The sample size for household interviews was determined using the [26] formula, which provides a statistically valid method for estimating sample sizes in social science research. The sample size for interviews were calculated using the Krejcie and Morgan formula, a well-established method for determining appropriate sample size in social research.

$$n = \frac{\left(X^2 \times N \times p \times (1-p)\right)}{\left(e^2 \times (N-1) + X^2 \times p \times (1-p)\right)}$$

where

- N = 407 (population).
- X^2 = 3.841 (Chi-square value for 95% confidence level).
- p = 0.5 (population proportion).
- e = 0.05 (margin of error).

$$n = \frac{(3.841 \times 407 \times 0.5 \times 0.5)}{(0.0025 \times (406-1) + 3.841 \times 0.5 \times 0.5)} = \frac{390.82}{1.98} = 198\ respondents$$

Stratified purposive sampling were used. Participants were selected to represent diversity across forest types and include elders, herbalists, forest committee members, and other knowledgeable individuals. This ensures that key knowledge holders are interviewed.

Based on this calculation, semi structured interviews were conducted with a total of 198 respondents from Ban Pong and Ban Rong Ta villages during May 2025. The achieved sample size of 198 informants met the Krejcie and Morgan recommended sample size for the total village population of 407 households. This represents 48.6 percent of the population and satisfies the statistical requirement for reliable inference in quantitative ethnobotanical research.

2.4.2. Interview Procedures

Ethnobotanical data were collected through semi-structured interviews, focus group discussions (FGDs), and participatory ranking exercises. These methods ensure the capture of both individual knowledge and collective community perspectives.

Semi-structured interviews were conducted with key informants such as herbalists, elders, and artisans. Questions focused on species identification, categories of use, preparation methods, harvesting techniques, and cultural significance.

Plants were classified into six use categories: food, medicine, construction, fuelwood, cultural/ritual, and commercial. Taxonomic verification followed [20,21], ensuring consistency with standardized botanical nomenclature. This classification provides the basis for calculating the UVI and the SEVI.

Ethnobotanical documentation followed international standards emphasizing informant-based reporting, cultural interpretation, and multi-use enumeration. Scientific names were verified using regionally accepted taxonomic frameworks to ensure nomenclatural consistency [10].

All interviews and FGDs were conducted in the local language with the assistance of interpreters. Field notes and photographs were used to document ethnobotanical knowledge, subject to informed consent.

2.5. Index Calculation

2.5.1. Importance Value Index (IVI)

The IVI was calculated to quantify ecological significance of woody angiosperm species in vegetation plots. IVI is a composite measure derived from three parameters. For each species i, IVI was calculated following standard forest ecology methodology as:

$$\mathrm{IVI_i} = \mathrm{RD_i} + \mathrm{RF_i} + \mathrm{RDo_i}$$

where

RD = Relative Density.
RF = Relative Frequency.
RDo = Relative Dominance.

Basal area was calculated from DBH (DBH, measured at 1.3 m) or all woody stems ≥10 cm DBH following standard forest inventory protocols. IVI values range from 0 to 300, with higher values indicating greater ecological importance through combined abundance, distribution, and biomass contribution. IVI was calculated separately for each forest type to enable comparative analysis of ecological dominance patterns [2,3,18,21,26].

2.5.2. Use Value Index (UVI)

The UVI was used to quantify the ethnobotanical importance of each angiosperm species based on the frequency of use reports provided by community informants. UVI was calculated following the method originally proposed by Phillips and Gentry (1993) [2] and subsequently applied widely in quantitative ethnobotany:

$$UVI_i = \frac{\sum U_i}{N}$$

where U_i is the number of use reports for species i, and N is the total number of informants interviewed.

In this study, UVI was calculated separately for each use category (food, medicine, construction, fuelwood, cultural, and commercial), following established ethnobotanical practice [2,19]. This categorical approach enables distinction between multipurpose species and those valued primarily for specialized uses.

2.5.3. Socio-Economic Value Index (SEVI)

SEVI was constructed using four core components commonly applied in quantitative ethnobotanical and socio-economic valuation studies: market value, citation count, use categories and use frequency [5,19,27]. The integration of these components generates a composite score reflecting the overall socio-economic relevance of each species. Species with high SEVI values are therefore likely to play a central role in livelihood security, including medicinal plants traded in local markets, edible species with commercial potential, and timber or multipurpose species that function as cash resources for rural households [18,28].

To capture market and livelihood relevance quantitatively, a composite SEVI was calculated for each species through a two-step process. First, raw SEVI scores were computed by averaging four socio-economic dimensions:

$$SEVIraw_i = \frac{U_i + M_i + F_i + C_i}{4}$$

where

U_i = number of use categories.
M_i = reported market value.

F_i = use frequency.
C_i = citation count.

Second, to enable cross-species comparison on a standardized scale, raw SEVI values were normalized using min-max standardization:

$$SEVI_i = \frac{SEVI\_raw_i}{SEVI\_max}$$

where SEVI_max represents the highest raw SEVI value observed across all species. This standardization transforms SEVI to a 0–1 scale, where species with the highest socio-economic importance receive SEVI = 1.0, and species with no documented use receive SEVI = 0. All comparative analyses (correlations with IVI and UVI, rankings, and statistical tests) utilized these standardized SEVI values to ensure comparability across indices measured on different scales. Standardized SEVI values can be interpreted as proportional socio-economic importance relative to the most valued species in the study area [5,19].

2.6. Species Accumulation and Sampling Adequacy

Species accumulation curves were constructed to evaluate sampling adequacy and to assess patterns of species richness across forest types within the Ngao Model Forest. Accumulation analyses were based on species presence–absence data from the 15 plots, rather than individual abundance, to ensure that the curves represented cumulative species richness in relation to sampling effort, following established biodiversity assessment protocols [29,30]. Each 10 × 10 m vegetation plot was treated as an independent sampling unit, and cumulative species richness was calculated as plots were added sequentially.

Species accumulation curves were generated separately for each forest type, as well as for the pooled dataset encompassing all forest types. The x-axis represented sampling effort expressed as the cumulative number of plots surveyed, while the y-axis represented cumulative species richness. To reduce potential bias associated with spatial arrangement along transects, plot order was randomized prior to curve construction, as recommended for vegetation and floristic studies [31].

No non-parametric species richness estimators were applied in this study. Instead, accumulation curves were used descriptively to compare relative rates of species addition among forest types and to evaluate sampling adequacy within the constraints of a fixed number of permanent plots. This descriptive approach is appropriate where the primary objective is comparative analysis across habitats rather than estimation of total species richness [30,31].

2.7. Statistical Analysis

To test the working hypothesis that IVI is weakly correlated with UVI and SEVI, Spearman's rank correlation coefficient (ρ) was calculated for species recorded in both vegetation plots and ethnobotanical surveys with a total of 55 species.

Pairwise correlations were calculated for IVI vs. UVI, IVI vs. SEVI_standardized, and UVI vs. SEVI_standardized. Statistical significance was evaluated at $\alpha = 0.05$. Spearman's method was selected due to non-normal distribution of index values and to assess monotonic relationships without assuming linearity. All statistical analyses were conducted using R 4.5.1 statistical software.

3. Results

3.1. Species Observed During Transect Walk

A total of 112 angiosperm species, representing 77 genera and 60 families, were recorded across the three forest sites in the Ngao Model Forest. The MDF exhibited the highest floristic diversity, with 67 species documented across transect surveys, encompassing 35 genera and 26 families. In contrast, the DDF sites showed lower species richness: DDF1 recorded 31 species from 18 genera and 15 families, while DDF2 documented 44 species from 24 genera and 19 families (Table S2). It should be noted that these totals represent comprehensive transect walk inventories encompassing all growth forms (trees, shrubs, herbs, vines) and size classes.

Across the study area, the most species-rich families were Dipterocarpaceae, Fabaceae, and Rubiaceae, which together accounted for nearly half of all recorded individuals. In DDF1, vegetation structure was strongly dominated by Dipterocarpaceae (66 individuals), followed by Fabaceae and Melastomataceae (10 individuals each). DDF2 exhibited an even greater dominance of Dipterocarpaceae (125 individuals), with secondary representation from Fabaceae and Rubiaceae (8 individuals each). In contrast, MDF plots displayed a more even family composition, with Fabaceae (15 individuals), Anacardiaceae (9), and Dipterocarpaceae (7) as the leading families.

These patterns reflect fundamental ecological differences between the moist, structurally heterogeneous MDF and the open, fire-adapted DDF systems, where dominance by a small number of dipterocarp species is characteristic.

3.2. Ecological Structure from Transect Walks (IVI)

Ecological transect walks revealed clear differences in stand structure composition across forest types. Representative conditions observed during plot establishment are shown in Figure 2. DDF1 and DDF2 plots were characterized by an open canopy structure, sparse tree density, and a well-developed herbaceous and shrub layer (Figure 2A,B). In contrast, the understorey layer included a mixture of regenerating woody species and non-woody angiosperms (Figure 2C,D).

Figure 2. Representative views of vegetation structure and understorey composition recorded along ecological transect walks. Panels (**A**,**B**) show stand structure and understorey conditions within DDF plots, while panels (**C**,**D**) illustrate dominant understorey angiosperm species encountered within sampling plots.

Representative vegetation conditions across the three forest sites are shown in Figure 2. The contrasting understory density, canopy structure, and ground layer characteristics visible in these forest stands illustrate the fundamental differences in habitat structure that shape both ecological processes and ethnobotanical resource availability (Figure 2).

3.2.1. Component Contributions to Ecological Dominance in DDF1

Across the three transect walks conducted the aggregated inventory confirms a canopy and sub-canopy assemblage characteristic of Northern Thailand's monsoonal forests. bar diagrams further revealed contrasting structural patterns between forest, showing that MDF dominants had more balanced contributions of RD, RF, and RDo, whereas Dipterocarp stands were characterized by extreme dominance contributed almost exclusively by basal area. Dipterocarps dominated structural prominence, while fruit- and oil-bearing angiosperms appeared consistently in the middle strata. The IVI shows that dipterocarp taxa typical of dry forests (e.g., *Shorea obtusa* Wall. ex Blume, *Pentacme siamensis* (Miq.) Kurz hold the highest cumulative IVI across plots, with *Pterocarpus macrocarpus* Kurz, and other hardwoods contributing importantly to relative dominance (basal area) and frequency. The resulting pattern matches expectations for these fire-prone, nutrient-poor sites, where slow-growing canopy dominants drive forest architecture and carbon storage.

The relative contributions of Relative Density (RD), Relative Frequency (RF), and Relative Dominance (RDo) to the IVI varied among dominant species within DDF1 as illustrated in Figure 3. In DDF1, *S. obtusa* exhibited the highest IVI (83.2), driven primarily by exceptionally high Relative Dominance (RDo = 45.3), indicating that this species contributes disproportionately to stand basal area through large-diameter individuals. *Canarium subulatum* Guillaumin showed more balanced contributions across all three components (RD = 12.1, RF = 11.8, RDo = 15.6), reflecting consistent presence and moderate size distribution throughout the forest type. *Pentacme siamensis* demonstrated high Relative Frequency (RF = 14.2) but lower Relative Dominance (RDo = 8.4), indicating widespread occurrence but smaller individual sizes. These contrasting patterns reveal that ecological dominance in DDF1 arises through multiple pathways: *S. obtusa* achieves dominance through size and biomass accumulation, while *P. siamensis* achieves importance through spatial ubiquity despite smaller stature (Figure 3). This structural diversity has implications for forest resilience and resource provisioning, as different dominance strategies respond differently to disturbance regimes such as fire and selective harvesting.

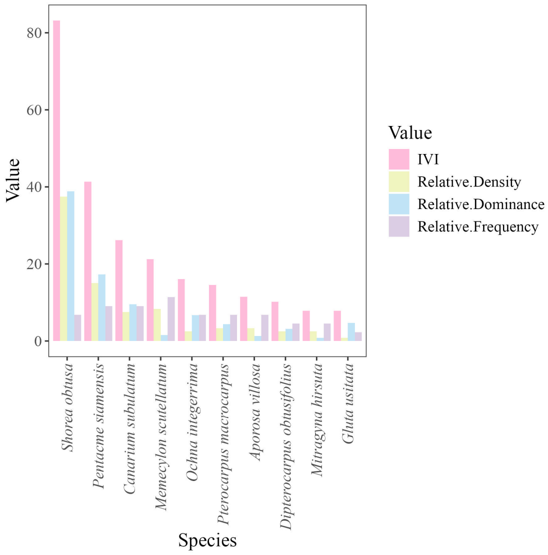

Figure 3. Importance Value Index (IVI) and its components—Relative Density (RD), Relative Dominance (RDo), and Relative Frequency (RF)—for the ten most ecologically significant tree species recorded in the study area.

3.2.2. Component Contributions to Ecological Dominance in DDF2

DDF2 exhibited even stronger ecological dominance by a single species compared to DDF1, as shown in Figure 4. *Shorea obtusa* overwhelmingly dominated the stand with an IVI of 157.9—nearly double that observed in DDF1—driven by exceptionally high Relative Dominance (RDo = 73.8) and Relative Density (RD = 54.3). This pattern indicates that DDF2 is characterized by high-density stands of large *S. obtusa* individuals that monopolize both canopy space and basal area. Secondary dominants, including *P. siamensis* (IVI = 19.4), *Morinda tomentosa* B.Heyne ex Roth (IVI = 8.6), and *Buchanania lanzan* Spreng. (IVI = 7.8), showed markedly lower importance values with more balanced component contributions. The extreme dominance by *S. obtusa* in DDF2 reflects characteristic dry dipterocarp forest structure under frequent low-intensity fire regimes, where fire-adapted dipterocarps suppress competitors and maintain near-monospecific canopy conditions (Figure 4).

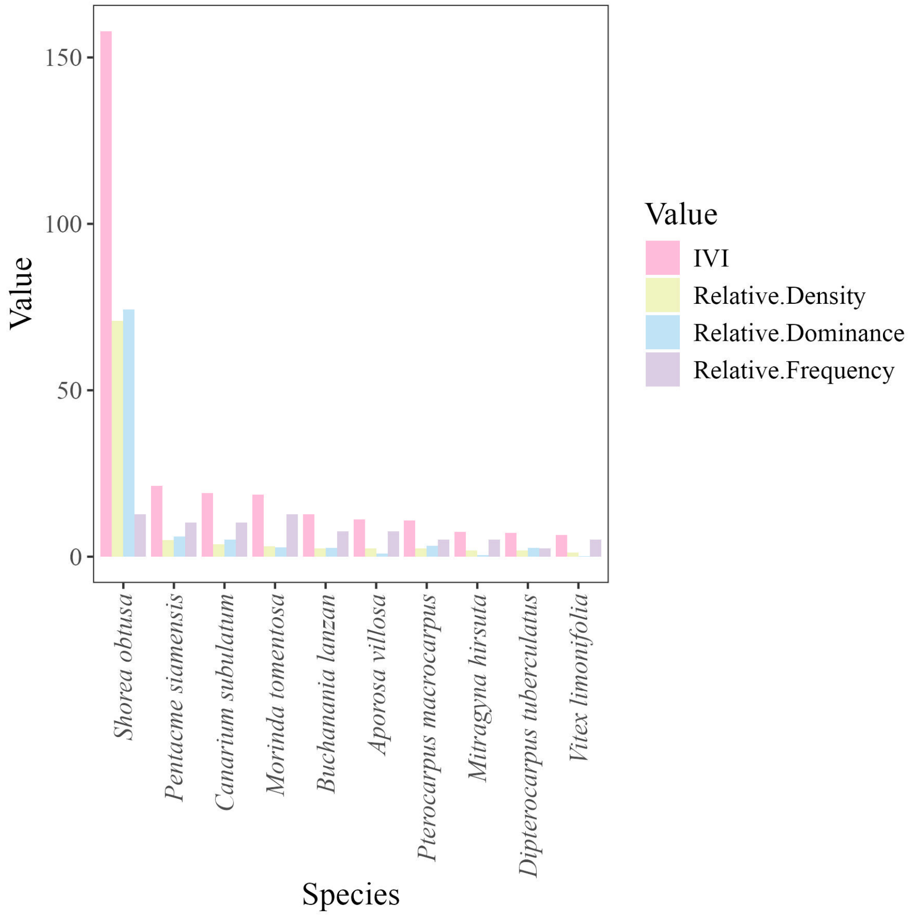

Figure 4. Structural composition of DDF2 showing the Importance Value Index (IVI) and its components—Relative Density (RD), Relative Dominance (RDo), and Relative Frequency (RF)—for the ten leading tree species.

From an ethnobotanical perspective, this structural simplification may constrain the diversity of forest-derived resources available directly within DDF2 plots, potentially explaining why communities supplement forest harvests with species from ecotones, secondary growth, and managed landscapes.

3.2.3. Mixed Deciduous Forest Structural Diversity

In contrast to the dipterocarp-dominated dry forest sites, MDF exhibited a more equitable distribution of ecological importance among multiple canopy species, as illustrated in Figure 5. *Pterocarpus macrocarpus* emerged as the leading dominant (IVI = 39.8) with balanced contributions from all three components (RD = 15.2, RF = 13.8, RDo = 10.8), indicating both widespread occurrence and substantial biomass contribution. *Dalbergia cultrata* Graham ex Benth. (IVI = 28.0) and *Spondias pinnata* (L.f.) Kurz (IVI = 27.1) showed similarly balanced component profiles, contributing to a structurally diverse canopy. The absence of extreme dominance by any single species in MDF— in stark contrast to the near-monospecific dominance observed in DDF2—reflects the greater habitat heterogeneity and moisture availability characteristic of MDFs. This structural complexity is evident in the relatively even distribution of RD, RF, and RDo values across multiple species (Figure 5). From a management perspective, the structural diversity of MDF translates into greater functional redundancy and potentially higher resilience to selective harvesting or climate variability. Furthermore, the greater number of co-dominant species in MDF aligns with the higher ethnobotanical diversity observed in community interviews, as structural complexity provides a broader portfolio of harvestable resources including timber, NTFPS, and medicinal plants.

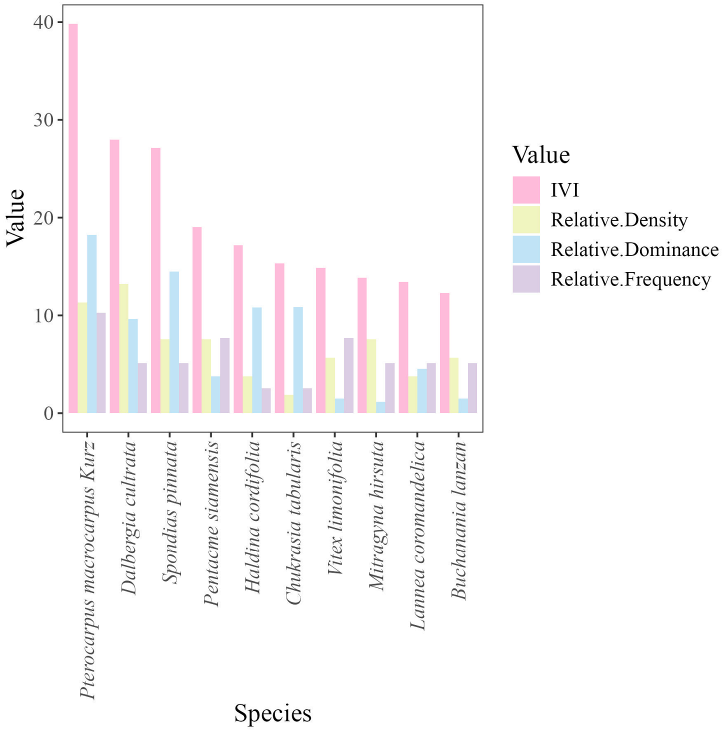

Figure 5. Structural composition of the MDF showing the Importance Value Index (IVI) and its components—Relative Density (RD), Relative Dominance (RDo), and Relative Frequency (RF)—for the ten leading tree species.

The IVI is thus best interpreted as the ecological backbone of the Ngao Model Forest. These species stabilize canopy structure, accumulate basal area, and anchor long-term biomass. They are not necessarily the plants most frequently eaten or traded, but they define the physical forest within which culturally important species are sought. In practical terms, any management option that affects the regeneration of these high-IVI trees will strongly influence forest hydrology, light regimes, and fire behavior, indirectly shaping availability of many NTFPs.

3.2.4. Species Accumulation Curves in Evaluating Patterns Across Forest Types

Species accumulation curves were constructed to evaluate sampling adequacy and assess patterns of species richness across forest types within the Ngao Model Forest (Figure 6). Across all forest types combined, cumulative species richness increased rapidly during initial sampling, reaching 112 angiosperm species by the 15th plot, with curves beginning to plateau, indicating that additional sampling effort would yield diminishing returns in terms of new species discovery.

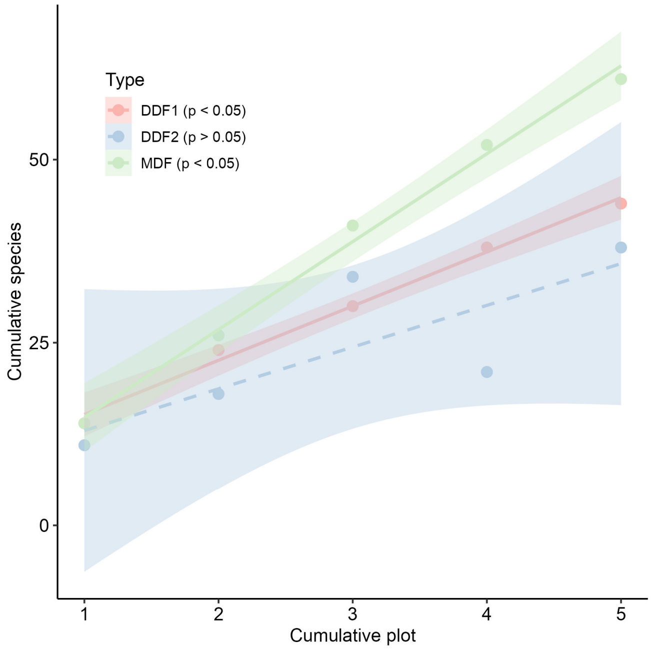

Figure 6. Species accumulation curves showing cumulative species richness across sampling plots in DDF1, DDF2, and MDF.

Figure 6 shows that the high complementarity observed between forest types (71.7% site-specific species) has important implications for both conservation and ethnobotanical resource management. The distinctiveness of MDF flora suggests that traditional knowledge and use patterns may be similarly differentiated across forest types, as communities access different species assemblages in different habitats. This habitat-specific distribution of plant diversity reinforces the importance of maintaining heterogeneous forest landscapes for both biodiversity conservation and sustained provision of culturally important plant resources.

When examined separately by forest type, MDF exhibited the steepest accumulation curve, reaching 67 species across five plots with a continuously increasing slope that suggests incomplete sampling of the species pool. In contrast, DDF1 accumulated 31 species and DDF2 accumulated 44 species, with both curves approaching asymptotes more rapidly than MDF. The pooled curve for both DDF sites combined showed intermediate accumulation, suggesting moderate compositional turnover between the two dry dipterocarp locations.

The higher cumulative species richness observed in MDF has important implications for quantitative ethnobotany and species use patterns in the Ngao Model Forest (Figure 6). Greater species richness in MDF likely translates into a broader portfolio of usable plant resources, thereby increasing the diversity of provisioning services available to local communities. From an ethnobotanical perspective, environments with higher habitat heterogeneity and productivity tend to support a wider range of culturally important species, which may result in higher use value and greater functional diversity of plant uses such as food, medicine, and construction materials. In contrast, the lower accumulation rate observed in the DDF sites suggests a more restricted species pool, potentially leading to concentrated reliance on a smaller number of dominant or culturally salient species. The non-asymptotic accumulation pattern in DDF2 may further indicate ecological filtering under drought- and fire-prone conditions, which can shape not only species composition but also patterns of traditional knowledge transmission and use specialization. Consequently, forest-type differences in species richness are likely to influence the structure of local ethnobotanical knowledge systems, resource selection strategies, and the resilience of community-based forest use practices in the Ngao Model Forest landscape (Figure 6).

Across all forest types, cumulative species richness increased with additional sampling plots. As shown in Figure 6, MDF exhibited the highest cumulative species richness throughout the sampling effort, reaching approximately 61 species after five plots. DDF1 showed a moderate increase in species richness, with cumulative species numbers reaching approximately 44 species at the final plot. DDF2 recorded the lowest cumulative species richness overall, reaching approximately 38 species after five plots.

The shape of the accumulation curves differed among forest types. The MDF curve showed a steady and continuous increase across all plots, with no clear plateau observed by the fifth plot. The DDF1 curve increased gradually and showed signs of partial leveling toward the final plots. In contrast, the DDF2 curve displayed greater variability, with a slower increase between plots three and four before increasing again at plot five.

Species accumulation patterns varied markedly among forest types, indicating differential sampling adequacy. MDF exhibited a continuously rising accumulation curve that failed to approach an asymptote, suggesting that additional sampling effort would yield substantial new species discoveries. This non-asymptotic pattern indicates incomplete sampling of the MDF species pool, likely due to high floristic diversity and spatial heterogeneity characteristic of MDF. In contrast, both DDF sites showed curves approaching asymptotes by the fifth plot, indicating more complete sampling of these structurally simpler, lower-diversity forest types dominated by fire-adapted dipterocarps. The higher cumulative species richness observed in MDF (67 species) compared to DDF1 (31 species) and DDF2 (44 species) reflects genuine ecological differences in floristic diversity rather than sampling artifacts, though the non-asymptotic MDF curve indicates that actual species richness may be higher than documented. Despite incomplete sampling in MDF, the achieved species inventories provide adequate characterization of dominant and commonly used species—the primary focus of IVI and ethnobotanical valuation—while acknowledging that rare or spatially restricted species may be underrepresented. Species complementarity analysis revealed substantial compositional turnover among forest types. Of the 60 angiosperm tree species (DBH $\geq$ 10 cm) recorded across all plots, 43 species (71.7%) were restricted to a single forest type, while only 17 species (28.3%) occurred across two or more forest types, indicating high beta diversity across the study landscape.

Forest type-specific distributions were strongly differentiated. Twenty-nine species (48.3%) occurred exclusively in MDF, representing nearly half of the total flora. In contrast, 11 species (18.3%) were unique to DDF1, and only 3 species (5.0%) were unique to DDF2.

Between the two DDF sites, 11 species (61% of DDF1 flora, 61% of DDF2 flora) were shared, indicating moderate compositional similarity within the dry dipterocarp forest type despite spatial separation. However, only 8 species (13.3% of total flora) occurred across all three forest sites, demonstrating limited overlap between moist mixed deciduous and dry dipterocarp conditions. These widespread generalist species included *Aporosa villosa* (Lindl.) Baill., *C. subulatum*, *D. cultrata*, *Mitragyna hirsuta* Havil., and *P. macrocarpus*.

This pattern of high beta diversity indicates strong habitat partitioning along moisture and structural gradients, with distinct floristic assemblages characterizing moist MDF versus DDF conditions. The high proportion of MDF-specific species suggests that this forest type harbors unique biodiversity not represented in drier forest types, emphasizing the conservation importance of protecting diverse forest types across the landscape to capture regional species diversity.

3.3. Quantitative Relationships Among Ecological and Ethnobotanical Indices

Spearman correlation analysis revealed statistically significant relationships between ecological importance (IVI) and ethnobotanical value indices (UVI and SEVI), while also demonstrating substantial independence between these valuation dimensions (Table 1). IVI showed significant positive correlations with both UVI ($\rho = 0.288$, $p = 0.033$) and SEVI ($\rho = 0.300$, $p = 0.026$), indicating that ecologically dominant species tended to have higher cultural use and socio-economic value. The modest magnitude of these correlations is particularly noteworthy from a forest management perspective, as it reveals that ecological dominance and cultural importance represent partially independent dimensions of species value rather than redundant measures of the same underlying construct.

Table 1. Spearman rank correlation coefficients among Importance Value Index (IVI), Use Value Index (UVI), and Socio-Economic Value Index (SEVI) for species recorded in both ecological plots and ethnobotanical surveys ($n = 55$ species).

Index Comparison	**Spearman ρ**	***p*-Value**	**Interpretation**
IVI vs. UVI	0.288	0.033 *	Weak positive
IVI vs. SEVI	0.300	0.026 *	Weak positive
UVI vs. SEVI	0.971	<0.001 ***	Strong positive

Significance levels: * $p < 0.05$, *** $p < 0.001$. IVI = Importance Value Index (ecological dominance); UVI = Use Value Index (cultural utilization); SEVI = Socio-Economic Value Index (economic importance).

This pattern of weak-to-moderate positive correlation suggests that community plant use is shaped by multiple factors beyond simple ecological abundance. While ecologically dominant species are somewhat more likely to be culturally utilized, possibly due to greater encounter rates, accessibility, or familiarity, the strength of this relationship ($\rho \approx 0.3$) indicates that cultural preferences, functional properties, traditional knowledge systems, and specific use requirements drive plant selection independently of ecological dominance patterns. This finding validates the integrative analytical framework employed in this study, as relying on ecological data alone would systematically underestimate the importance of culturally significant but ecologically uncommon species, while ethnobotanical data alone would overlook the ecosystem functions provided by abundant but underutilized species.

UVI and SEVI exhibited very strong positive correlation ($\rho = 0.971$, $p < 0.001$), reflecting the mathematical incorporation of use frequency into the SEVI calculation alongside market value and citation frequency. This high correlation validates the internal consistency of ethnobotanical data collection and confirms that both indices capture similar underlying patterns of cultural importance, with SEVI providing additional socio-economic context through market valuation

Examination of species-level patterns revealed ecologically and culturally important cases that illustrate the value of integrative assessment. Species such as *P. macrocarpus* and *S. obtusa* exhibited both high IVI and high SEVI, representing multipurpose resources that are both ecologically dominant and culturally valued. In contrast, *D. cultrata* showed high ecological importance (IVI = 28.0) but minimal ethnobotanical use (UVI = 0, SEVI = 0), suggesting an ecologically significant species with limited direct cultural utility. Conversely, species including *Irvingia malayana* Oliv. ex A.W.Benn (UVI = 1.12, SEVI = 242.1) and *S. pinnata* (UVI = 1.12, SEVI = 263.7) demonstrated high cultural and economic value despite moderate ecological dominance, representing priority species for targeted conservation given their importance to livelihoods combined with potentially limited ecological abundance.

These contrasting patterns underscore the importance of integrated ecological-ethnobotanical assessment for participatory forest management. Species occupying different positions along the IVI-UVI-SEVI spectrum require differentiated management approaches: ecologically dominant species with high cultural use may sustain harvesting pressure but require monitoring to ensure regeneration; culturally important species with low ecological dominance warrant protective measures and possible enrichment planting; and abundant but underutilized species may represent opportunities for sustainable livelihood diversification through promotion of non-traditional uses.

3.4. Cultural Use Patterns from Interviews (UVI)

Integrating the transect-associated interview list and key informant additions from Ban Pong and Rong Ta sheets revealed clear UVI hierarchies. The combined ranking (Figure 3) places multipurpose foods and medicines at the top: *S. pinnata* (ma kok), *I. malayana* (krabok; edible kernels and valued wood), *Schleichera oleosa* (Lour.) Oken (ta khro; seed oil and bark), *Tiliacora triandra* (Colebr.) Diels (yanang; culinary/medicinal vine), and *S. obtusa* (teng; resin, timber) consistently show the highest UVI values. These species are recognized by a wide share of informants and reported across multiple use categories (food, medicine, tools, fuel, construction). One elder from Ban Pong summarized this breadth succinctly: "the sour fruit for curry, the leaves for fever, and the wood for house posts are in the same walk," underscoring how a single foraging trip yields multiple products.

Food-medicine overlaps are especially strong. *S. pinnata* was frequently linked to sour curry (kaeng som) and pickling, while its young leaves were mentioned for digestive complaints. Informants described *I. malayana* kernels as a household "store of energy"—roasted as snacks, ground into pastes, or sold when cash is short. *Sc. oleosa*'s seed oil was cited as a versatile product—traditionally for hair and skin applications, and occasionally as lamp oil in the past. *T. triandra*, although a vine and not structurally dominant, was repeatedly listed for its "cooling" properties in soups and traditional decoctions; a Rong Ta informant put it plainly: "yanang is for heat in the body." These narratives are consistent with the high UVI scores and illustrate why culturally valued species may outrank canopy dominants in use-report frequency. This aligns with findings from other Thai communities, where species with modest population abundance remain central to household diets and herbal practices due to their functional and cultural utility [1].

One interview addition warrants note because it did not appear in the transect walk, *Senegalia rugata* (Lam.) Britton & Rose (soap pod tree) is cited for natural shampoo and cleansing, typically found on disturbed margins or deliberately retained near gardens. Their absence in transects is therefore expected: both are human-managed or edge species whose primary cultural niches lie outside the 10 × 10 m forest plots. In the same vein, respondents referenced edible ferns (e.g., *Diplazium esculentum* (Retz.) Sw.) and bamboo shoots (*Dendrocalamus* spp.), which fluctuate seasonally and are harvested from streambanks or young secondary growth—microhabitats not encompassed by the fixed plot placements during the sampling month.

3.5. Socio-Economic Valuation (SEVI) and Interview-Only Species

The SEVI further clarifies livelihood relevance by synthesizing market signals, use frequency, citation breadth, and diversity of uses. In the data, *S. oleosa*, *I. malayana*, *S. pinnata*, *S. obtusa* and *P. macrocarpus* rank highly, reflecting both frequent household use and market-proximate value (e.g., sale of kernels, seed oil, resin, or timber under legal/customary rules). Notably, several interview-only species (including *Aegle marmelos* (L.) Correa, *S. rugata*, and culinary herbs such as *T. triandra*) achieve moderate to high SEVI because they are repeatedly cited, used often, and occasionally traded locally, even though they lack IVI in forest plots. This demonstrates that SEVI is sensitive to cultural-economic reality, not just to forest presence.

Why, specifically, are these interview-only species absent from the transects? The analysis and field notes indicate three non-exclusive explanations. First, phenology: villagers time harvest of bamboo shoots, edible ferns, and leafy vines to seasonal flushes; our transect month preceded some pulses, so plants were physiologically inconspicuous. Second, microhabitat: culturally important edibles and medicinals are concentrated along riparian corridors, trail margins, or homegarden–forest interfaces—sites intentionally placed outside plot transects to avoid edge effects. Third, human management: species like *A. marmelos* or *S. rugata* are protected, planted, or tolerated near houses or community temples; they are part of the community's resource portfolio but not the wild stand captured by fixed forest plots. In interviews, one Rong Ta elder explained: "We don't look for bael inside the dry forest; it is usually near homes or the temple," capturing this spatial logic succinctly.

3.6. Integration of IVI–UVI–SEVI and Implications

Cross-index comparisons reveal three functional species groups that are directly actionable for management. Ecological dominants (high IVI; e.g., *S. obtusa*, *P. siamensis* sustain canopy structure and fire ecology and also provide resin, poles, and culturally significant timber—hence their moderate-to-high UVI/SEVI. Livelihood multipurpose species (high UVI/SEVI, moderate IVI; e.g., *S. pinnata*, *I. malayana*, *S. oleosa*) are central to household nutrition and petty trade and should be prioritized for enrichment planting in buffer zones and community woodlots. Species clustered into distinct livelihood categories along the UVI–SEVI gradient, with medicinal and food-use taxa generally scoring higher socio-economic values in comparison to timber species, which were ecologically dominant but culturally restricted in purpose (Figure 7).

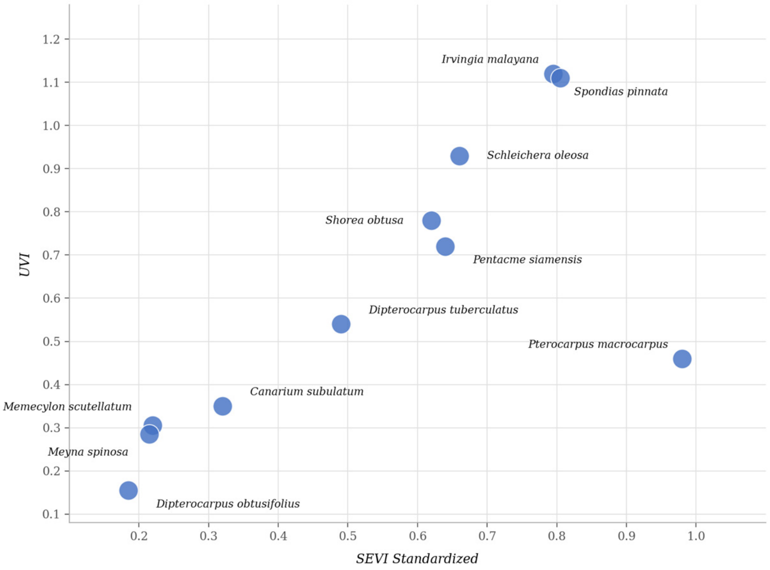

Figure 7. Comparison between the Use Value Index (UVI) and the Socio-Economic Value Index (SEVI) for major woody angiosperms recorded in transect inventories.

Cultural/edge specialists (interview-only or low IVI but non-trivial SEVI; e.g., *A. marmelos*, *S. rugata*, and *T. triandra*) should be incorporated into homegarden–forest interface plans, riparian restoration, and village herbariums. Scatter plotting of UVI against SEVI (Figure 8) demonstrated that several interview-only species attained high livelihood valuation independent of their representation in woody plots, reinforcing their functional role outside transect inventories. Together, these groups explain why interview-based species lists are longer than transect lists and why some culturally valued species are not in Figure 7: they occur in different spaces and at different times than fixed-plot forestry normally observes.

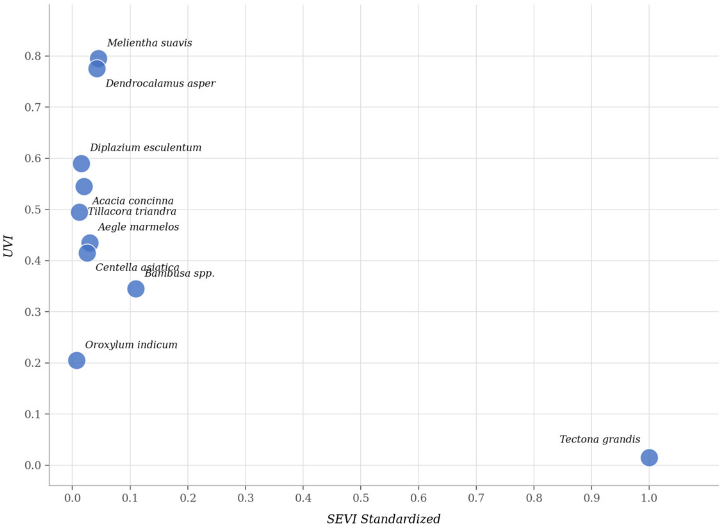

Figure 8. Relationship between the Use Value Index (UVI) and the Socio-Economic Value Index (SEVI) for culturally important species that are absent or poorly represented in vegetation plots.

4. Discussion

This study integrated ecological structure (IVI), ethnobotanical use (UVI), and socio-economic importance (SEVI) to evaluate species value within three forest strata (MDF, DDF1, DDF2) of the Ngao Model Forest. By combining standardized vegetation plots (n = 15; five per forest stratum) with structured interviews (n = 198 respondents), the analysis provides a multidimensional assessment of species importance that extends beyond conventional forest inventory metrics.

4.1. Ecological Structure Across Forest Types

Clear structural contrasts emerged among forest strata. The two dry dipterocarp sites (DDF1 and DDF2) were characterized by strong dominance of a small number of canopy species, particularly *S. obtusa* and *P. siamensis*. Their high IVI values were driven primarily by relative dominance (basal area) rather than density alone, indicating that large, mature individuals disproportionately shape stand structure in fire-adapted dry forests. This structural concentration is consistent with ecological filtering under recurrent fire and seasonal drought conditions typical of northern Thailand's dipterocarp systems [32,33].

In contrast, the mixed deciduous forest (MDF) exhibited more evenly distributed IVI values across multiple species, reflecting greater structural heterogeneity and taxonomic evenness. The absence of extreme dominance in MDF suggests higher habitat complexity and moisture availability, allowing a broader assemblage of species to contribute to forest architecture. These differences confirm that ecological dominance patterns vary substantially across forest types within the same landscape.

Species accumulation curves further reinforced these distinctions. MDF exhibited a continuously increasing accumulation pattern, suggesting higher floristic heterogeneity, while DDF sites approached asymptotes more rapidly, indicating comparatively simpler species pools. The high beta diversity observed across strata (71.7% site-specific species) demonstrates strong habitat partitioning along moisture and disturbance gradients.

4.2. Evaluation of the Working Hypothesis

The working hypothesis proposed that ecological dominance (IVI) would be weakly correlated with ethnobotanical and socio-economic indices (UVI and SEVI). Spearman rank correlation analysis supported this hypothesis.

IVI showed weak but statistically significant positive correlations with both UVI ($\rho = 0.288$, $p < 0.05$) and SEVI ($\rho = 0.300$, $p < 0.05$). These results indicate that while more ecologically dominant species are somewhat more likely to be culturally and economically valued, ecological abundance explains only a limited proportion of variation in plant use patterns.

The modest strength of these correlations is theoretically important. It demonstrates that ecological availability exerts partial influence on plant selection, likely through increased encounter rates and familiarity, but cultural valuation is shaped by additional criteria independent of dominance. These include organoleptic properties, medicinal efficacy, seasonal accessibility, processing requirements, spiritual associations, and knowledge transmission systems [4,11,34].

The strong correlation between UVI and SEVI ($\rho = 0.971$, $p < 0.001$) reflects the mathematical incorporation of use frequency and citation breadth within the SEVI formulation and confirms internal consistency of the ethnobotanical dataset.

Overall, the hypothesis is supported: ecological dominance and cultural–economic valuation represent partially independent dimensions of species importance rather than redundant measures.

4.3. Divergence Between Ecological and Cultural Importance

Certain canopy dominants, such as *D. cultrata*, exhibited moderate ecological importance but negligible ethnobotanical value. Conversely, species such as *S. pinnata*, *I. malayana*, and *S. oleosa* demonstrated high UVI and SEVI despite moderate IVI values. These multipurpose species contribute significantly to household diets, traditional medicine, and petty trade, yet are not structurally dominant within forest interiors. This divergence reinforces a key finding of quantitative ethnobotanical research: ecological abundance alone is an unreliable predictor of cultural or economic significance [2,12,19].

Additionally, several culturally important species were absent from vegetation plots but achieved moderate SEVI scores through interviews. Their absence reflects spatial distribution patterns rather than ecological insignificance. Many occur in riparian corridors, homegarden–forest interfaces, or managed edge habitats intentionally excluded from fixed forest plots [29,30]. This spatial differentiation underscores that livelihood landscapes extend beyond forest interior structure captured by standard vegetation sampling [31].

Thus, reliance on IVI alone would systematically underestimate culturally salient resources, while ethnobotanical surveys without ecological context would overlook species critical for structural stability and ecosystem function [35,36].

4.4. Functional Species Groups for Management

Integrating IVI, UVI, and SEVI reveals three functional species categories relevant for participatory forest management:

1. Ecological Dominants (High IVI):

Species such as *S. obtusa* and *P. siamensis* maintain canopy structure, influence fire regimes, and anchor biomass accumulation. Their management affects hydrology, light availability, and regeneration dynamics.

2. Multipurpose Livelihood Species (High UVI/SEVI, Moderate IVI):

Species such as *S. pinnata* and *I. malayana* provide direct subsistence and income benefits. These taxa warrant monitoring and potential enrichment planting to ensure sustained availability.

3. Cultural/Edge Specialists (Low IVI, Non-trivial UVI/SEVI):

Species concentrated in homegardens or riparian margins contribute disproportionately to dietary diversity and medicinal practices. Their conservation requires landscape-level integration beyond forest interior plots.

Recognizing these distinctions allows management interventions to be tailored according to species function rather than ecological abundance alone.

4.5. Implications for Model Forest Governance

Model Forest frameworks emphasize balancing ecological sustainability with community livelihoods. The weak but significant alignment between ecological and cultural indices demonstrated here suggests that management strategies based solely on structural dominance risk misrepresenting community-defined priorities.

The IVI–UVI–SEVI comparative framework offers a practical tool for participatory governance by:

- Identifying species requiring regeneration monitoring.
- Highlighting livelihood-critical taxa for enrichment planting.
- Revealing habitat-specific resource distributions.
- Informing zoning strategies across heterogeneous forest landscapes.

Because ecological and cultural importance only partially overlap, integrated valuation improves prioritization decisions within community-managed forests.

4.6. Methodological Considerations

Several methodological considerations warrant attention.

First, vegetation sampling was limited to 15 plots (five per forest stratum). While sufficient for comparative structural assessment, this sample size limits landscape-scale generalization.

Second, plot placement along actively used forest zones ensured spatial alignment with ethnobotanical data but does not represent randomly distributed forest conditions across the entire landscape.

Third, vegetation surveys were conducted during a single season, potentially underrepresenting phenologically variable species.

Fourth, SEVI incorporates market values that may fluctuate temporally.

These limitations imply that observed relationships reflect associative patterns within actively managed forest zones rather than causal relationships applicable to all forest contexts [37].

4.7. Contribution to Quantitative Ethnobotany

This study contributes methodologically by operationalizing a three-index comparative framework (IVI–UVI–SEVI) within a formally designated Model Forest context. While IVI and UVI are widely applied independently, few studies quantitatively test their statistical correspondence within community-governed forest systems [38,39].

The integration of multiple valuation frameworks reflects growing recognition in community forestry that sustainable management requires balancing biodiversity conservation, ecosystem services, and livelihood needs [40,41].

The demonstration of weak but significant alignment between ecological and cultural valuation provides empirical evidence that multidimensional forest value cannot be reduced to structural dominance alone. This reinforces the need for integrative approaches in biodiversity assessment and participatory forest management [41,42].

Applying the IVI–UVI–SEVI framework across additional model forests in Thailand and Southeast Asia would enable comparative evaluation of how governance regimes, market access, and cultural practices shape species importance [43]. Such comparative work would strengthen the contribution of quantitative ethnobotany to socially inclusive forest management and biodiversity policy, consistent with emerging regional and global sustainability frameworks [44].

5. Conclusions

This study demonstrates that integrating ecological and ethnobotanical metrics provides a more complete understanding of species importance in the Ngao Model Forest than reliance on structural indices alone. Across 15 vegetation plots (5 per forest type) and key informant interviews in two communities, 112 angiosperm species were documented, revealing clear divergence between ecological dominance and livelihood relevance.

First, forest structure in DDF1 and DDF2 was strongly shaped by a small number of canopy species, particularly *S. obtusa* and *P. siamensis*, which attained the highest IVI values due primarily to high basal area and stem dominance. In contrast, several species with lower IVI, such as *S. pinnata*, *I. malayana*, and *S. oleosa*, ranked among the highest for UVI and SEVI, reflecting frequent use across food, medicinal, and commercial categories. This weak correspondence between IVI and UVI/SEVI indicates that ecological abundance is not a reliable proxy for cultural or livelihood importance.

Second, species identified exclusively through interviews, including *A. marmelos* and *T. triandra*, achieved moderate to high UVI and SEVI scores despite absence from transect plots. Their importance was associated with human management, edge habitats, and seasonal harvesting, rather than with forest interior dominance. These results highlight that plot-based inventories alone may underestimate the role of culturally important species embedded in homegardens, riparian zones, and forest–village interfaces.

Third, comparison of IVI, UVI, and SEVI values suggests three functional groups relevant for management. First, structurally dominant canopy species that maintain forest architecture; second, multipurpose species that contribute directly to household subsistence and small-scale income, and lastly culturally valued species occurring primarily outside sampled plots. Recognizing these distinctions allows management interventions to be tailored to species function rather than abundance alone.

Moreover, the study has important limitations. Vegetation surveys were conducted during a single field season, which may have constrained detection of seasonally visible species. Plot-based sampling did not encompass all microhabitats used by communities, and ethnobotanical data are subject to recall bias and temporal variability in market prices. Consequently, the observed relationships among IVI, UVI, and SEVI should be interpreted as associative patterns, not causal effects.

Despite these constraints, the findings provide empirical support for incorporating ethnobotanical and socio-economic information into forest assessment frameworks. For model forest contexts, combining ecological metrics with community-derived use data can improve species prioritization for monitoring, enrichment planting, and participatory management, while avoiding overreliance on dominance-based indicators. The approach demonstrated here offers a context-specific contribution to discussions on sustainable forest use and biodiversity valuation, with relevance to, but not prescriptive claims for, broader sustainability and biodiversity policy frameworks.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f17030353/s1, Table S1: APG Herbarium Listing; Table S2: Ngao Model Forest Species List

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