

# Biocultural roles of naturalized alien plants in highland communities of Central Java, Indonesia

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**Abstract.** Sholekha AM, Restanti AD, Rohman CM, Ainaya FA, Putri NRA, Putri A, Dewangga A, Saensouk S, Setyawan AD. 2025. *Biocultural roles of naturalized alien plants in highland communities of Central Java, Indonesia. Asian J Ethnobiol* 8: 26-39. Naturalized alien plant species (NAPS) are often perceived as threats to biodiversity and ecosystem stability. However, in many rural communities, these species may also serve important roles in food systems, healthcare, rituals, and livelihood strategies. This study explores the ethnobotanical utilization and cultural significance of NAPS in five highland villages in Central Java, Indonesia, based on interviews with 125 respondents and field observations. A total of 143 species were documented, with the majority being used for food (39.2%) and medicinal purposes (34.5%). The Index of Cultural Significance (ICS) revealed that certain species—such as *Cosmos caudatus*, *Curcuma longa*, and *Psidium guajava*—are highly valued across multiple dimensions and locations. Cross-village comparisons highlighted distinct biocultural filtering processes, shaped by local ecology, demographic structure, and cultural preferences. While some NAPS were shared across villages, many were site-specific, suggesting localized knowledge systems and adaptive use patterns. The findings underscore the need for a more nuanced, culturally grounded approach to invasive species management, one that balances ecological concerns with the needs of rural livelihoods and cultural heritage. Integrating local knowledge and community participation into plant governance frameworks is essential for achieving sustainable and socially just conservation outcomes.

**Keywords:** Cultural significance index, ethnobotany, invasive species management, rural livelihoods, traditional knowledge

## INTRODUCTION

Naturalized alien plant species (NAPS) represent a critical yet underexplored dimension in biodiversity conservation and rural livelihood systems. Unlike invasive alien species (IAS), which are widely recognized for their ecological threats, NAPS refer to alien species that have established self-sustaining populations in new environments without continuous human intervention (Richardson et al. 2000; Pyšek et al. 2020). In tropical developing countries like Indonesia, where ecological resilience intersects with socio-cultural complexity, the distinction between naturalized and invasive species becomes both ecologically and culturally significant.

Indonesia, one of the world's mega-diverse countries, hosts over 30,000 plant species, with more than 1,900 identified as alien (Tjitrosoedirdjo 2005; Sayfulloh et al. 2020). Among these, many have naturalized over decades due to historical introductions through agriculture, trade, colonial botanical exchange, and landscape ornamentation (Abywijaya et al. 2014; Shackleton et al. 2019). While some species transition into invasive behavior, others integrate into local agroecosystems and cultural practices,

often without formal recognition in national botanical inventories. Their dual nature—being simultaneously beneficial and potentially harmful—calls for a nuanced understanding that combines ecological science with ethnobotanical perspectives (Shrestha and Shrestha 2019; Rai and Singh 2020).

Generations of ecological adaptation, experimentation, and the transmission of traditional knowledge shape the cultural use of alien plant species in highland communities. In remote or semi-remote villages, where access to formal healthcare and market economies may be limited, naturalized plants often substitute or supplement native biodiversity in food, medicine, ritual, and domestic utility (Turner 1988; Heinrich et al. 2009). However, most national and regional conservation frameworks treat alien species as uniformly negative, disregarding localized contexts of cultural utility and livelihood dependency (Shackleton et al. 2007, 2019; Carneiro et al. 2024). A significant scientific and policy gap remains in integrating cultural significance assessments into invasive species management, particularly in biodiversity hotspots such as Java's uplands.

The use of the Index of Cultural Significance (ICS) offers a systematic method to quantify how much a given species contributes to local livelihoods and belief systems. Originally proposed by Turner (1988) and further developed by researchers in ethnobotany and conservation (e.g., González et al. 2010; Maruapey et al. 2022), the ICS incorporates qualitative variables such as frequency of use, diversity of utility, and cultural preference. Applying ICS to naturalized alien plants allows researchers to differentiate between culturally embedded species and those that pose significant ecological threats, facilitating management strategies that are both ecologically sound and culturally respectful (Supiandi et al. 2019).

This study investigates the cultural utilization and management implications of NAPS in five highland villages of Central Java: Gondosuli, Berjo, Sewurejo, Polokarto, and Balerante. These sites are situated in the transitional agro-ecological zones of the Lawu and Merapi mountains, characterized by diverse altitudes, land-use systems, and cultural histories. All five villages demonstrate varying degrees of interaction with alien plant species, influenced by local agriculture, tourism, and traditional medicine systems. Previous localized studies have documented the use of naturalized species, such as *P. guajava*, *Chromolaena odorata*, and *C. caudatus*; however, no regional synthesis has yet linked these data across multiple communities to assess broader patterns and implications (Nahdi and Kurniawan 2019; Handayani et al. 2021; Kusumawati et al. 2022).

Understanding how highland communities use NAPS is particularly important in the face of global climate change and increasing landscape fragmentation. Highland regions are often biodiversity refugia, but they are also highly vulnerable to biological invasions due to land-use conversion, tourism influx, and climate-driven shifts in species distribution (Seebens et al. 2018; Cuthbert et al. 2022). In Java, these challenges are compounded by

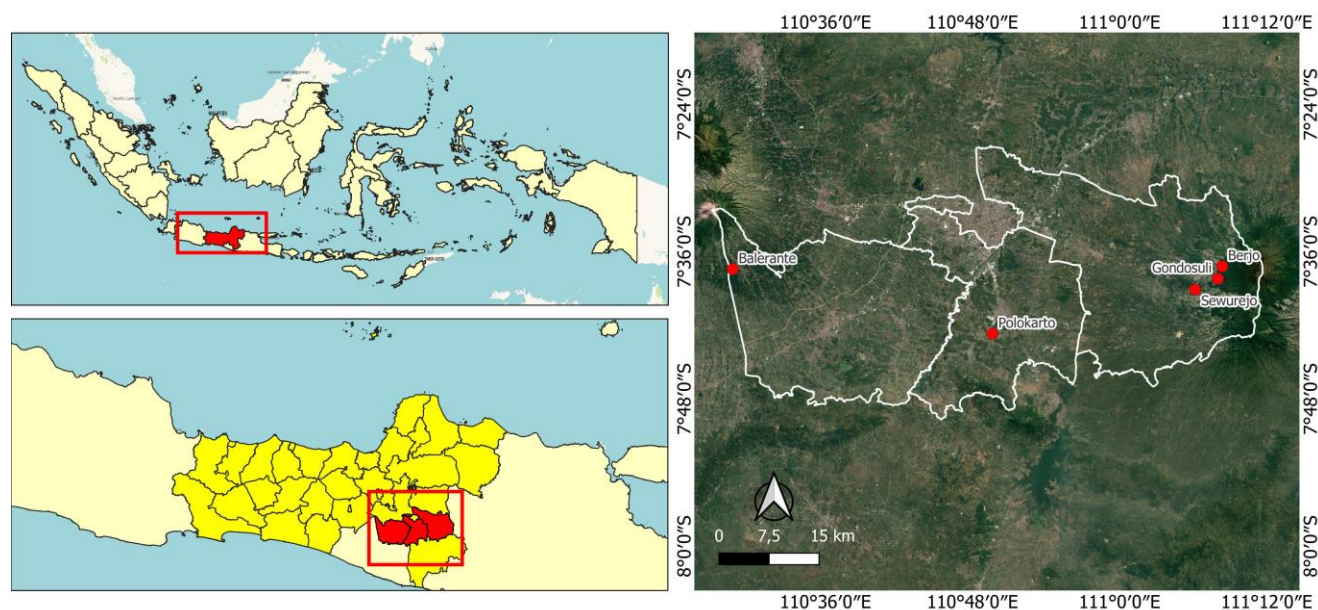
population pressure and the ongoing degradation of upland forests and agroforests (Mokany et al. 2022). Documenting and interpreting local plant use—especially when it involves non-native species—can thus inform community-based conservation and sustainable land management initiatives that are responsive to both ecological and cultural priorities.

Therefore, this study aims to document the diversity and origin of naturalized alien plant species (NAPS) utilized by local communities in five highland villages of Central Java, quantify their cultural significance using the Index of Cultural Significance (ICS), and explore the implications of NAPS utilization for future conservation strategies, particularly in reconciling invasive species control with the preservation of traditional ecological knowledge. The results are expected to contribute to policy dialogues on adaptive co-management of plant resources, offering a case for the inclusion of cultural dimensions in managing alien flora in tropical highland systems.

## MATERIALS AND METHODS

### Study area

The research was conducted across five highland villages located in Central Java Province, Indonesia (Figure 1): Gondosuli, Berjo, and Sewurejo (Karanganyar District), Polokarto (Sukoharjo District), and Balerante (Klaten District). These villages are situated along the foothills of Mount Lawu and Mount Merapi, within altitudes ranging from 400 to 1,500 meters above sea level (Table 1). The regions are characterized by temperate tropical climates with high annual rainfall and heterogeneous land use, including agroforestry, homegardens, roadside vegetation, and secondary forest margins, which support the spontaneous or intentional growth of alien plant species.



**Figure 1.** Map of study sites in five highland villages of Central Java, Indonesia

**Table 1.** Environmental and geographic characteristics of the five study villages.

| Village   | District    | Coordinates            | Altitude (masl) | Dominant Land Use                    | Climatic Context           |
|-----------|-------------|------------------------|-----------------|--------------------------------------|----------------------------|
| Gondosuli | Karanganyar | 7°38'12"S, 111°8'01"E  | ~1,150          | Agroforestry, homegardens, rice      | Humid tropical highland    |
| Berjo     | Karanganyar | 7°37'11"S, 111°8'22"E  | ~870            | Mixed gardens, rice, and fruit trees | Moist subtropical upland   |
| Sewurejo  | Karanganyar | 7°39'05"S, 111°6'10"E  | ~650            | Homegardens, secondary forest        | Transitional tropical zone |
| Polokarto | Sukoharjo   | 7°42'40"S, 110°49'38"E | ~120            | Settlements, fields, roadside flora  | Lower tropical lowland     |
| Balerante | Klaten      | 7°37'45"S, 110°27'17"E | ~530            | Rainfed fields, forest margins       | Volcanic foothill climate  |

Gondosuli and Berjo are located in the Tawangmangu highlands, an ecotourism and vegetable farming region that has long interacted with introduced plants via tourism and horticulture. Sewurejo, in Mojogedang Subdistrict, is a peri-rural settlement with widespread mixed homegarden systems. Polokarto, in Sukoharjo District, is among the largest and most agriculturally intensive low-montane villages in the region, with alien species often growing along irrigation dikes and marginal plots. Balerante lies adjacent to the Merapi National Park and represents a transitional zone between conservation forest and agricultural land, frequently exposed to seed dispersal via floods, livestock, and road networks.

These five villages were selected to represent ecological variation, land-use diversity, and contrasting levels of exposure to alien plant species due to factors such as elevation, tourism intensity, agricultural dependence, and proximity to forested areas.

### Data collection

This study employed a combination of qualitative and quantitative data collection techniques, including structured interviews, field observations, and literature triangulation, to document the cultural utilization of naturalized alien plant species (NAPS) by local communities. Respondents were selected through purposive sampling based on long-term residence and demonstrated knowledge of plant use, followed by simple random sampling to ensure demographic representativeness across age and gender. The criteria included a minimum age of 20 years, at least five years of residence, and familiarity with the use of local or naturalized plant species. A total of 230 individuals participated in the interviews: 46 from Gondosuli, 52 from Berjo, 40 from Sewurejo, 47 from Polokarto, and 45 from Balerante. Demographic data—such as age, gender, and educational background—were collected to assess potential patterns in the distribution of ethnobotanical knowledge.

Data collection involved semi-structured interviews using a standardized questionnaire, conducted individually and face-to-face in either Javanese or Indonesian, according to respondent preference. Interviews included open-ended questions related to the plant's local name, parts used (leaves, roots, stems, flowers, fruits, or whole plant), categories of use (e.g., food, medicinal, ornamental, ritual, fuel, forage), methods of application (e.g., raw, boiled, decoction, topical), usage frequency, and presence of substitutes or exclusivity of function. Each session lasted approximately 20-30 minutes, and responses were recorded on tally sheets, which were then digitized after each

interview to ensure accuracy and consistency. Oral informed consent was obtained, and respondent identities were anonymized for confidentiality.

Field observations were conducted simultaneously to validate species presence and observe habitat context. Plants mentioned during interviews were photographed and described based on their growth habit (cultivated, wild, or naturalized) and habitat type (homegardens, field edges, roadsides, or forest fringes). Where needed, voucher specimens were collected for herbarium verification.

To support triangulation and ecological interpretation, secondary data sources were also consulted, including official village monographs, land-use records, climate data from BMKG (2023), and land classification data from BPS (2022). Relevant floristic and ethnobotanical literature specific to Central Java (Darmastuti et al. 2024; Nurcahyo et al. 2024) further contextualizes the distribution patterns of species and possible introduction pathways.

### Plant identification and taxonomic standardization

Plant species mentioned by respondents were identified through a combination of vernacular name verification, field observations, and consultation with standard botanical references. Whenever possible, respondents directly showed the plants in their natural settings, allowing for in situ identification and photographic documentation. For unfamiliar or ambiguous specimens, voucher samples were collected for further verification using regional floras and herbarium materials.

Taxonomic identification and standardization relied on reputable references, including Setyawati et al. (2015) and global databases such as Plants of the World Online (POWO, <https://powo.science.kew.org>), Global Biodiversity Information Facility (GBIF, <https://www.gbif.org>), World Flora Online (WFO, <http://www.worldfloraonline.org>), and iNaturalist (<https://www.inaturalist.org>). Scientific names followed binomial nomenclature with author citation, and family classifications adhered to the APG IV system. Where species-level identification was not feasible, taxa were noted at the genus level using "cf." (e.g., *Amaranthus cf. hybridus*).

To determine alien status, each species was evaluated based on three main criteria: being introduced from outside Indonesia, forming self-sustaining populations without continued human intervention, and reproducing naturally in rural or disturbed habitats. Native geographic origins were identified using POWO and WFO and grouped by continent or floristic region.

**Table 2.** Scoring criteria used in the ICS calculation

| Variable        | Score | Description  |
|-----------------|-------|--|
| Quality (q)     | 5     | Staple food or primary medicinal use                                 |
|                 | 4     | Secondary food, key ingredient, or widely used remedy                |
|                 | 3     | Occasional use for nutrition, health, or functional household use    |
|                 | 2     | Ritualistic, recreational, or symbolic use                           |
|                 | 1     | Known to be used but not actively applied                            |
| Intensity (i)   | 5     | Used daily or very frequently  |
|                 | 4     | Used regularly (weekly/monthly)                                      |
|                 | 3     | Used occasionally (seasonally or when available)                     |
|                 | 2     | Used rarely  |
|                 | 1     | Very low frequency, used in the past or only by specific individuals |
| Exclusivity (e) | 2     | No substitute available; culturally preferred or unique species      |
|                 | 1     | Has alternatives but is still commonly used                          |
|                 | 0.5   | Substitutable and not culturally unique                              |

Note: Adapted from Turner (1988) and Maruapey et al. (2022)

### Cultural significance assessment (ICS calculation)

To assess the cultural importance of each naturalized alien plant species (NAPS), this study applied the Index of Cultural Significance (ICS) method, adapted from Turner (1988). This semi-quantitative approach evaluates species based on their perceived social, economic, and ritual value using three weighted variables: quality of use (*q*), intensity of use (*i*), and exclusivity of use (*e*). The ICS for each species was calculated using the formula:

$$ICS = \sum (q \times i \times e)$$

Where: the summation applies across all identified use categories (*k*). Each variable was scored according to standardized criteria (see Table 2).

Final ICS values were then grouped into five interpretive categories: very high ( $ICS \geq 100$ ), high (50-99), moderate (20-49), low (5-19), and very low ( $< 5$ ). This classification enabled comparative analysis across villages and helped highlight species with enduring or declining cultural roles.

To ensure scoring consistency, two researchers independently coded all interview responses, and discrepancies were resolved through a consensus process. Additionally, a third-party audit was conducted on 10% of the data to validate reliability. The ICS results were compiled and visualized using Microsoft Excel, supporting the identification of culturally significant species in the five study locations. Each use category (e.g., food, medicine, fodder, ornament) was treated as an individual unit of cultural interaction, contributing separately to the overall ICS score of the species.

### Data analysis and visualization

Data from interviews and field observations were analyzed using both quantitative and qualitative approaches to interpret cultural patterns in the use of naturalized alien plant species (NAPS) across the five study villages. Quantitative variables—such as the number of cited species, categories of use, plant parts utilized, and Index of Cultural Significance (ICS) scores—were processed using Microsoft Excel and SPSS to generate frequency distributions, percentages, and cross-tabulations. Analyses focused on species richness at the village and family levels, distribution of use categories (e.g., food, medicinal, ornamental), variation in ICS scores, and the influence of demographic factors including age, gender, and education.

To explore spatial and cultural variability, overlaps and distinctiveness in species use among villages were examined, along with differences in usage intensity and perceived cultural value. Meanwhile, qualitative data—particularly those concerning ritual functions, symbolic meanings, and plant-related narratives—were compiled to complement the ICS framework. These insights captured non-material aspects of plant use and provided context for observed trends, such as shifts in traditional knowledge or the persistence of intergenerational practices.

Visual representations were generated to facilitate interpretation, including bar graphs for use category frequency, pie charts for plant parts and dominant families, and scatter plots or boxplots for village-level variation in ICS values. Venn diagrams illustrate shared and unique species among communities. All visual outputs were integrated into the Results section to support data-driven insights.

To ensure validity and consistency, a triangulation approach was applied. Statements from respondents were cross-verified with field observations, and local plant names were validated using vernacular dictionaries and expert input. The species origin was confirmed through global taxonomic databases, including Plants of the World Online (POWO), GBIF, and World Flora Online (WFO). This multi-source verification reinforced the reliability of taxonomic identification and ethnobotanical classification across study sites.

## RESULTS AND DISCUSSION

### Socio-demographic characteristics of respondents

A total of 230 respondents were interviewed across five highland villages in Central Java, with demographic details summarized in Table 3. Of these, 53.9% were female and 46.1% were male ( $n=106$ ), resulting in a relatively balanced gender distribution across locations. Polokarto and Balerante had slightly more male participants, while Berjo and Sewurejo recorded a higher proportion of women. In terms of age, the largest group (41.3%) was between 41 and 60 years old—an age range commonly associated with strong traditional ecological knowledge. The youngest group (20-30 years) accounted for only 9.1%, raising concerns about the potential for generational gaps in the transmission of ethnobotanical knowledge.

Educational levels among respondents were generally low to moderate. Nearly half (46.5%) had completed only elementary school, 27.0% had attended junior high school, and just 3.9% had received tertiary education. Notably, Balerante and Berjo reported the highest numbers of individuals with no formal schooling or limited literacy, likely linked to geographic isolation and limited institutional access. These socio-demographic characteristics are crucial for understanding the distribution and retention of ethnobotanical knowledge, as education, age, and gender significantly influence both the acquisition and intergenerational transmission of plant-related cultural practices.

### Diversity of naturalized alien plant species

A total of 143 naturalized alien plant species (NAPS) were recorded across the five study villages, representing 52 plant families. These 143 species represent non-redundant taxa observed across all sites, while site-level richness includes overlapping species that occur in multiple villages. Species richness varied notably across sites, as illustrated in Figure 2, with Sewurejo recording the highest number (62 species), followed by Berjo (51), Gondosuli (50), Polokarto (31), and Balerante (26). These differences likely reflect variations in land-use intensity, disturbance regimes, and cultural exposure to introduced flora.

The most frequently represented families were Asteraceae (14 species), Fabaceae (11 species), Poaceae (10 species), Zingiberaceae (9 species), and Amaranthaceae (6 species). These families are widely recognized for their ecological plasticity, ethnobotanical versatility, and broad dispersal patterns in tropical regions. Their dominance is evident in both cultivated and spontaneous contexts, as shown in the family-level distribution of species across villages (Figure 3). Asteraceae, for example, was present in all sites and included both intentionally cultivated plants, such as *C. caudatus* and *Tagetes erecta*, as well as opportunistically utilized weeds, including *C. odorata*.

In terms of growth habit, herbs made up the majority of recorded species (59.4%), followed by shrubs (24.5%), climbers (9.8%), and trees (6.3%). Herbaceous species were especially prevalent in homegardens and roadside habitats, aligning with the preference for easily accessible, fast-growing plants in subsistence-oriented agroecosystems. This trend is clearly depicted in the graphical summary of growth forms (Figure 4). Climbing species such as *Sechium edule* and *Phaseolus vulgaris* were typically cultivated, while trees were underrepresented unless they offered additional value as food, fuel, or multipurpose resources.

Regarding the plant parts used, a total of 931 use-reports were recorded across all five study villages. Leaves were the most frequently mentioned part, accounting for 34.4% of all reports (n=320), followed by fruits (26.9%, n=250), roots or rhizomes (19.4%, n = 180), flowers (12.9%, n = 120), whole plants (9.8%, n = 91), and stems (9.7%, n = 90). A few species—such as *Portulaca oleracea*—were used in their entirety, particularly in medicinal and ornamental contexts, highlighting the multifunctionality and adaptability of many naturalized alien plant species (NAPS) in local ethnobotanical systems. The predominance of leaf use aligns with traditional Javanese practices, where leafy materials are commonly prepared as salads, decoctions, or poultices. These patterns are visually summarized in Figure 5.

In terms of floristic origin, the majority of naturalized alien plant species (NAPS) recorded in the study originated from Tropical America (48 species, 33.6%), followed by Southeast Asia (26 species, 18.2%), and the Indian Subcontinent (24 species, 16.8%), with smaller contributions from Africa (12 species, 8.4%), Temperate Asia (10 species, 7.0%), Europe (8 species, 5.6%), and Australia-Pacific (5 species, 3.5%); an additional 10 species (7.0%) had uncertain origins. These source regions reflect a complex history of plant introductions driven by trade, colonization, and cultural exchange, particularly during the colonial and post-colonial periods. The prominence of American taxa such as *P. guajava* and *Annona muricata* illustrates the legacy of transoceanic diffusion, while the substantial number of species from Southeast and South Asia indicates strong regional agroecological connectivity. The distribution of floristic origins is illustrated in Figure 6, emphasizing the global integration of introduced species into the subsistence systems and daily lives of highland communities in Central Java. For a consolidated summary of the data visualized in Figures 2-6, including exact species counts and proportions, see Table 4.

### Utilization categories of NAPS

Naturalized alien plant species (NAPS) recorded across the five study villages were classified into seven main utilization categories based on respondent interviews: food, medicine, ornamental, fodder, fuelwood, ritual and recreational, and other uses, such as cleaning agents or insect repellents. Among these, food uses accounted for the largest proportion of citations (33.5%), as shown in Table 5. Commonly cited food species included *C. caudatus*, *S. edule*, *P. oleracea*, and *P. guajava*, which are often integrated into homegardens or cultivated seasonally for soups, salads, or snacks.

**Table 3.** Demographic characteristics of respondents in the five study villages of Central Java, Indonesia (n = 230)

| Village   | n   | Male (%) | Female (%) | Mean age (years) | Households farming (%) | Mean years of residence |
|-----------|-----|----------|------------|------------------|------------------------|-------------------------|
| Berjo     | 45  | 51.1     | 48.9       | 49.2             | 88.9                   | 33.5                    |
| Balerante | 48  | 50.0     | 50.0       | 47.8             | 91.7                   | 32.8                    |
| Gondosuli | 46  | 54.3     | 45.7       | 50.5             | 89.1                   | 34.1                    |
| Sewurejo  | 45  | 48.9     | 51.1       | 48.6             | 93.3                   | 31.6                    |
| Polokarto | 46  | 52.2     | 47.8       | 49.9             | 87.0                   | 33.2                    |
| Total     | 230 | 51.3     | 48.7       | 49.2             | 90.0                   | 33.1                    |

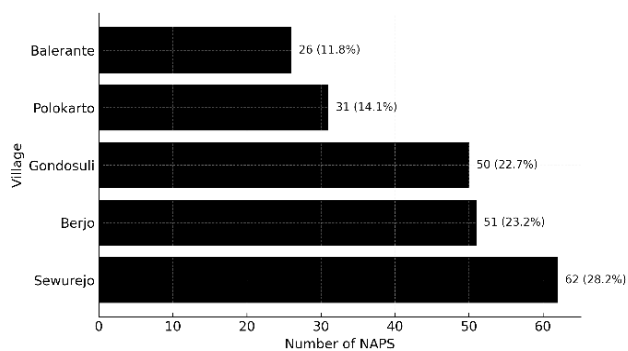


Figure 2. Species richness of naturalized alien plant species (NAPS) (n=143 species)

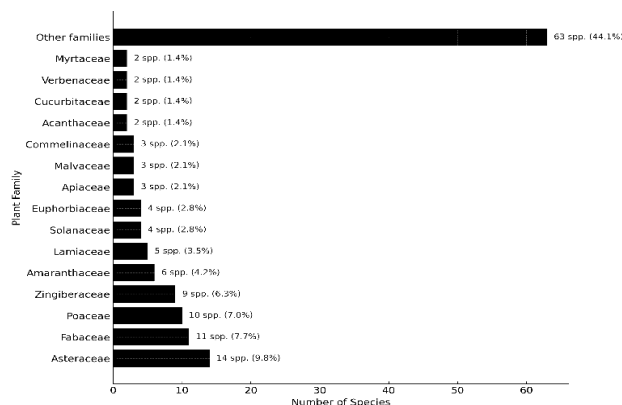


Figure 3. Distribution of naturalized alien plant species (NAPS) by plant family across five study villages in Central Java (n=143)

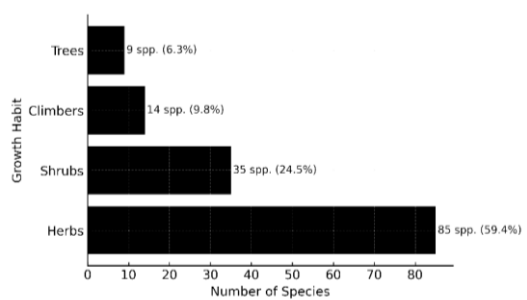


Figure 4. Growth habit of naturalized alien plant species (NAPS) in highland agroecosystems of Central Java (n=143)

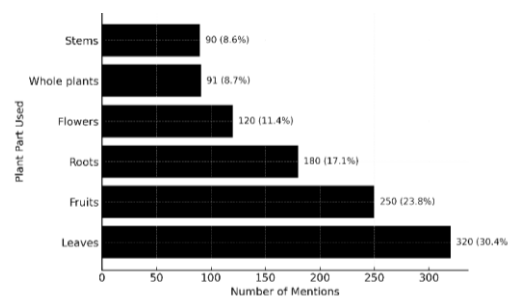


Figure 5. Parts of the plant used and their frequency of mention across all villages (n=931)

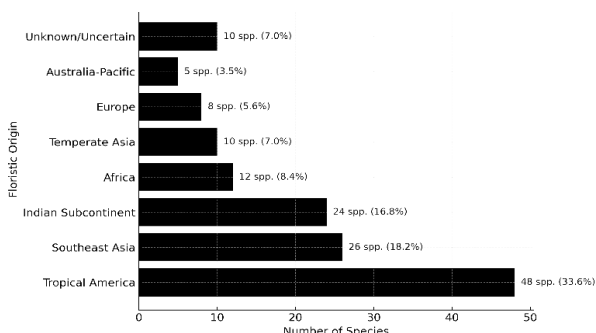


Figure 6. Floristic origin of naturalized alien plant species (NAPS) in highland communities of Central Java, Indonesia (n=143)

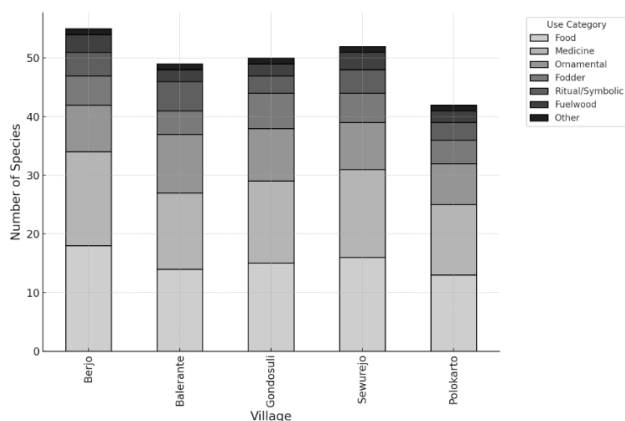


Figure 7. Number of species per use category across villages

Medicinal uses represented 29.9% of total use reports, reflecting the continued reliance on traditional remedies. Species such as *Ageratum conyzoides*, *C. longa*, *Kaempferia galanga*, and *A. muricata* were widely used in decoctions, infusions, or topical applications to treat fever, inflammation, and digestive disorders. Several species, including *Zingiber officinale*, *Amaranthus hybridus*, and *Punica granatum*, were recognized for both nutritional and medicinal properties, highlighting the integrated view of health and diet in rural Javanese culture.

Ornamental purposes accounted for 11.8% of citations, comprising visually appealing species such as *Cuphea hyssopifolia*, *Dracaena fragrans*, *T. erecta*, and *Tradescantia spathacea*, typically cultivated around dwellings or sacred spaces. Fodder uses (6.4%) involved opportunistic harvesting of species like *C. odorata*, *A. conyzoides*, and *Stachytarpheta jamaicensis* from disturbed habitats. Fuelwood applications were less common (3.5%) and generally involved pruning residues of *P. guajava* and *Chimonobambusa quadrangularis*.

Ritual and symbolic uses (4.2%) included symbolic flower offerings (*T. erecta*), protective charms (*Ricinus communis*), and materials for traditional games. A small fraction of species (0.6%) was reported for other applications, such as natural insect repellents, cleaning agents, or dye sources. The multifunctionality of many NAPS is further illustrated in Figure 7, where overlapping roles—particularly between food and medicine—underscore their cultural integration despite their alien origin.

**Table 4.** Summary of key descriptive metrics on naturalized alien plant species (NAPS): Species richness, family representation, growth forms, used parts, and floristic origins

| Visualization description                   | Variable            | Count (species/mentions) | (%)   |
|---|---------------------|--------------------------|-------|
| Species richness per village                | Sewurejo            | 62                       | 43.4  |
|   | Berjo               | 51                       | 35.7  |
|   | Gondosuli           | 50                       | 35.0  |
|   | Polokarto           | 31                       | 21.7  |
|   | Balerante           | 26                       | 18.2  |
|   | Total               | 143                      | 100.0 |
| Species count per most represented families | Asteraceae          | 14                       | 9.8   |
|   | Fabaceae            | 11                       | 7.7   |
|   | Poaceae             | 10                       | 7.0   |
|   | Zingiberaceae       | 9                        | 6.3   |
|   | Amaranthaceae       | 6                        | 4.2   |
|   | Lamiaceae           | 5                        | 3.5   |
|   | Solanaceae          | 4                        | 2.8   |
|   | Euphorbiaceae       | 4                        | 2.8   |
|   | Apiaceae            | 3                        | 2.1   |
|   | Malvaceae           | 3                        | 2.1   |
|   | Commelinaceae       | 3                        | 2.1   |
|   | Acanthaceae         | 2                        | 1.4   |
|   | Cucurbitaceae       | 2                        | 1.4   |
|   | Verbenaceae         | 2                        | 1.4   |
|   | Myrtaceae           | 2                        | 1.4   |
| Other families                              | 63                  | 44.1                     |       |
| Total                                       | 143                 | 100.0                    |       |
| Growth habits of NAPS                       | Herbs               | 85                       | 59.4  |
|   | Shrubs              | 35                       | 24.5  |
|   | Climbers            | 14                       | 9.8   |
|   | Trees               | 9                        | 6.3   |
|   | Total               | 143                      | 100.0 |
| Parts of plants used                        | Leaves              | 320                      | 34.4  |
|   | Fruits              | 250                      | 26.9  |
|   | Roots/rhizomes      | 180                      | 19.4  |
|   | Flowers             | 120                      | 12.9  |
|   | Whole plants        | 91                       | 9.8   |
|   | Stems               | 70                       | 6.4   |
|   | Total               | 931                      | 100.0 |
| Floristic origin of NAPS                    | Tropical America    | 48                       | 33.6  |
|   | Southeast Asia      | 26                       | 18.2  |
|   | Indian Subcontinent | 24                       | 16.8  |
|   | Africa              | 12                       | 8.4   |
|   | Temperate Asia      | 10                       | 7.0   |
|   | Europe              | 8                        | 5.6   |
|   | Australia-Pacific   | 5                        | 3.5   |
| Total                                       | 143                 | 100.0                    |       |

Further details on the typical plant parts used and preparation methods across each use category are provided in Table 5. For instance, leaves and fruits are predominant in food and medicinal preparations, while stems and branches are more commonly used in fodder and fuelwood contexts. This variation reflects functional specialization and the practical knowledge embedded in everyday resource use.

#### Cultural significance values (ICS)

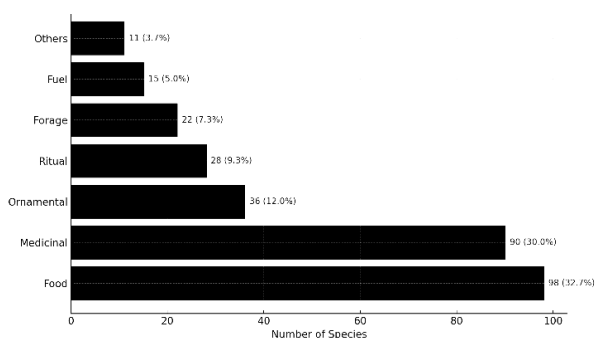
To evaluate the cultural relevance of naturalized alien plant species (NAPS) within local communities, the Index of Cultural Significance (ICS) was calculated for each species using three weighted variables: quality, intensity, and exclusivity of use, based on respondent interviews. Of the total 143 species recorded across the five villages, 121 species (84.6%) yielded valid ICS scores, while 22 species lacked sufficient data to support calculation.

The ICS values varied significantly among the villages, reflecting differences in ethnobotanical knowledge and cultural attachment. Berjo and Sewurejo exhibited the highest average ICS scores per species, indicating stronger and more diversified cultural engagement with NAPS. In contrast, Polokarto and Balerante recorded lower ICS averages, suggesting more limited utilization or transmission of knowledge. This village-level variation is visualized in Figure 9, which illustrates the range and central tendencies of ICS values per species across sites. Notably, Berjo recorded eight species with  $ICS \geq 100$ , including *C. caudatus*, *S. edule*, and *C. longa*, whereas Polokarto had none in this highest category.

Figure 8 summarizes the number of species-use assignments across the seven utilization categories, highlighting the multifunctionality of many NAPS. A total of 193 functional assignments were recorded, exceeding the number of unique species with valid ICS scores, as multiple uses were often reported for a single species (e.g., food and medicine). This figure reflects cumulative cultural functions, not discrete species counts, and underscores the versatility and adaptive value of alien plants in local traditions. A complementary view is offered by Figure 8, which illustrates the overall frequency distribution of species across the seven categories, reinforcing the predominance of food and medicinal uses in the cultural landscape—particularly in Berjo and Sewurejo.

**Table 5.** Number of plant parts used and modes of preparation for each use category across all villages (n=931 use reports)

| Use Category    | Main Plant Parts Used                        | Common Modes of Preparation                        | Frequency of Mentions (%) |
|-----------------|--|--|---------------------------|
| Food            | Leaves, Fruits, Stems                        | Raw (salads), Boiled, Cooked in dishes             | 312 (33.5%)               |
| Medicinal       | Leaves, Roots/Rhizomes, Whole plant, Flowers | Decoction, Topical application, Infusion, Poultice | 278 (29.9%)               |
| Ornamental      | Whole plant, Flowers, Stems                  | Grown around homes, ceremonial arrangement         | 110 (11.8%)               |
| Fodder          | Leaves, Stems                                | Fresh cut and fed to livestock                     | 60 (6.4%)                 |
| Ritual/Symbolic | Flowers, Whole plant, Fruits                 | Used in offerings, charms, and spiritual uses      | 39 (4.2%)                 |
| Fuelwood        | Stems, Branches                              | Firewood, a by-product of pruning                  | 33 (3.5%)                 |
| Other Uses      | Whole plant, Leaves                          | Natural cleaners, insect repellents, and dyes      | 6 (0.6%)                  |



**Figure 8.** Number of use assignments per utilization category among NAPS (n=193 total use assignments; 121 species with valid ICS scores). Note: The numbers reflect functional assignments rather than unique species; overlaps between categories are expected

Based on ICS scores, species were grouped into five tiers of cultural significance. As shown in Table 6, 37 species (30.6%) were classified as having high to very high cultural importance ( $ICS \geq 50$ ), while 41 species (33.9%) had moderate importance ( $ICS=20-49$ ). The remainder were of low or very low importance, revealing a divide between alien species that are deeply integrated into local practices and those occupying marginal or incidental roles.

Species with the highest ICS values were typically multifunctional, widely available, and embedded in daily and ritual practices. For instance, *C. caudatus* ( $ICS=126$ ) was cited for its culinary use, postpartum ritual significance, and purported blood-purifying properties. *C. longa* ( $ICS=115$ ) was a staple in herbal remedies and symbolic rituals, while *P. guajava* ( $ICS = 98$ ) served both dietary and medicinal purposes. *T. erecta* ( $ICS=90$ ) combined ornamental, ritual, and insect-repelling functions. These species, consistently reported across sites and demographic groups, exemplify how certain alien taxa have

become “local exotics”—non-native yet culturally assimilated elements of traditional ecological knowledge systems. A complete list of high-ranking species, their primary uses, and village distribution is presented in Table 7.

### Cross-village comparison of NAPS usage

The comparative analysis of naturalized alien plant species (NAPS) utilization across the five study villages revealed distinct differences in species richness, usage patterns, and cultural value, influenced by both ecological and socio-cultural factors. Sewurejo recorded the highest richness (62 species), followed by Berjo (51) and Gondosuli (50), likely due to their complex agroecosystems and openness to cultivation and experimentation. In contrast, Polokarto (31) and Balerante (26) exhibited lower diversity, possibly due to more restricted land use or limited exposure to plant introductions.

Despite being located within the same regional landscape, the cultural value assigned to specific NAPS varied across villages. Figure 9 presents the Index of Cultural Significance (ICS) values of the top 15 most culturally embedded species, highlighting taxa such as *C. caudatus*, *C. longa*, and *P. guajava*, which consistently rank highly due to their multifunctional uses in food, medicine, and rituals.

Only 17 species (11.9%) were shared across all villages, including multifunctional plants such as *C. caudatus*, *P. guajava*, *C. longa*, and *T. erecta*. Many other species were unique to one or two sites, indicating localized adoption and knowledge transmission. The inter-village comparison of ICS scores is further visualized in Figure 10, which shows the distribution and variation of cultural importance for individual species across villages. Berjo and Sewurejo show higher overall median and upper range values, reflecting their richer ethnobotanical interaction with NAPS.

**Table 6.** Classification of NAPS based on ICS score and frequency across the five villages (n = 121 species)

| ICS score category       | Description                       | Number of species | (%)   |
|--------------------------|-----------------------------------|-------------------|-------|
| Very High ( $\geq 100$ ) | Culturally indispensable          | 11                | 9.1%  |
| High (80-99)             | Widely used and locally important | 26                | 21.5% |
| Moderate (50-79)         | Functional and context-specific   | 34                | 28.1% |
| Low (20-49)              | Occasionally used or declining    | 30                | 24.8% |
| Very Low ( $<20$ )       | Marginal or little known          | 20                | 16.5% |
| Total                    | —                                 | 121               | 100%  |

**Table 7.** Top culturally significant naturalized alien plant species ( $ICS \geq 80$ ), their primary uses, and distribution across villages

| Scientific Name                              | Local Name           | Primary Use(s)          | ICS Score | Village Presence* |
|--|----------------------|-------------------------|-----------|-------------------|
| <i>Curcuma longa</i> L.                      | <i>Kunyit</i>        | Medicine, Ritual        | 120       | All villages      |
| <i>Cosmos caudatus</i> Kunth                 | <i>Kenikir</i>       | Food, Medicine          | 115       | GON, SEW, BAL     |
| <i>Psidium guajava</i> L.                    | <i>Jambu biji</i>    | Food, Medicine          | 110       | BER, GON, POL     |
| <i>Sechium edule</i> (Jacq.) Sw.             | <i>Labu siam</i>     | Food                    | 105       | BER, BAL, SEW     |
| <i>Kaempferia galanga</i> L.                 | <i>Kencur</i>        | Medicine, Ritual        | 102       | All villages      |
| <i>Annona muricata</i> L.                    | <i>Sirsak</i>        | Food, Medicine          | 101       | GON, POL          |
| <i>Tagetes erecta</i> L.                     | <i>Bunga kenikir</i> | Ritual, Ornamental      | 100       | BAL, POL, BER     |
| <i>Portulaca oleracea</i> L.                 | <i>Gulang-gulang</i> | Food, Medicine          | 98        | GON, SEW          |
| <i>Ricinus communis</i> L.                   | <i>Jarak</i>         | Medicine, Ritual        | 95        | BAL, SEW, POL     |
| <i>Tithonia diversifolia</i> (Hemsl.) A.Gray | <i>Paitan</i>        | Fodder, Soil ameliorant | 91        | POL, BAL          |
| <i>Piper betle</i> L.                        | <i>Sirih</i>         | Ritual, Medicine        | 90        | BER, GON, BAL     |

Note: \*Village codes: BER: Berjo, BAL: Balerante, GON: Gondosuli, SEW: Sewurejo, POL: Polokarto

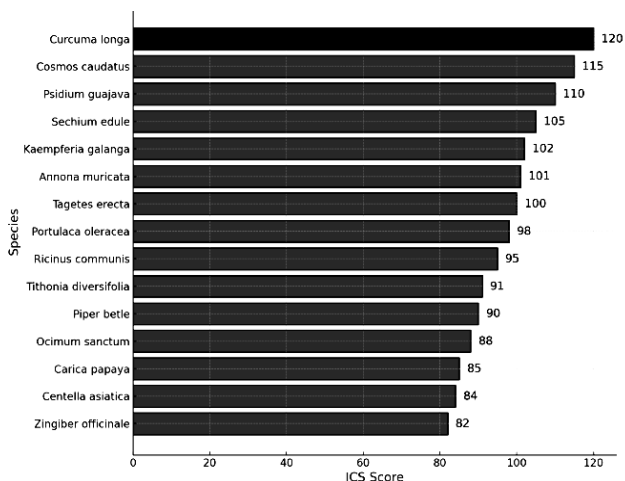


Figure 9. Cultural significance index (ICS) values of the top 15 NAPS

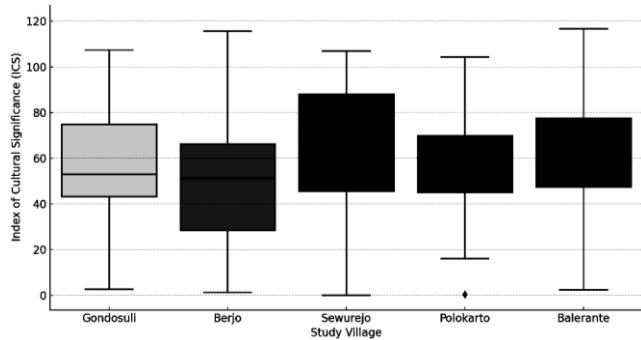


Figure 10. Boxplot of ICS scores per species in each study village

Patterns of use also varied. Berjo emphasized medicinal applications, linked to its reliance on traditional healing. Sewurejo and Gondosuli prioritized food uses, particularly homegarden species like *S. edule* and *P. oleracea*. Polokarto favored ornamental and fodder species, such as *A. conyzoides* and *S. jamaicensis*, while Balerante, near Merapi National Park, reported more ritual uses, including *R. communis* and *D. fragrans*.

Village-specific preferences were evident. *Tagetes erecta* was culturally important in Berjo and Balerante, while *Cnidioscolus aconitifolius* (chaya) was cited mostly in Gondosuli and Sewurejo, reflecting recent agricultural outreach. Interestingly, *C. odorata*, although invasive, was harvested in Polokarto as livestock fodder. A summary of the most dominant species per village, based on ICS score and primary use, is provided in Table 8, illustrating how different villages culturally prioritize different species

Table 8. Village-specific dominant NAPS based on the highest ICS score and primary use

| Village   | Dominant species (Scientific name) | Local name           | Primary use(s)     | ICS Score |
|-----------|------------------------------------|----------------------|--------------------|-----------|
| Berjo     | <i>Curcuma longa</i> L.            | <i>Kunyit</i>        | Medicine, Ritual   | 120       |
| Balerante | <i>Tagetes erecta</i> L.           | <i>Bunga kenikir</i> | Ritual, Ornamental | 100       |
| Gondosuli | <i>Cosmos caudatus</i> Kunth       | <i>Kenikir</i>       | Food, Medicine     | 115       |
| Sewurejo  | <i>Sechium edule</i> (Jacq.) Sw.   | <i>Labu siam</i>     | Food               | 105       |
| Polokarto | <i>Ricinus communis</i> L.         | <i>Jarak</i>         | Medicine, Ritual   | 95        |

depending on ecological opportunities, proximity to forests, or institutional interventions.

These variations highlight the nuanced integration of alien plants into local ecosystems, which is influenced by environmental, cultural, and institutional factors. Recognizing such patterns is crucial for developing context-sensitive management and community-based conservation strategies that align ecological impacts with social benefits.

Visual representation of NAPS data

The comparative analysis of naturalized alien plant species (NAPS) across the five study villages revealed marked differences in species richness, usage focus, and cultural valuation. Sewurejo recorded the highest richness (62 species), followed by Berjo (51) and Gondosuli (50), likely reflecting more diverse agroecosystems and greater openness to incorporating new plants. In contrast, Polokarto (31) and Balerante (26) had fewer species, possibly due to more limited land use, proximity to conservation zones, or reduced exposure to agricultural innovation. These differences are summarized visually in Figure 11, which presents a stacked bar chart comparing the number of NAPS per use category across villages. The chart highlights how food and medicinal plants dominate in Sewurejo and Gondosuli, while ornamental and ritual species are more emphasized in Polokarto and Balerante.

Despite shared regional ecology, inter-village species overlap was low. Only 17 species (11.9%) were found in all villages, including culturally embedded plants such as *C. caudatus*, *P. guajava*, *C. longa*, and *T. erecta*. Many species were confined to one or two sites, reflecting localized diffusion and selective adoption shaped by cultural preferences and environmental familiarity. The extent of overlap and uniqueness is depicted in Figure 12, a Venn diagram comparing culturally important NAPS among Berjo, Balerante, and Gondosuli. The diagram reveals that while certain culturally significant species are shared, each village retains a distinct ethnobotanical identity.

Utilization patterns also varied. Berjo emphasized medicinal uses (over 40%), likely due to reliance on traditional health practices. Sewurejo and Gondosuli prioritized food plants such as *S. edule* and *P. oleracea*, reflecting strong homegarden traditions. Polokarto favored ornamental and fodder species such as *A. conyzoides* and *S. jamaicensis*. At the same time, Balerante, adjacent to Mount Merapi National Park, showed higher frequencies of ritual and symbolic uses, including *R. communis* and *D. fragrans*.

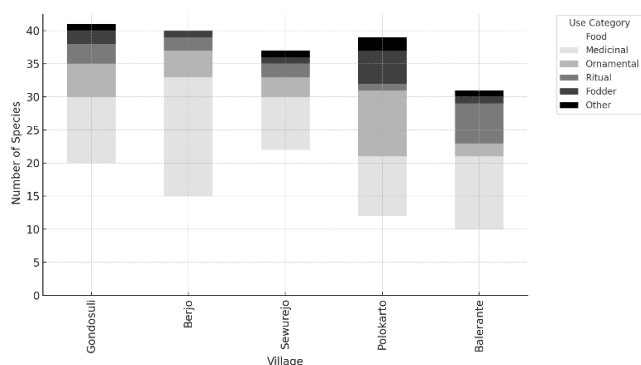


Figure 11. Cross-village overlap of NAPS (stacked bar)

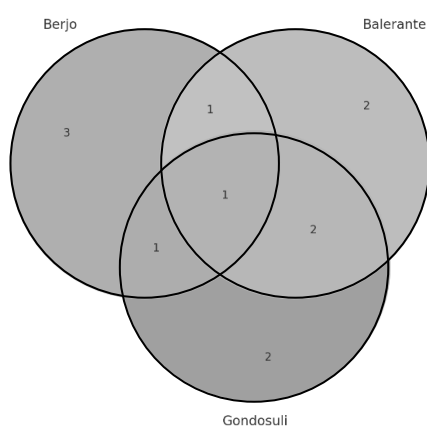


Figure 12. Venn diagram of culturally important NAPS in three villages, among Berjo, Balerante, and Gondosuli

Village-specific preferences emerged clearly. *Tagetes erecta* was especially valued in Berjo and Balerante for ornamental and ceremonial purposes. *Cnidioscolus aconitifolius*, introduced through agricultural extension, was reported mainly in Gondosuli and Sewurejo, indicating successful localized adoption. Interestingly, *C. odorata*, despite its invasive status, was harvested in Polokarto for livestock fodder, illustrating practical local adaptation.

The cultural valuation of key NAPS also varied significantly across villages. Figure 13 presents a heatmap of ICS (Index of Cultural Significance) scores for dominant species across all five sites. This visual illustrates the differing degrees to which the same species are culturally valued in different communities, confirming that the same alien plant may be deeply embedded in one context and marginal in another.

These findings underscore the complex, place-based integration of alien species shaped by environmental conditions, cultural norms, and external influences, emphasizing the need for context-specific management and community-based plant governance.

### Multifunctionality and use patterns

Naturalized alien plant species (NAPS) recorded in the study villages exhibit varying degrees of multifunctionality, with several species playing dual or even multiple roles across distinct use categories. While

some plants are strictly associated with a single function (e.g., food or medicinal), others bridge across domains such as ritual, ornamentation, and health.

Among the top culturally significant species, *C. longa* is primarily used for medicinal purposes but also features in ritual offerings and culinary preparations. *P. guajava* is widely consumed for its fruit (food use), while its leaves are employed in traditional remedies for gastrointestinal disorders. *Tagetes erecta*, known for its ornamental value, also holds ritual significance in several villages. Similarly, *C. caudatus* serves both dietary and medicinal roles, especially in daily household practices.

*Ricinus communis* and *P. oleracea* further exemplify this multifunctionality. *Ricinus communis* is valued for its medicinal oil and ritual symbolism, whereas *P. oleracea* is appreciated both as a foraged leafy vegetable and for its therapeutic properties. The widespread occurrence of multifunctional uses highlights how NAPS have been culturally integrated and adapted to meet multiple household needs. These relationships are illustrated in Figure 14, which shows a visual typology of selected multifunctional NAPS, linking each species to both its primary and secondary use categories. The distribution suggests that cultural acceptance and functional diversity are key drivers behind the persistence and proliferation of NAPS in local agroecosystems.

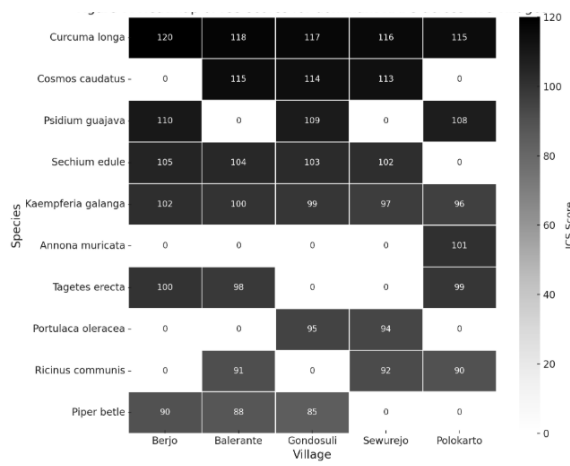


Figure 13. Heatmap showing village-wise ICS scores for dominant species



Figure 14. Visual typology of multifunctional NAPS by primary and secondary uses

## Discussion

### *The ethnobotanical value of naturalized alien plants*

Naturalized alien plant species (NAPS) are frequently portrayed within ecological narratives as drivers of biodiversity loss and environmental disturbance (van Kleunen et al. 2018; Pyšek et al. 2020). Yet, this study highlights the diverse and meaningful roles NAPS now play in the daily lives of highland communities in Central Java. Far from being purely invasive, many NAPS have become culturally embedded, fulfilling essential functions in subsistence, healthcare, and ritual life. This integration is reflected in high Index of Cultural Significance (ICS) values, demonstrating their functional and symbolic relevance.

Species such as *C. caudatus*, *C. longa*, and *P. guajava* exemplify how alien plants can become staple vegetables, medicinal ingredients, and ritual symbols. Their incorporation results from intentional selection, local experimentation, and the intergenerational transmission of knowledge—what Howard (2003), Pardo-de-Santayana et al. (2007), and Sökand et al. (2024) describe as cultural filtering.

Multifunctionality is a key attribute driving their retention. Several NAPS are valued for their combined nutritional, medicinal, ornamental, and symbolic roles, reinforcing their cultural salience (Albuquerque et al. 2006). In Java, where food traditions, *jamu* (herbal medicine), and ritual practices are deeply intertwined, such plants are more likely to persist despite their non-native origins.

Nonetheless, cultural integration does not equate to ecological safety. *Chromolaena odorata* and *R. communis*, though recognized as invasive (Setyawati et al. 2015), are utilized locally for fodder, protection, or ritual functions. Their dual identity illustrates the limits of blanket classifications and supports more nuanced perspectives (Shackleton et al. 2007; Kueffer and Hirsch Hadorn 2008). These findings call for culturally grounded management approaches. Understanding NAPS as embedded within local livelihoods and knowledge systems is critical for ensuring that invasive species strategies remain context-sensitive and socially just (Shrestha and Shrestha 2019).

### *Socio-cultural drivers of NAPS utilization*

The adoption and continued use of naturalized alien plant species (NAPS) in the five highland villages studied are shaped by more than just ecological availability. A complex set of socio-cultural drivers—including historical interactions, food practices, gendered knowledge systems, and livelihood strategies—influence how these species are integrated, adapted, or excluded from daily life.

Customary food systems are among the most prominent drivers. NAPS like *S. edule* and *A. hybridus* are closely tied to seasonal diets and household food security. The cultural preference for *sayuran lalapan* (wild or semi-cultivated vegetables) provides a niche for adaptable alien species. This pattern reflects broader trends where food heritage and agrobiodiversity are closely interlinked (Reyes-García et al. 2006; Zimmerer et al. 2019; Britwum and Demont 2022).

Traditional health systems also play a vital role. Plants such as *C. longa*, *K. galanga*, and *A. muricata* are commonly used in *jamu* (herbal medicine) to treat ailments and promote

wellness. Their use is often maintained through oral transmission, particularly by older women, who serve as key knowledge holders (Sosef et al. 2017; Mji 2019). Similar gendered and age-based patterns have been observed elsewhere in Indonesia (Peltzer and Pengpid 2018).

In some villages, NAPS are also maintained for ritual or symbolic roles. *Tagetes erecta* is used in offerings, while *R. communis* serves protective purposes. These functions persist even when native alternatives are available, suggesting that symbolic importance can shield certain alien plants from displacement. The concept of “cultural keystone species” (Garibaldi and Turner 2004) is applicable in these contexts.

Institutional interventions have also shaped NAPS adoption. Programs such as school gardens and seed distribution have introduced species like *C. aconitifolius*, now integrated into Gondosuli and Sewurejo. The success of such introduction hinges on community acceptance, not just agronomic suitability. NAPS utilization reflects ongoing cultural negotiation, shaped by belief systems, gender roles, and policy. For management strategies to be effective, they must consider these cultural dynamics to avoid undermining local resilience in food and health systems.

### *Functional versatility and local adaptation*

The cultural embeddedness of many naturalized alien plant species (NAPS) in Central Java is closely linked to their functional versatility—their ability to serve multiple roles across household, agro-ecological, and ritual contexts. This multifunctionality increases their perceived value and supports their persistence amid shifting environmental and socio-economic conditions. Plants that meet various needs are more likely to be retained, cultivated, and passed on through generations, a trend echoed in other ethnobotanical studies (Albuquerque et al. 2006; Galluzzi et al. 2010).

Several NAPS documented in this study reflect such multifunctionality. *Cosmos caudatus*, for example, serves as a vegetable, postpartum tonic, and digestive aid. *Curcuma longa* is used as a spice, herbal remedy, and ritual ingredient. Their ability to span culinary, medicinal, and symbolic domains elevates them from functional plants to cultural assets (Nabhan 2009; Peredo Parada and Barrera Salas 2023).

Ecological adaptability further supports NAPS retention. Many are fast-growing, herbaceous species capable of thriving in marginal soils, fallow plots, and disturbed areas like roadsides or homegarden fringes. This plasticity is particularly valuable in resource-limited settings where native species may be seasonal or labor-intensive to grow. The prevalence of pioneer species such as *P. oleracea* and *S. jamaicensis* reflects this opportunistic use of accessible greenery.

Adaptation often involves cultural reinterpretation. Over time, introduced species may acquire Javanese or hybrid vernacular names, signifying symbolic and linguistic assimilation. Some are no longer perceived as foreign but have become “local exotics” through deep cultural integration—an observation also reported in other tropical regions (Shackleton et al. 2007; de Medeiros et al. 2021).

Importantly, multifunctional NAPS also support household resilience. During periods of food scarcity or illness, such plants offer affordable, accessible buffers. Their role in coping with stress and uncertainty mirrors patterns found in broader agrobiodiversity and climate adaptation literature (Zimmerer et al. 2019). The persistence of NAPS reflects both ecological suitability and cultural functionality. Management efforts must therefore consider their embedded role in local livelihoods and resilience systems—not just their ecological footprint.

#### *Knowledge distribution and demographic correlates*

The utilization of naturalized alien plant species (NAPS) across the five highland villages is unevenly distributed, reflecting demographic variation in ecological knowledge shaped by factors such as age, gender, education, land access, and livelihood roles. These variables influence not only who knows which plants, but also how knowledge is accessed, interpreted, and transmitted.

Age emerged as a key correlate of familiarity with NAPS. Respondents above 40 years consistently reported greater awareness of alien species and their uses. This generational gradient aligns with findings from other ethnobotanical contexts in Southeast Asia and Latin America, where traditional ecological knowledge (TEK) tends to accumulate with age and is rarely formalized (Paniagua-Zambrana et al. 2014; Sumarwati et al. 2022). As younger generations shift away from subsistence farming and ritual practices, their reliance on—and exposure to—non-commercial plants declines, raising concerns about knowledge discontinuity.

Gender also shaped knowledge domains. Women, who oversee food preparation and family healthcare, were more familiar with leafy vegetables, culinary herbs, and *jamu* species. Men more often cited NAPS related to fodder, fuelwood, and live fences. These patterns reflect gendered divisions of labor in rural Java and suggest complementary, rather than exclusive, knowledge systems (Howard 2003; Pfeiffer and Butz 2005; Kreager and Schröder-Butterfill 2014).

Education exerted a more complex influence. While formal schooling often correlates with reduced TEK (Reyes-García et al. 2006), this study found that respondents with basic education—especially those completing primary or junior high school—were often more articulate about both traditional and contemporary plant uses. Those without schooling demonstrated experiential depth but less analytical expression, while highly educated individuals tended to be disconnected from homegarden-based practices.

Land access and farming participation further influenced NAPS knowledge. Households maintaining active homegardens exhibited higher familiarity with multifunctional species, especially for food and medicine. In contrast, those with limited land or employed off-farm were less engaged in plant-based practices and more reliant on markets or packaged goods.

These patterns show that TEK is both stratified and dynamic, embedded in broader socio-economic realities. As rural transitions continue, valuable knowledge about alien plant uses and their risks may erode. Management

strategies must therefore support knowledge revitalization through intergenerational learning, participatory documentation, and culturally responsive agroecological education. Recognizing the demographic structure of knowledge is essential for socially inclusive and ecologically sound conservation policy.

#### *Cross-village differences and biocultural filtering*

Although the five study villages are geographically located within the same region of Central Java, the results reveal marked inter-village differences in species richness, use intensity, and the cultural salience of naturalized alien plant species (NAPS). These variations are not incidental; they are shaped by a process of biocultural filtering—whereby communities selectively adopt, adapt, or exclude species based on ecological suitability, cultural values, and collective experience (Pardo-de-Santayana et al. 2007; Reyes-García et al. 2009).

Sewurejo and Berjo, for example, exhibited the highest NAPS diversity and ICS values. Both villages possess more extensive agroforestry systems and stable land tenure, which support a variety of microhabitats and encourage experimentation with multifunctional species. Their broader range of NAPS usage—encompassing food, medicine, ornamentals, and rituals—suggests that ecological opportunity and cultural openness intersect to foster greater ethnobotanical diversity. In contrast, Polokarto and Balerante reported lower NAPS richness and narrower use types, with a stronger emphasis on ornamental or symbolic roles. This pattern may reflect ecological constraints (e.g., smaller garden plots, drier soils) as well as selective cultural retention practices.

The appearance of village-specific species—those cited only in one or two locations—further underscores localized ethnobotanical trajectories. These species are not necessarily ecologically excluded elsewhere but may have failed to gain cultural relevance, were previously associated with negative experiences, or were replaced by more familiar alternatives. For instance, *C. aconitifolius* appeared only in Gondosuli and Sewurejo, despite identical institutional introductions, highlighting the role of cultural acceptance alongside agronomic feasibility.

Only 17 of 143 recorded NAPS were found in all five villages, emphasizing that even within closely related communities, plant use is highly heterogeneous. This supports observations by Shackleton et al. (2007), who note that alien species may be celebrated in one context and reviled in another, depending on how communities have historically engaged with them.

Biocultural filtering thus operates as an informal governance mechanism, selectively reinforcing species that align with local needs, values, and management capacity. This underscores the need for conservation and invasive species strategies to recognize—not override—place-based ecological knowledge and cultural preferences. The distinct patterns of NAPS use across villages reflect the dynamic interaction of ecological diversity and culturally embedded decision-making processes.

### *Risks and opportunities of NAPS integration*

While the cultural integration of naturalized alien plant species (NAPS) provides tangible benefits to rural communities—such as food security, accessible healthcare, and symbolic continuity—it simultaneously raises important concerns regarding ecological risk, dependence, and long-term sustainability. The core challenge lies in reconciling the dual nature of NAPS as both culturally valued resources and potential ecological disruptors.

Many NAPS recorded in this study, such as *C. longa*, *P. guajava*, and *S. edule*, illustrate cases of positive coexistence. These species are often grown in controlled settings like homegardens, exhibit non-invasive tendencies, and help compensate for the declining availability of native species. Their integration into local agroecosystems enhances food diversity and supports low-cost healthcare, particularly in remote or economically marginal areas. In such cases, NAPS contribute constructively to ecological function and local resilience. Conversely, other NAPS—especially those occupying disturbed or unmanaged habitats—present clear ecological risks. *C. odorata*, though occasionally used as livestock fodder, is a globally notorious invasive capable of suppressing native flora, altering fire regimes, and degrading habitats (Setyawati et al. 2015). *R. communis*, widely grown for ornamental or protective functions, may spread rapidly and produce toxic compounds hazardous to livestock and human health.

These contrasting outcomes highlight the importance of context in assessing NAPS. A species seen as invasive in one location may be perceived as beneficial elsewhere, depending on how it is managed, its ecological behavior, and cultural framing. This reinforces arguments by Kueffer and Hirsch Hadorn (2008) and Shackleton et al. (2019) for localized, participatory assessment models rather than generalized ecological judgments. At the same time, current NAPS practices offer pathways toward culturally attuned conservation. Non-invasive, multifunctional alien species could be integrated more systematically into homegarden programs, school-based agroecology, or local food security initiatives. This approach would recognize their ethnobotanical value while embedding sustainability principles in rural development planning.

However, such integration must be accompanied by critical reflection. There is a risk that overreliance on alien species—particularly through top-down promotion or market incentives—may erode attention to native biodiversity and traditional crop systems. If younger generations grow up prioritizing introduced species, cultural homogenization and biotic substitution may occur over time. Hence, managing NAPS effectively requires adaptive, culturally grounded strategies, including intergenerational learning, participatory risk mapping, and community-informed governance.

### *Implications for invasive species management and conservation*

The findings of this study emphasize the need for more nuanced strategies in managing naturalized alien plant species (NAPS). Conventional approaches typically focus on eradication or containment, guided by ecological risk assessments and global databases (van Kleunen et al. 2018;

Pyšek et al. 2020). However, these strategies may be socially and ethically problematic when applied to species that are deeply embedded in local food systems, traditional healing practices, or cultural traditions. A rigid application of such models can marginalize rural knowledge systems and disrupt long-established relationships between people and plants.

One important implication is the need for context-specific classification. Not all alien species are invasive or harmful in every setting; some have been intentionally introduced and selectively retained for their utility or cultural significance. Species like *C. longa* and *C. caudatus* have become essential to daily life without showing invasive tendencies. Therefore, ecological assessments should be complemented by evaluations of cultural significance and local benefits (Shackleton et al. 2019).

The study also highlights the value of local knowledge and participatory approaches in managing alien species. Communities in Central Java have already adopted informal mechanisms to distinguish between useful and problematic species. Recognizing and incorporating these practices into policy—through participatory mapping, community-based monitoring, or co-management—can improve sustainability and local legitimacy (Kueffer and Hirsch Hadorn 2008; Shrestha and Shrestha 2019).

Additionally, alien plants should not be dismissed outright but viewed within a resilience-based framework. In marginal or degraded areas, some alien species offer important ecosystem services, from soil stabilization to supplementary food or medicine. With proper management, such species can complement native biodiversity rather than threaten it. Their integration into conservation-compatible land use plans may support both ecological and social goals.

Ultimately, a coordinated policy across the agriculture, conservation, and cultural heritage sectors is essential. Disjointed agendas, such as promoting a species through agricultural extension while targeting it for removal under conservation law, lead to inefficiencies and local resistance. A transdisciplinary and culturally sensitive approach will ensure that alien species management aligns with rural realities and supports sustainable resource governance.

In conclusion, this study shows that naturalized alien plant species (NAPS) are deeply integrated into the cultural, medicinal, and nutritional life of highland communities in Central Java. Species like *C. caudatus*, *C. longa*, and *P. guajava* scored high in cultural significance, reflecting biocultural naturalization. Village-specific use patterns reflect ecological and socio-cultural filtering. The findings call for more nuanced invasive species management, recognizing that some NAPS provide vital benefits. Sustainable use of low-risk alien plants, informed by both science and tradition, can support biodiversity conservation while enhancing cultural resilience and rural livelihoods.

## REFERENCES

- Abywijaya IK, Hikmat A, Widyatmoko D. 2014. Keanekaragaman dan pola sebaran spesies tumbuhan asing invasif di Cagar Alam Pulau Sempu, Jawa Timur. *Jurnal Biologi Indonesia* 10 (2): 221-235. [Indonesian]

- Albuquerque UP, Lucena RFP, Monteiro JM, Florentino ATN, Almeida CFCBR. 2006. Evaluating two quantitative ethnobotanical techniques. *Ethnobot Res Appl* 4: 51-60.
- BMKG. 2023. *Climate Outlook 2023*. Badan Meteorologi Klimatologi dan Geofisika, Jakarta. [Indonesian]
- BPS. 2022. *Luas Penggunaan Lahan dan Luas Kawasan Hutan Menurut Kabupaten/Kota di Provinsi Jawa Tengah (Km<sup>2</sup>), 2021*. Badan Pusat Statistik, Semarang. [Indonesian]
- Britwum K, Demont M. 2022. Food security and the cultural heritage missing link. *Glob Food Secur* 35: 100660. DOI: 10.1016/j.gfs.2022.100660.
- Carneiro L, Hulme PE, Cuthbert RN, Kourantidou M, Bang A, Haubrock PJ, Bradshaw CJA, Balzani P, Bacher S, Latombe G, Bodey TW, Probert AF, Quilodrán CS, Courchamp F. 2024. Benefits do not balance costs of biological invasions. *BioScience* 74 (5): 340-344. DOI: 10.1093/biosci/biae010.
- Cuthbert RN, Diagne C, Hudgins EJ et al. 2022. Biological invasion costs reveal insufficient proactive management worldwide. *Sci Total Environ* 819: 153404. DOI: 10.1016/j.scitotenv.2022.153404.
- Darmastuti SA, Nazar IA, Setyawan AD. 2024. Plant diversity and its use in Javanese urban home garden: An ethnobotanical study in Central Java, Indonesia. *Asian J Ethnobiol* 7 (1): 32-42. DOI: 10.13057/asianjethnobiol/y070104.
- de Medeiros PM, Dos Santos GMC, Barbosa DM, Gomes LCA, Santos EMDC, da Silva RRV. 2021. Local knowledge as a tool for prospecting wild food plants: experiences in northeastern Brazil. *Sci Rep* 11 (1): 594. DOI: 10.1038/s41598-020-79835-5.
- Galluzzi G, Eyzaguirre P, Negri V. 2010. Home gardens: neglected hotspots of agro-biodiversity and cultural diversity. *Biodivers Conserv* 19: 3635-3654. DOI: 10.1007/s10531-010-9919-5.
- Garibaldi A, Turner N. 2004. Cultural keystone species: implications for ecological conservation and restoration. *Ecol Soc* 9 (3): 1. DOI: 10.5751/ES-00669-090301.
- González JA, García-Barriuso M, Amich F. 2006. Ethnobotanical study of medicinal plants traditionally used in the Arribes del Duero, western Spain. *J Ethnopharmacol* 107 (3): 324-341. DOI: 10.1016/j.jep.2006.03.032.
- Handayani A, Zuhud EAM, Junaedi DI. 2021. Assessing the utilization of naturalized alien plant species by community to inform its management strategy: A case study in Cibodas Biosphere Reserve, West Java, Indonesia. *Biodiversitas* 22 (7): 2579-2588. DOI: 10.13057/biodiv/d220705.
- Heinrich M, Ankli A, Frei B, Weimann C, Sticher O. 2009. Medicinal plants in Mexico: healers' consensus and cultural importance. *Soc Sci Med* 47 (11): 1859-1871. DOI: 10.1016/S0277-9536(98)00281-6.
- Howard PL. 2003. *Women and plants: gender relations in biodiversity management and conservation*. Zed Books, London.
- Kreager P, Schröder-Butterfill E. 2014. Ageing and Gender Preferences in Rural Indonesia. In: Devasahayam TW (eds.). *Gender and Ageing: Southeast Asian Perspectives*. ISEAS Publishing, Singapore.
- Kueffer C, Hirsch Hadorn G. 2008. How to achieve effectiveness in problem-oriented landscape research: the example of research on biotic invasions. *Living Rev Landsc Res* 2 (2): 1-21. DOI: 10.12942/lrlr-2008-2.
- Kusumawati IA, Mardiani MO, Purnamasari E, Batoro J, van Noordwijk M, Hairiah K. 2022. Agrobiodiversity and plant use categories in coffee-based agroforestry in East Java, Indonesia. *Biodiversitas* 23 (10): 5412-5422. DOI: 10.13057/biodiv/d231052
- Maruapey A, Ohorella S, Karepesina S. 2022. Nilai kepentingan budaya keanekaragaman jenis sayuran indigenous dalam kehidupan masyarakat di Kampung Sire Distrik Mare Timur Kabupaten Maybrat Papua Barat. *Jurnal Agrohut* 13 (1): 11-24. DOI: 10.51135/agh.v13i1.119. [Indonesian]
- Mji G. 2019. Women as healers and indigenous knowledge systems and its holders: An intertwined epistemological and ontological struggle for recognition. In: Mji G (eds.). *The Walk Without Limbs: Searching for Indigenous Health Knowledge in a Rural Context in South Africa*. AOSIS, Cape Town. DOI: 10.4102/aosis.2019.BK98.03.
- Mokany K, Ware C, Woolley SN, Ferrier S, Fitzpatrick MC. 2022. A working guide to harnessing generalized dissimilarity modelling for biodiversity analysis and conservation assessment. *Glob Ecol Biogeogr* 31 (4): 802-821. DOI: 10.1111/geb.13459.
- Nabhan GP. 2009. *Where our food comes from: retracing Nikolay Vavilov's quest to end famine*. Island Press, Washington DC.
- Nahdi MS, Kurniawan AP. 2019. The diversity and ethnobotanical study of medicinal plants in the southern slope of Mount Merapi, Yogyakarta, Indonesia. *Biodiversitas* 20 (8): 2279-2287. DOI: 10.13057/biodiv/d200824
- Nurchayho FD, Zen HM, Rahma HS, Triyanto A, Yasa A, MD Naim D, Setyawan AD. 2024. Ethnobotanical study of medicinal plants used by local communities in the Upper Bengawan Solo River, Central Java, Indonesia. *Intl J Bonorowo Wetlands* 14 (1): 25-36. DOI: 10.13057/bonorowo/w140104.
- Paniagua-Zambrana NY, Cámara-Leret R, Bussmann RW, Maciá MJ. 2014. The influence of socioeconomic factors on traditional knowledge: A cross scale comparison of palm use in northwestern South America. *Ecol Soc* 19 (4): 9. DOI: 10.5751/ES-06934-190409.
- Pardo-de-Santayana M, Tardío J, Blanco E, Carvalho AM, Lastra JJ, San Miguel E, Morales R. 2007. Traditional knowledge of wild edible plants used in the northwest of the Iberian Peninsula (Spain and Portugal): a comparative study. *J Ethnobiol Ethnomed* 3: 27. DOI: 10.1186/1746-4269-3-27.
- Peltzer K, Pengpid S. 2019. Traditional health practitioners in Indonesia: Their profile, practice and treatment characteristics. *Complement Med Res* 26 (2): 93-100. DOI: 10.1159/000494457.
- Peredo Parada S, Barrera Salas C. 2023. Multifunctional plants: ecosystem services and undervalued knowledge of biocultural diversity in rural communities—local initiatives for agroecological transition in Chile. *Land* 13 (1): 39. DOI: 10.3390/land13010039.
- Pfeiffer JM, Butz RJ. 2005. Assessing cultural and ecological variation in ethnobiological research: the importance of gender. *J Ethnobiol* 25 (2): 240-278. DOI: 10.2993/0278-0771(2005)25[240:ACAEV]2.0.CO;2.
- Pyšek P, Hulme PE, Simberloff D, Bacher S, Blackburn TM, Carlton JT, Dawson W, Essl F, Foxcroft LC, Genovesi P, Jeschke JM. 2020. Scientists' warning on invasive alien species. *Biol Rev* 95 (6): 1511-1534. DOI: 10.1111/brv.12627.
- Rai PK, Singh JS. 2020. Invasive alien plant species: Their impact on environment, ecosystem services and human health. *Ecol Indic* 111: 106200. DOI: 10.1016/j.ecolind.2019.106200.
- Reyes-García V, Broesch J, Calvet-Mir L, Fuentes-Peláez N, McDade TW, Parsa S, Tanner S, Huanca T, Leonard WR, Martínez-Rodríguez MR, TAPS Bolivian Study Team. 2009. Cultural transmission of ethnobotanical knowledge and skills: An empirical analysis from an Amerindian society. *Evol Human Behav* 28 (5): 274-285.
- Reyes-García V, Vadez V, Byron E, Apaza L, Leonard WR, Perez E, Wilkie D. 2006. Market economy and the loss of folk knowledge of plant uses: estimates from the Tsimane of the Bolivian Amazon. *Curr Anthropol* 46 (4): 651-656. DOI: 10.1086/432777.
- Richardson DM, Pyšek P, Rejmánek M, Barbour MG, Panetta FD, West CJ. 2000. Naturalization and invasion of alien plants: concepts and definitions. *Divers Distrib* 6 (2): 93-107. DOI: 10.1046/j.1472-4642.2000.00083.x.
- Sayfulloh A, Riniarti M, Santoso T. 2020. Invasive alien species plants in Sukaraja Atas Resort, Bukit Barisan Selatan National Park. *Jurnal Sylva Lestari* 8 (1): 109-120. DOI: 10.23960/jsl18109-120.
- Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Essl F. 2018. Global rise in emerging alien species results from increased accessibility of new source pools. *Proc Natl Acad Sci USA* 115 (10): E2264-E2273. DOI: 10.1073/pnas.1719429115.
- Setyawati T, Narulita S, Bahri IP, Raharjo GT. 2015. *A guide book to invasive alien plant species in Indonesia*. Ministry of Environment and Forestry, Jakarta. [Indonesian]
- Shackleton CM, McGarry D, Fourie S, Gambiza J, Shackleton SE, Fabricius C. 2007. Assessing the effects of invasive alien species on rural livelihoods: Case examples and a framework from South Africa. *Hum Ecol* 35: 113-127. DOI: 10.1007/s10745-006-9095-0.
- Shackleton RT, Shackleton CM, Kull CA. 2019. The role of invasive alien species in shaping local livelihoods and human well-being: A review. *J Environ Manag* 229: 145-157. DOI: 10.1016/j.jenvman.2018.05.007.
- Shrestha UB, Shrestha BB. 2019. Climate change amplifies plant invasion hotspots in Nepal. *Divers Distrib* 25 (10): 1599-1612. DOI: 10.1111/ddi.12963.
- Sosef MS, Dauby G, Blach-Overgaard A, van Der Burgt X, Catarino L, Damen T, Deblauwe V, Dessein S, Dransfield J, Droissart V, Duarte MC. 2017. Exploring the floristic diversity of tropical Africa. *BMC Biol* 15: 15. DOI: 10.1186/s12915-017-0356-8.
- Sõukand R, Kalle R, Prakofjewa J, Sartori M, Pironi A. 2024. The importance of the continuity of practice: Ethnobotany of Kihnu island (Estonia) from 1937 to 2021. *Plants People Planet* 6 (1): 186-196. DOI: 10.1002/ppp3.10423.
- Sumarwati S. 2022. Traditional ecological knowledge on the slope of Mount Lawu, Indonesia: All about non-rice food security. *J Ethn Foods* 9 (1): 9. DOI: 10.1186/s42779-022-00120-z.
- Supiandi MI, Mahanal S, Zubaidah S, Julung H, Ege B. 2019. Ethnobotany of traditional medicinal plants used by Dayak Desa Community in Sintang, West Kalimantan, Indonesia. *Biodiversitas* 20 (5): 1264-1270. DOI: 10.13057/biodiv/d200516
- Tjitrosoedirdjo SS. 2005. Inventory of the invasive alien plant species in Indonesia. *Biotropia* 25: 60-73.
- Turner NJ. 1988. The importance of a rose: Evaluating the cultural significance of plants in Thompson and Lillooet Interior Salish. *Am Anthropol* 90 (2): 272-290.
- van Kleunen M, Essl F, Pergl J et al. 2018. The changing role of ornamental horticulture in alien plant invasions. *Biol Rev* 93 (3): 1421-1437. DOI: 10.1111/brv.12402.
- Zimmerer KS, de Haan S, Jones AD, Creed-Kanashiro H, Tello M, Carrasco M, Meza K, Amaya FP, Cruz-García GS, Tubbeh R, Olivencia YJ. 2019. The biodiversity of food and agriculture (Agrobiodiversity) in the anthropocene: Research advances and conceptual framework. *Anthropocene* 25: 100192. DOI: 10.1016/j.ancene.2019.100192.