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Research article

Native and alien plant species diversity across forest types in the mid-hills of central Nepal

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Abstract

Invasion of alien plant species is one of the major drivers that alter ecosystems, and threaten native plant diversity. In this study, we compared the diversity of native and alien plant species (naturalized and invasive) in three forest types in the mid-hills of central Nepal. We selected eight community-managed forests in three districts with similar management practices. Altogether, 24 plots (50 m × 20 m each) were sampled to collect vegetation data. We recorded 274 (88%) native and 24 (8%) alien plant species. The species richness did not vary significantly across the forest types. Among the alien plants, 12 species were naturalized, 11 were invasive including the globally worst species *Chromolaena odorata*, and the remaining one was casual. Native plant diversity was high in the *Pinus roxburghii* forest while alien plant diversity was high in the *Schima-Castanopsis* forest. The *Shorea robusta* forest with relatively mature trees, low anthropogenic disturbances, and dense canopy cover had the lowest diversity of invasive alien plants followed by *Pinus roxburghii* and *Schima-Castanopsis* forests. Contrary to the expectation, there was no significant relationship between canopy cover and species richness of native and alien plant species. Although the three studied forest types did not significantly vary in plant species richness the recorded number of alien species indicates that the community forests of the mid-hills are being invaded rapidly by alien plants. Implementation of appropriate control measures is recommended to reduce the abundance of invasive alien plants in forests and avert likely negative impacts on native species and ecosystems.

Keywords: Biological invasions, Chromolaena odorata, community-managed forests, invasive alien species, plant diversity.

Introduction

Alien plant species often disrupt indigenous biodiversity, posing severe threats to biodiversity conservation and global ecosystem functions (Glowka *et al*. 1994; Paudel *et al*. 2023). Forecasting the distribution of invasions across habitats is crucial for the effective management of these species, and the protection of native organisms. However, the spread of alien plants within a landscape is influenced by habitat conditions and dispersal mechanisms, and the relative importance of these factors varies among habitats (Johnston and Pickering 2001).

By considering their colonization tendencies, alien plant species are sorted into two distinct categories: naturalized (non-invasive) and invasive (Tiwari *et al*. 2005; Shrestha *et al*. 2021). If alien plants are established in a particular habitat for a short term but do not form stable long-term populations then these are classified as causal species. Approximately 3.9% of the total global vascular plant count consists of naturalized and invasive alien plant species that have extended beyond their original ranges (Van Kleunen *et al*. 2015). Natural processes like flooding, landslides, wind, and rainfall play a pivotal role in the seed dispersal of naturalized plant species. The number of naturalized and invasive plant species varies across land use types (Paudel *et al*. 2023). Importantly, amplified human-induced disturbances and environmental factors contribute positively to the proliferation and development of invasive plants (Simberloff 2009; Hui *et al*. 2011). Despite this, the diversity of invasive plants is consistently diminished under canopy cover and within forest cores (Khaniya and Shrestha 2020). In contrast, grasslands consistently harbor a higher diversity of invasive species than forests (Dhakal *et al*. 2024).

The number of invasive alien plant species (IAPS) decreases with increasing elevation, and a high level of invasion problems are recorded in the Tarai and mid-hill regions of central Nepal causing significant impacts on the economy, ecology, and human well-being (Bhattarai *et al*. 2014; Siwakoti *et al*. 2016; Shrestha and Shrestha 2021). In central Nepal, particularly in the Chitwan-Annapurna Landscape (CHAL), 23 IAPS are spreading extensively across various ecosystems, among which 11 species have posed significant challenges, with *Ageratum houstonianum* being the

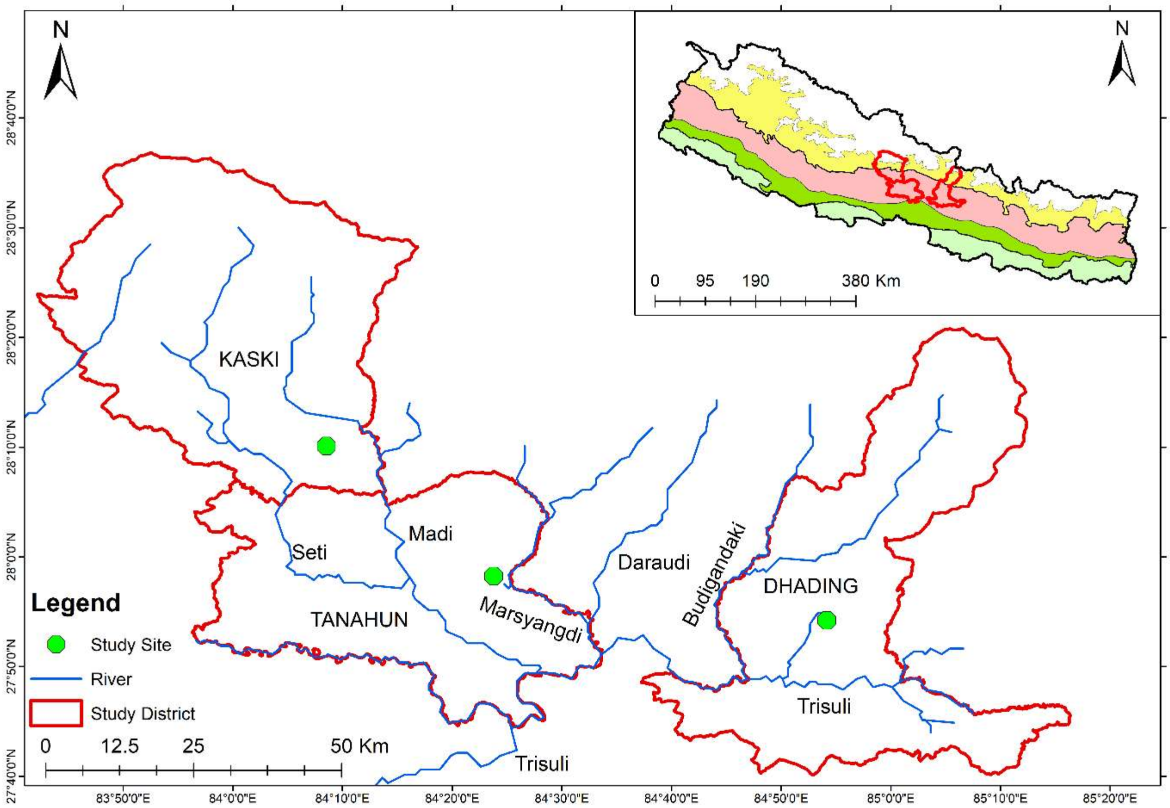

Figure 1. Map of the study area showing the sampling locations within the mid-hill region, encompassing three districts in central Nepal.

most problematic species in agroecosystems, while *Chromolaena odorata* and *Ageratina adenophora* in natural ecosystems (Siwakoti *et al.* 2016; Shrestha *et al.* 2019). Along the road networks of the mid-hills of central Nepal, 14 IAPS belonging to 12 genera and 6 families were reported by Adhikari *et al.* (2024). Among them, *Ageratum houstonianum* was the most frequent species followed by *Bidens pilosa* in both road verge and interior habitats.

In Nepal, there are 227 naturalized plant species including 30 species identified as IAPS (Shrestha *et al.* 2022, 2024). The distribution of alien plants across different vegetation types in Nepal has been studied with a particular focus on invasive alien plants (Siwakoti *et al.* 2016; Paudel *et al.* 2021; Shrestha *et al.* 2021; Dhakal *et al.* 2024; Dhungana *et al.* 2024). However, the literature indicates that IAPS are spreading at an alarming rate in Nepal and the baseline data of alien plants from dominant vegetation types remain insufficient. Therefore, we aimed to document and compare the diversity of vascular plants, particularly focusing on native and alien plants in different forest types of mid-hills of central Nepal.

Materials and methods

STUDY AREA

We conducted this study in three districts *viz*., Dhading, Kaski, and Tanahun, in the mid-hill region of central Nepal (Figure 1). Kaski and Tanahun districts are within Gandaki Province and represent part of Chitwan-Annapurna Landscape (CHAL). Dhading District is located in Bagmati Province. The geographical coordinates of the study area range from 27.87868°N to 28.187280°N latitude and 84.09126°E to 84.91853°E longitude, with elevations spanning 700 m to 1450 m above sea level (asl) (Table 1). The primary vegetation types in the study districts comprise *Shorea robusta* forest, *Schima-Castanopsis* forest, and *Pinus roxburghii* forest.

The study area lies within Nepal's subtropical region, characterized by cold winters and relatively warm summers and spring seasons. The mean temperature in the three study districts does not show significant variation. Ten years (2012–2021) average climatic data indicate that the monthly mean maximum temperature across the three study sites of the three districts peaked in May at 32.55°C, while the lowest was recorded in January at 7.74°C. In Dhading and Tanahun, the monthly mean rainfall was lowest in November (3 mm) and highest in August (385 mm), with a mean annual rainfall of 1415 mm. In Kaski, the monthly mean rainfall was lowest in December (6 mm) and highest in June (635 mm), with a mean annual rainfall of 2969 mm (DHM 2022).

DATA COLLECTION

Vegetation data were collected using the modified Whittaker nested vegetation sampling method (Stohlgren *et al.* 1995). Within the main plot of 0.1 hectares (50 m × 20 m), 13 nested subplots were established: one subplot of 100 m² (20 m × 5 m) positioned at the center, two subplots of 10 m² (5 m × 2 m) located at opposite corners, and ten subplots of 1 m² (2 m × 0.5 m) situated around the periphery. In total, 24 plots were sampled across eight community forests representing three forest types: *Shorea robusta*

Table 1. Habitat characteristics of the study forests[1] in three districts (Dhading, Kaski, and Tanahun).

Habitat characteristics	Dhading			Kaski		Tanahun		
	SR	SC	PR	SR	SC	SR	SC	PR
Sample size (*n*)	3	3	3	3	3	3	3	3
Mean Elevation (m)	762	1067	1454	737	744	994	988	979
Latitude (°N)	27.90	27.89	27.87	28.18	28.85	27.93	27.92	27.94
Longitude (°E)	84.89	84.15	84.91	84.08	84.10	84.42	84.41	84.40
Distance from settlement (m)	200	500	900	500	500	700	300	50
Distance from walking trail (m)	50	400	300	200	200	400	200	30
Fire marks (0–3)[‡]	1	0	3	0	0	0	0	2
Grazing intensity (0–3)[‡]	1	2	1	1	2	1	1	3
Mean canopy cover (%)	72	59	32	58	81	44	40	47
Species diversity (1-D)	0.40	0.47	0.12	0.45	0.52	0.31	0.51	0.12
Total species richness	47	62	56	64	52	51	60	76
Total native species richness (#spp./0.1 ha)	37	48	51	57	39	50	56	63
Total naturalized species richness (#spp./0.1 ha)	5	6	3	2	5	0	1	6
Total invasive species richness (#spp./0.1 ha)	5	8	2	5	8	1	3	7

[1]Forest types: SR – *Shorea robusta*, SC – *Schima-Castanopsis*, PR – *Pinus roxburghii.*

[‡]Fire marks and grazing intensity were recorded on a scale of 0–3 (0: no disturbance; 1: up to 10% vegetation and/or ground affected; 2: 10–30% vegetation and/or ground affected; 3: 30–60% vegetation and/or ground affected).

forest (three replicate plots in each district, *n* = 9), *Schima-Castanopsis* forest (three replicate plots in each district, *n* = 9), and *Pinus roxburghii* forest (three replicate plots in Dhading and Tanahun, *n* = 6). Only six plots were sampled in the *Pinus roxburghii* forest because a comparable forest was not found near the selected study site in the Kaski district. Sample plots were randomly established with a minimum distance of 200 m between plots along the surface to represent all parts of forest as far as possible in the sampled forest. The forests were selected to ensure that, as far as possible, they shared a similar management system, including community protection programs such as grazing bans, forest fire control, restrictions on the collection of fuelwood and fodder, and limited human movement within the forest. Study forests were located at different altitudes (Table 1).

Plot characteristics such as elevation, latitude, longitude, slope, and aspect were documented using a Global Positioning System (GPS) device and a clinometer. Similarly, vegetation characteristics of each plot such as tree diameter at breast height (DBH), canopy cover, disturbance levels, species richness of vascular plants including ferns, and occurrence were recorded. Canopy cover was estimated using the visual estimation method (Daubenmire 1959). Disturbances such as fire and grazing were recorded on a scale of 0–3 (0: no disturbance; 1, 2, and 3 indicate the vegetation and/or ground affected up to 10%, 10–30%, and 30–60%, respectively. Sampling was avoided if the disturbance level was more than 60%.

SPECIES IDENTIFICATION AND CATEGORIZATION

Plant species recorded during the study were collected and prepared as herbarium specimens to confirm their identity. The identification of the specimens was based on various references (e.g., Polunin and Stainton 1984; Malla *et al.* 1986; Siwakoti and Varma 1999; Watson *et al.* 2011; Fraser-Jenkins *et al.* 2015). Some plant specimens were identified through expert consultations, and these were further confirmed by comparing them with the specimens housed at the National Herbarium and Plant Laboratories, Lalitpur, Nepal (KATH), and the Tribhuvan University Central Herbarium, Kirtipur, Kathmandu (TUCH). To differentiate the plant status (whether they were native, invasive, or naturalized), relevant publications (e.g., Press *et al.* 2000; Tiwari *et al.* 2005; Shrestha *et al.* 2022, 2024) and online resources (e.g., EOL 2024; POWO 2024) were used.

VEGETATION ANALYSIS

Cover classes recorded from the plots were converted into mid-values (i.e., 1 = 2.5%, 2 = 15%, 3 = 37.5%, 4 = 62.5%, 5 = 85%, and 6 = 97.5%) (Daubenmire 1959), which were applied to the cover categories of plants (naturalized and invasive alien species) for each forest type. The combined cover of each plant category was obtained by summing the cover values of individual plant species. The basal area, measured at breast height (1.37 m), used to calculate diversity indices of trees, was obtained using the following formula:

$$\text{Tree basal area (BA)} = \frac{\pi(\text{DBH})^2}{4}$$

Where, DBH = diameter of an individual at breast height.

The total basal area of a tree species in each plot was obtained by summing the basal areas (BA) of all individual trees of that species within each vegetation type.

Species diversity was determined as Simpson index (1–D) from tree basal area, a higher value of this index indicates greater diversity. Only tree species diversity indices were calculated.

$$\text{Simpson's original index (D)} = \sum n_i(n_i-1)/N(N-1)$$

$$\text{Simpson index (1–D)} = 1-\{\sum n_i(n_i-1)/N(N-1)\}$$

Where, n_i = total basal area of a tree species in a plot, and N = sum of the basal area of all tree species in a plot.

Additionally, the similarity between the forest types was compared using Sorensen's similarity index (Zobel *et al.* 1987).

Sorensen's similarity index (SSI) = 2C/(A+B) × 100

Where, A = total number of species present in the first forest, B = total number of species in the second forest, and C = number of common species in the two forests.

STATISTICAL ANALYSIS

Species richness among the forest types was compared by using one-way ANOVA. Due to unequal sample sizes, the mean species richness of each plant category was compared. The relationship between canopy cover and species richness of different plant categories was examined through regression analysis. Before performing these analyses, the normality of the data was checked through the Shapiro-Wilk test. All analyses were conducted in Microsoft Excel 2016 and the Statistical Package for Social Sciences (SPSS, version 20).

Results

PLANT DIVERSITY

A total of 312 species of vascular plants were recorded in the study area, representing 233 genera and 86 families. Among these, 274 (87.8%) species were native, 12 (3.9%) were naturalized, 11 (3.5%) were invasive and 1 (0.3%) was casual. Of the total, 14 plant species (4.5%) could not be identified due to the absence of reproductive parts in the voucher specimens but their life form was determined. Regarding life forms, herbaceous plants (including 24 species of Pteridophytes under 17 genera and 12 families) were the most abundant with 179 (57%) species. These were followed by shrubs with 64 species (21%), trees with 44 species (14%), and climbers with 25 species (8%) (Figure 2a). Among the plant families, Fabaceae had the highest number of species (34), followed by Poaceae (25), Asteraceae (19), Lamiaceae (11) and Rubiaceae (10).

The ratio of native plant richness to mean species richness was highest (94%) in the *Shorea robusta* forest. In contrast, the highest ratios for IAPS (7%) and naturalized taxa (5%) were recorded in the *Schima-Castanopsis* forest and *Pinus roxburghii* forest, respectively (Figure 3). Similarly, the total species richness of native and alien plant species was highest in the *Schima-Castanopsis* forest, followed by the *S. robusta* forest and the *P. roxburghii* forest (Table 2); but, the mean species richness of native and alien plant species tended to be high in the *P. roxburghii* forest and low in the *S. robusta* forest (Figure 4). However, the variation in species richness among plant categories in different forest types was statistically insignificant.

DIVERSITY OF NATURALIZED AND INVASIVE ALIEN PLANT SPECIES

A total of 24 alien plant species were recorded in the sample plots combining all study forests, comprising 12 naturalized, 11 invasive, and 1 casual species, representing 11 families and 20 genera. In terms of life forms, the number of herbaceous species was the highest, with 16 (67%) species followed by shrubs with 4 (16%) species, trees with 3 (13%) species, and climbers with 1 (4%) species (Figure 2b). All the recorded naturalized and invasive species originated from tropical regions and Central America. The highest number of species belonged to the family Asteraceae (7 species), followed by Fabaceae (4 species) and Euphorbiaceae (3 species) (Table 3). The total coverage of all invasive alien species was highest in the *P. roxburghii* forest (4.65%) and lowest in the *Schima-Castanopsis* forest (2.5%). Similarly, for naturalized species, the total cover was highest in the *P. roxburghii* forest (0.95%) and lowest in the *Shorea robusta* forest (0.32%) (Table 4).

The tree canopy cover and species richness exhibited insignificant negative relationships across all plant categories, including total species, native species, naturalized species, and invasive species (Figure 5).

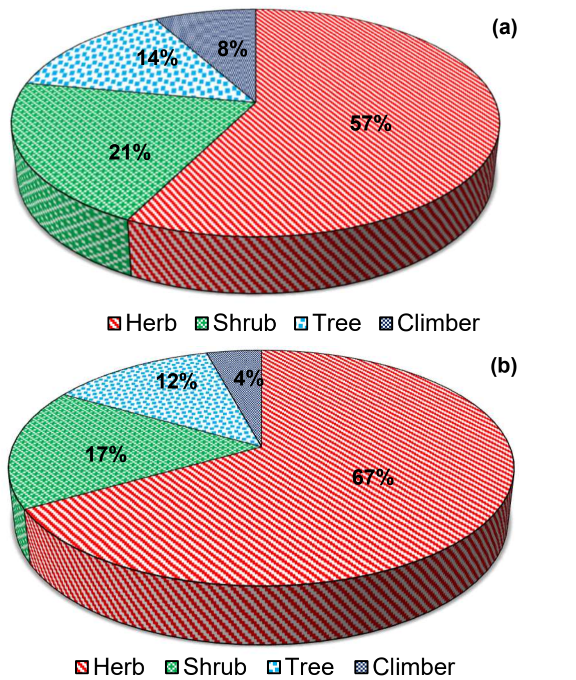

Figure 2. Percentage share of herbs, shrubs, trees, and climbers of (a) total species (n = 312), and (b) alien plant species (n = 24).

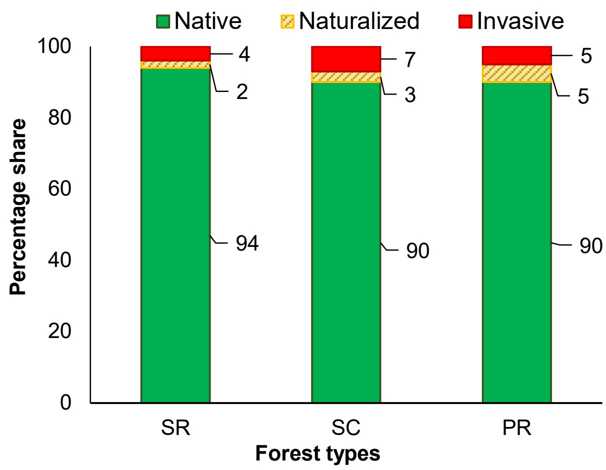

Figure 3. Percentage share of different categories of plants to the mean species richness across forest types; SR = *Shorea robusta* (n = 59), SC = *Schima-Castanopsis* (n = 59), and PR = *Pinus roxburghii* (n = 66).

Table 2. Total species richness of various plant categories across forest types.

Forest types	Sample size (plots)	Native	Naturalized	Invasive	Unidentified	Total
Shorea robusta (SR)	9	155	6	7	6	174
Schima-Castanopsis (SC)	9	186	8	10	10	214
Pinus roxburghii (PR)	6	139	7	7	4	157

Table 3. List of alien (naturalized, invasive, and casual) plant species in the study forests.

SN	Name of alien plant species	Plant category	Family	Presence in the forests ‡	Native range
1	*Ageratina adenophora* (Spreng.) R.M. King and H. Rob.	Invasive	Asteraceae	SRD, SCD, PRD, SCK, SRK, SCT, PRT	Mexico
2	*Ageratum conyzoides* L.	Invasive	Asteraceae	SRD, SCK, SCK, PRT	Central and South America
3	*Ageratum houstonianum* Mill.	Invasive	Asteraceae	SRD, SCD, SCK, PRT, SCT	Mexico and Central America
4	*Axonopus compressus* (Sw.) P. Beauv.	Naturalized	Poaceae	SCD, SCK	Tropical and Subtropical America
5	*Bidens pilosa* L.	Invasive	Asteraceae	SCD, PRD, SCK, PRT	Tropical Americas
6	*Chromolaena odorata* (L.) R.M. King and H. Rob.	Invasive	Asteraceae	SRD, SCD, SCK. SRK, PRT, SCT	Mexico, Central and South America
7	*Crassocephalum crepidioides* (Benth.) S. Moore	Naturalized	Asteraceae	SCK	Africa
8	*Drymaria cordata* Willd. ex Schult. (L.)	Naturalized	Caryophyllaceae	SRD, SCD, PRD, SCK, SRK, PRT, PRT	Africa, North America and S America
9	*Euphorbia heterophylla* L.	Naturalized	Euphorbiaceae	SCK, SRK	North and South America
10	*Euphorbia hirta* L.	Naturalized	Euphorbiaceae	SRD, SCD	North and South America
11	*Evolvulus nummularius* (L.) L.	Naturalized	Convolvulaceae	SRD	North and South America
12	*Ipomoea quamoclit* L.	Naturalized	Convolvulaceae	PRD, SRD	Tropical America
13	*Jatropha curcas* L.	Naturalized	Euphorbiaceae	PRT	Tropical America
14	*Leucaena leucocephala* (Lam.) de wit.	Invasive	Fabaceae	SCD, SCK, SRK	North America
15	*Mimosa pudica* L.	Invasive	Fabaceae	SCD, SCK, SRK,	Mexico to South America
16	*Oxalis corniculata* L.	Naturalized	Oxalidaceae	PRD, PRT	Mexico to Venezuela, Peru and Caribbean
17	*Oxalis latifolia* Kunth	Invasive	Oxalidaceae	SCD	Central and South America
18	*Peperomia pellucida* (L.) Kunth	Naturalized	Piperaceae	SCD, PRT	Tropical Africa
19	*Psidium guajava* L.	Naturalized	Myrtaceae	SRD, SCD, SCK	Tropical and Subtropical America
20	*Senna occidentalis* (L.) Link	Invasive	Fabaceae	SCK	Tropical Americas
21	*Senna tora* (L.) Roxb.	Invasive	Fabaceae	SCK	South America
22	*Spermacoce alata* Aubl.	Invasive	Rubiaceae	SRD, SCD, SCK, SRK, PRT, SRK	West Indies and Tropical America
23	*Synedrella nodiflora* (L.) Gaertn.	Naturalized	Asteraceae	SCD, PRT, SCT	Tropical and Subtropical America
24	*Tectona grandis* L. f.	Casual	Lamiaceae	SRD	India to Indo-China

‡PRD = *Pinus roxburghii* forest in Dhading, PRT= *Pinus roxburghii* forest in Tanahun, SCD = *Schima-Castanopsis* forest in Dhading, SCK = *Schima-Castanopsis* forest in Kaski, SCT = *Schima-Castanopsis* forest in Tanahun, SRD = *Shorea robusta* forest in Dhading, SRK = *Shorea robusta* forest in Kaski, SRT = *Shorea robusta* forest in Tanahun.

SIMILARITY AND DIVERSITY INDICES

For total plant species, the Sorensen's similarity index was highest between the *Shorea robusta* forests of Kaski and Tanahun (52%) and between the *Pinus roxburghii* forest of Tanahun and the *Schima-Castanopsis* forest of Dhading (52%). The similarity index was lowest between the *Shorea robusta* forest of Kaski and the *Pinus roxburghii* forest of Dhading (25%) (Table 5). The *Schima-Castanopsis* forest of Kaski showed the highest Simpson index (0.52), while the lowest value (0.12) was observed in *Pinus roxburghii* forests in Dhading and Tanahun (Table 1).

Discussion

Forest vegetation plays a major role in shaping plant diversity due to its complex biotic and abiotic characteristics. Our study highlights variations in plant species diversity among different forest types in the mid-hills of central Nepal, though these

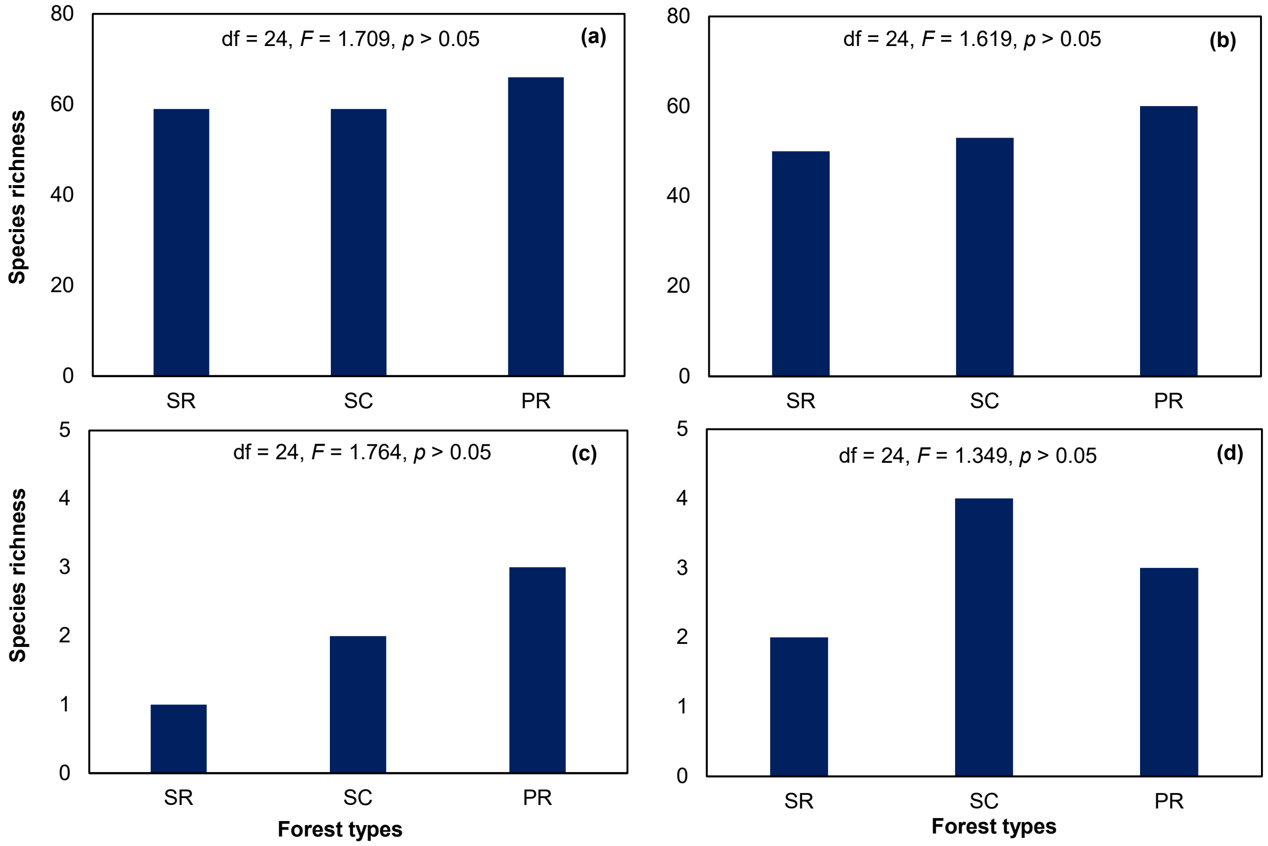

Figure 4. Variation in mean species richness among forest types: (a) total species, (b) native species, (c) naturalized species, and (d) invasive species. The p-values are based on one-way ANOVA. SR = *Shorea robusta* forest, SC = *Schima-Castanopsis* forest, PR = *Pinus roxburghii* forest.

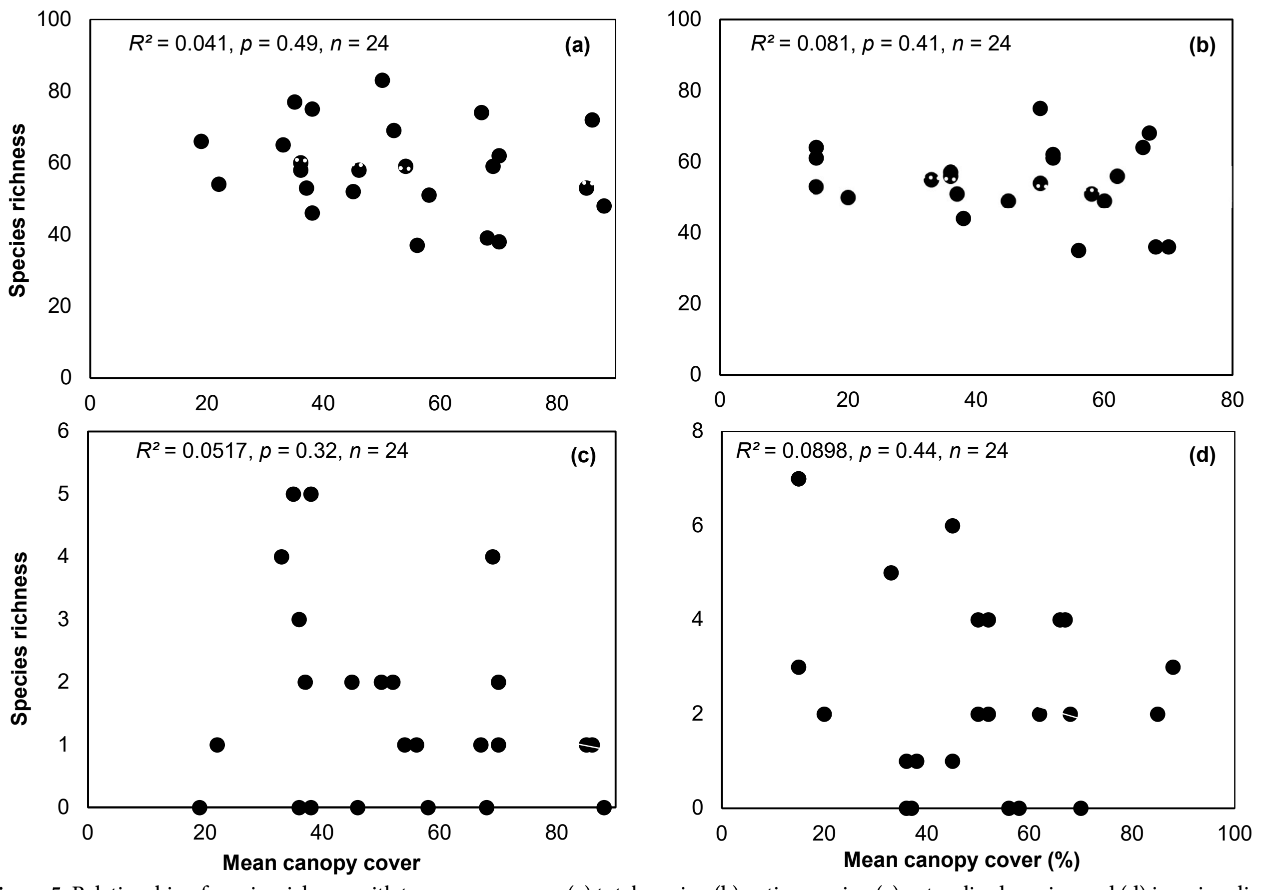

Figure 5. Relationship of species richness with tree canopy cover: (a) total species, (b) native species, (c) naturalized species, and (d) invasive alien plant species. Total sample plot, n = 24.

Table 4. Mean cover value (%, mean ± SD) of invasive alien plant species and naturalized plant species across forest types of three districts (mean cover values >5% are in boldface).

Plant species	Forest types		
	Shorea robusta	*Schima-Castanopsis*	*Pinus roxburghii*
Ageratina adenophora	1.28 ± 1.28	**7.93 ± 11.87**	**11.65 ± 13.82**
Ageratum conyzoides	0.21 ± 0.64	0.48 ± 1.28	2.25 ± 3.92
Ageratum houstonianum	0.32 ± 0.68	1.2 ± 1.41	2.89 ± 5.4
Bidens pilosa	0.64 ± 1.93	1.22 ± 2.56	3.21 ± 5.53
Chromolaena odorata	3.63 ± 8.94	**5.52 ± 7.47**	4.17 ± 7.54
Leucaena leucocephala	0.64±0.21	0.64±0.21	0
Mimosa pudica	0.85 ± 1.41	0.24 ± 0.64	0.32 ± 0.78
Oxalis latifolia	0.21 ± 0.64	0.24 ± 0.64	0
Senna occidentalis	3.63 ± 8.94	0	0
Senna tora	0.1 ± 0.33	0	0
Spermacoce alata	1.07 ± 1.89	0.96 ± 1.7	**5.46 ± 9.49**
Invasive alien species (mean)	2.50 ± 1.14	2.52 ± 1.67	4.65 ± 2.99
Naturalized plant species (mean)	0.37 ± 0.81	0.32 ± 0.57	0.95 ± 2.64

Table 5. Sorensen's similarity index (%) of the study forests.

Forest types‡	PRD	SCD	SCK	SRD	SRK
PRT	46	52	44	43	40
SCK	27	35	-	38	44
SCT	39	48	40	44	46
SRK	25	42	45	41	-
SRT	37	32	30	47	52

‡PRD = *Pinus roxburghii* forest in Dhading, PRT= *Pinus roxburghii* forest in Tanahun, SCD = *Schima-Castanopsis* forest in Dhading, SCK = *Schima-Castanopsis* forest in Kaski, SCT = *Schima-Castanopsis* forest in Tanahun, SRD = *Shorea robusta* forest in Dhading, SRK = *Shorea robusta* forest in Kaski, SRT = *Shorea robusta* forest in Tanahun.

relationships were not statistically significant. Climatic similarities among the study districts and forest types likely contributed to their comparable species composition. We documented a total of 312 vascular plant species belonging to 86 families, representing approximately 5% of Nepal's vascular flora (Shrestha *et al.* 2022). Notably, the families Poaceae and Fabaceae had the highest number of genera and species, aligning with findings from previous studies (Pandey 2007; Rajbhandari 2014; Joshi *et al.* 2023).

The abundance of herbaceous species varied across land use types, predominantly high in open spaces and areas with low canopy cover. Open and low canopy areas offer optimal conditions for herbaceous species due to increased light availability, reduced competition, and favorable microclimates (Arya and Ram 2013). In our study, tree canopy cover inhibited species richness, but contrary to our expectations, the relationship was insignificant. This may be due to the limited sample size in high-canopy sites or the complex interactions between canopy density, light availability, and resource competition. The relatively high species richness observed in *Pinus roxburghii* forests could be attributed to the forest's intermediate canopy cover, which balances light availability and competition, creating favorable conditions for understory growth. However, the relatively low richness in some plots may be due to the acidic soils and allelopathic effects (probably benzoic acid) commonly associated with pine species, which can inhibit the growth of certain understory plants (Kil and Yim 1983; Garg *et al.* 2022; Crandall *et al.* 2024).

The distribution of alien plant species, both naturalized and invasive, varied across land-use types due to anthropogenic factors and allelopathic effects. For example, *Schima-Castanopsis* and *Pinus roxburghii* forests in the study area had the highest number of alien plant species, influenced by human activities and ecological impacts (Sapkota 2012). In contrast, *Shorea robusta* forests exhibited fewer alien plant species, likely due to reduced disturbances, higher tree canopy cover, and greater distance from human settlements (Thomas *et al.* 1999; Sapkota 2012; Seipel *et al.* 2012). Our study revealed that three invasive alien plant species (IAPS), *Ageratina adenophora*, *Chromolaena odorata*, and *Spermacoce alata*, were invading all three forest types, with the highest cover. Therefore, these species should be prioritized for targeted management in the mid-hills of central Nepal.

Notably, invasive species commonly associated with agroecosystems, such as *Mimosa pudica* and *Oxalis latifolia*, were observed in forested areas. This could be attributed to seed dispersal mechanisms, soil disturbances, and nutrient influx from adjacent agricultural lands. The presence of these species in forests poses a potential threat to native biodiversity and forest ecosystem functioning. If not managed, the invasion of such species may lead to alterations in nutrient cycling, suppression of native species, and long-term changes in forest structure and composition (Simberloff 2009; Vila *et al.* 2011).

Sorenson's similarity index revealed prominent patterns across different forest types. For instance, *Shorea robusta* forests in the Kaski and Tanahun districts, *Pinus roxburghii* forests in Tanahun, and *Schima-Castanopsis* forests in the Dhading district shared a 52% similarity in vascular plant species, likely due to comparable disturbances and elevations. In contrast, *Shorea robusta* forests in Kaski and *Pinus roxburghii* in Dhading exhibited the lowest similarity index (25%), driven by abiotic factors such as climate, moisture levels, and geographical distance. Proximity to roads and human activities also influenced these variations as highlighted by Seipel *et al.* (2012).

Diversity indices, such as the Simpson index, are important vegetation parameters for assessing species richness, evenness, and the overall structure of plant communities. In the present study, the highest Simpson index (1-D) was observed in *Schima–Castanopsis* forests in the Kaski District, while the lowest value was recorded in *Pinus roxburghii* forests in the Dhading and Tanahun districts. Species composition and tree diversity tend to be higher in government-managed forests than in community-managed forests, likely due to selective thinning activities and other management practices (Baral and Katzensteiner 2009). Among the forest types, broadleaved species-dominated forests have been reported to exhibit higher diversity indices (Ram *et al.* 2004), which is consistent with our findings. This may be due to lower soil acidity and reduced allelopathic effects in broadleaved forests compared to pine forests.

In summary, this study explored the role of forest types in shaping plant diversity and composition in the mid-hills of central Nepal. We also assessed the threats posed by IAPS in terms of coverage across the forest types and examined how canopy cover and disturbance levels affect plant diversity in these regions. The increasing presence of IAPS in these forests threatens the integrity of native plant communities and ecosystems. The findings of this research can serve as baseline data for developing effective forest management strategies for these important forest types.

Conclusions

Forest type and composition play a major role in shaping native and alien plant diversity in the mid-hills of central Nepal. Our results show that vascular plant diversity varies among forest types, with high native plant diversity in *Pinus roxburghii* forests and high alien plant diversity in *Schima-Castanopsis* forests. The study concludes that the composition of mid-hill community-managed forests is changing, with an increasing number of alien plant species, particularly invasive ones, invading and replacing the native plants in the forest ecosystem. The greater number and cover of invasive alien plant species (IAPS) recorded in *Schima-Castanopsis* and *Pinus roxburghii* forests suggest that these important forest types in the mid-hills are under significant threat from plant invasion. Therefore, our study emphasizes the need for effective forest conservation and management strategies, such as increasing forest canopy cover and maintaining mature forest stands with minimal disturbances, to naturally resist the establishment and spread of alien plants. However, further studies with large-scale sampling on various aspects of plant invasion and the physicochemical parameters of forests are needed to validate these findings and support the development of appropriate conservation and management policies.

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