frontiers | Frontiers in Forests and Global Change

TYPE Original Research
PUBLISHED 23 January 2025
DOI 10.3389/ffgc.2024.1388607

Check for updates

OPEN ACCESS

EDITED BY
Patrick O. Waeber,
ETH Zürich, Switzerland

REVIEWED BY
Muhammad Waheed,
University of Okara, Pakistan
Rajendra Mohan Panda,
University of South Florida, United States
Sumit Chakravarty,
Uttar Banga Krishi Viswavidyalaya, India

*CORRESPONDENCE
Hamayun Shaheen
✉ shaheenecologist@gmail.com

RECEIVED 20 February 2024
ACCEPTED 14 August 2024
PUBLISHED 23 January 2025

CITATION
Irfan U, Shaheen H, Manzoor M, Nasar S, Khan RWA, Gillani SW, Alrefaei AF, Attique A, Kamal A, Razak SA and Riaz MT (2025) Population structure, floral diversity, habitat geography, and conservation status of Himalayan horse chestnut (*Aesculus indica*) in western Himalayan moist temperate forest ecosystems of Kashmir region. *Front. For. Glob. Change* 7:1388607. doi: 10.3389/ffgc.2024.1388607

COPYRIGHT
© 2025 Irfan, Shaheen, Manzoor, Nasar, Khan, Gillani, Alrefaei, Attique, Kamal, Razak and Riaz. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Population structure, floral diversity, habitat geography, and conservation status of Himalayan horse chestnut (*Aesculus indica*) in western Himalayan moist temperate forest ecosystems of Kashmir region

Urwa Irfan[1], Hamayun Shaheen[1]*, Muhammad Manzoor[1,2], Sidra Nasar[1], Raja Waqar Ahmed Khan[1], Syed Waseem Gillani[1,2], Abdulwahed Fahad Alrefaei[3], Arbaz Attique[1], Asif Kamal[4], Sarah Abdul Razak[5] and Malik Talha Riaz[6]

[1]Department of Botany, University of Azad Jammu & Kashmir, Muzaffarabad, Pakistan, [2]Department of Plant Science Quaid-i-Azam University, Islamabad, Pakistan, [3]Department of Zoology, College of Science, King Saud University, Riyadh, Saudi Arabia, [4]Key Laboratory of Tobacco Pest Monitoring, Controlling, and Integrated Management, Tobacco Research Institute of the Chinese Academy of Agricultural Sciences, Qingdao, China, [5]Institute of Biological Sciences, Faculty of Science, Universiti Malaya, Kuala Lumpur, Malaysia, [6]International Environmental Doctoral School, University of Silesia, Katowice, Poland

This study provides a comprehensive assessment of the population structure, floral diversity, habitat geography, phytosociology, threats, and conservation status of *Aesculus indica* in the western Himalayan region of Kashmir. This study was designed to investigate distribution patterns, community structure, floristic diversity, and phytosociological attributes of *A. indica* forests, as well as evaluate the habitat geography of species by using GIS analysis. Primary vegetation data and geographic features were collected via systematic quadrat-based sampling from 14 sites in the moist temperate ecosystem of Kashmir, ranging in elevation from 1,400 to 2,800 m. Population structure analysis revealed an average density of 435.85 stems/ha for *A. indica*, with a significant variation ranging from 220 to 1,100 stems/ha. The species exhibited a high basal cover of 356.33 cm, emphasizing its significant role in the canopy structure of Himalayan forests. The study identified *A. indica* as a keystone species supporting a diverse floral community comprised of 168 plant species from 51 families. Dominant families, including Asteraceae, Lamiaceae, Rosaceae, Poaceae, and Polygonaceae, contributed to more than 50% of the total recorded plant species. Phytosociological investigations revealed *A. indica* to be the dominant species with the highest importance value index (IVI) of 48.81, indicating its ecological significance in temperate forest ecosystems. The species exhibited a preference for north-facing aspects and an altitudinal range of 1,400–2,800 m, which constitute the most suitable habitats for *A. indica*. However, the study identified significant anthropogenic disturbances, including deforestation, overgrazing, and forest land encroachment, as major threats to *A. indica* populations in the study area. The deforestation intensity averaged 135 stumps/ha, with some sites exceeding 300 stumps/ha, indicating unsustainable fuelwood consumption patterns and habitat degradation. Overgrazing and trampling were also found to be major threats to *A. indica* seedlings, affecting the species' regeneration potential. Conservation strategies should prioritize the protection and restoration of *A. indica* habitats, especially the upper temperate forest zones with north-facing slopes, to ensure the long-term sustainability of the species. It is recommended to formulate effective conservation measures such as promoting sustainable forest practices, controlling invasive species, restoring degraded habitats, controlled grazing practices, community-based conservation initiatives, sustainable harvesting policies, educating local communities, and promoting alternative livelihoods that support local communities to ensure the preservation of *A. indica* populations as well as ecosystem health. The study emphasizes the urgent need for effective conservation measures to safeguard *A. indica* and its associated floral diversity in the western Himalayan region.

KEYWORDS

diversity, Himalayan chestnut, population structure, western Himalayas, moist temperate forest

1 Introduction

Himalayan horse chestnut *(Aesculus indica)* is a deciduous broad-leaved woody tree species distributed in temperate Himalayan forests (Verma et al., 2021). This perennial monoecious tree belongs to the family Sapindaceae, growing up to 30 meters in height and having white-pigmented, yellow splashy flowers and a round canopy. *A. indica* is distributed across the Himalayan region, ranging from Afghanistan in the west to Bhutan in the east, including areas of North Pakistan (Rafiq et al., 2016). Globally, the genus *Aesculus* has approximately 13 species distributed in temperate regions, whereas only 1 species, i.e., *A. indica*, is reported from the western Himalayan Kashmir region (Nasir, 1991). *A. indica* grows abundantly at varying elevations between 1,200 and 2,800 m. It forms healthy populations well-adapted at north-facing mountain slopes characterized by higher moisture availability and low intensity of solar insulation (Zhang et al., 2010). *A. indica* favors a cool, humid temperate climate with a temperature range of 15 to 35°C and an optimum annual precipitation of approximately 900 to 1,200 mm. It prefers deep, siliceous, and free-draining nutrient-enriched soil with significant levels of organic matter (Syed et al., 2016).

In the temperate forests of the Himalayan region, *A. indica* is a vital component of the ecosystem, performing various functions and growing alongside other broad-leaf and coniferous plants (Khan S. M. et al., 2012; Khan W. et al., 2012). *A. indica* can live for 100 years with an average DBH size of 300 cm. Its large compound leaves have 5–7 pointed leaves and oblong leaflets and measure 10–20 cm in length and 2–7 cm in breadth. The flowers are hermaphrodite, start blooming from June to July with a showy appearance, and occur in white and yellow variations (Syed et al., 2016). *A. indica* populations were recorded at altitudes of 1820–2280 m in the Himalayan region. These populations exhibited a density of 650 Ind/ha, a total basal area of 68.6 m^2/ha, and 186 dominant IVI values (Pant and Samant, 2012). As a keystone umbrella species on north-facing slopes, its canopy provides a habitat that supports the survival of various allied herb and shrub species (Bhatt and Tomar, 2002). Due to severe climatic conditions in the Himalayan region, various mountain communities heavily rely on this plant due to its availability and greater heating capacity as compared to other coniferous species as fuelwood to meet their daily energy demands (Rana et al., 2019). In the upper Himalayan Forest, some species, such as *Acer* sp. and *Prunus* sp. that easily grow at higher elevations have the potential to replace this species. *A. indica* fuelwood consumption patterns exhibited 0.234 kg/day/capita and 5 stumps/ha in different Himalayan regions (Lal and Samant, 2020). Seeds and leaves of the Himalayan horse chestnut are very significant in the traditional healthcare system for the treatment of various diseases of humans and animals, and they are culturally significant as seeds used in many traditional recipes (Kaur et al., 2011: Majeed et al., 2010).

Population studies in the Himalayan region reveal that *A indica* predominantly occurs in mixed broad-leaved forests, associated with other tree species such as *Pinus, Quercus, Cedrus,* and *Rhododendron* spp. (Alam et al., 2023). The age structure of *A. indica* populations in Himalayan forests typically shows an inverse J-shaped or bell-shaped curve, indicating a relatively stable population with ongoing recruitment. Young individuals are generally abundant, while older are less common individuals, suggesting a continuous but slow regeneration process (Das et al., 2021). The average tree density values of the species range from 50 to 70/ha with a basal cover of 25–35 m^2/ha in the Himalayan temperate forests (Jazib, 2023). The size-class distribution of *A. indica* populations in Himalayan forests is skewed toward smaller size classes, with seedlings and saplings dominating the populations with densities of 300–450 seedlings/ha, whereas mature trees are relatively scarce. This skewed size-class distribution reflects the slow growth rate and long life span of the species (Pandey et al., 2023). The populations of *A. indica* in Himalayan forests are threatened by various anthropogenic activities, including deforestation, overgrazing, and habitat fragmentation, resulting in a decline in the species' natural regeneration capacity and diversity (Singh and Mittal, 2018). Climate change poses a significant threat to *A. indica* populations in the Himalayan region, where the changes in temperature and precipitation patterns are likely to affect the species' distribution, phenology, and reproductive success (Tewari et al., 2018). Despite the ecological and economic significance of *A. indica*, there is a notable knowledge gap in understanding the population ecology and demography of the species in the Himalayas. Limited studies have been conducted on the population structure, size distribution, and understanding of the population dynamics and regeneration potential

10.3389/ffgc.2024.1388607

of *A. indica*. Addressing the existing knowledge gap in the population ecology, and conservation status of *A. indica* can contribute to the sustainable management and conservation of this valuable species in the Himalayan region. The hypothesis of the study was how the population structure of *A. indica* varies across the elevational gradient in the western Himalayan region of Kashmir, key factors influencing floral diversity in *A. indica* habitats, current conservation status, and what strategies will be effective for its long-term viability in the region. The specific objectives of the study include investigating the population structure, spatial and distribution pattern, record associated floral wealth, quantifying deforestation and grazing intensity, and assessing the regeneration, relative abundance, and cover of *A. indica* in the western Himalayan state of Kashmir, along with evaluating its fuelwood properties.

2 Materials and methods

2.1 Study area

The current study was conducted in the moist temperate forest ecosystems in the Western Himalayan state of Azad Jammu and Kashmir, which falls between 34.21° latitude and 73.28° longitude in North-East Pakistan (Manzoor et al., 2023). The state's terrain is hilly and rugged, with deep valleys carved out by numerous streams and rivers and forested mountain sides. Due to its significant elevational gradient, which reaches from 488 m in the southern half of the Punjab Plains to 6,212 m in the north, AJK is a regional biodiversity hotspot, supporting a broad variety of agroclimatic conditions and habitats. This zone is the typical monsoonal type and receives monsoon rainfall due to Himalayan mountainous systems in mostly July to September, with more than 70% more monsoon rainfall as compared to neighboring areas of Pakistan. The average minimum and maximum temperature recorded in July were 15°C to 35°C and in January was −10°C to 22°C. The average annual precipitation in the region is 1,511 mm. The fluctuating relative humidity recorded ranges from 58 to 84%, respectively. The snowfall period is from November to March, with up to 4 meters snow recorded in upper regions and 3 to 6 feet recorded in lower areas of the region. Due to heavy snowfall, winters are cold and prolonged (Shaheen et al., 2024). The main vegetation of the study area includes tree layer (*Abies pindrow*, *A. indica*, *Taxus wallichiana*, *Pinus wallichiana*, *Picea smithiana*, and *Acer caesium*), shrub layer (*Viburnum grandiflorum*, *Parrotiopsis jacquemontiana*, *Indigofera heterantha,* and *Rubus fruticosus*), and herb layer (*Fragaria nubicola*, *Oxalis corniculata*, *Dryopteris stewartii*, *Podophyllum hexandrum*, *Asplenium trichomanes*, and *Plantago major*).

2.2 Vegetation sampling

A total of 14 broad-leaved and mixed-moisture temperate forest sites were sampled in the study area. To find the *A. indica* populations, a preliminary survey was conducted in the moist temperate forests of the Kashmir region prior to the sampling process. It was followed by selecting 14 moist temperate forest sites in three districts, including Neelum, Muzaffarabad, and Hattian, to ensure the species' geographic range was covered (Figure 1). The area was surveyed during June to September 2021–2022. A total of 20 quadrats (each of 20 m x 20 m) were taken at each of the 14 study sites for the sampling of vegetation by using the systematic quadrat method. Primary phytosociological parameters of vegetation data comprising density, frequency, and cover were recorded at all sampling sites for *A. indica* in relation to the associated plant species, following standard protocols (Cox and Larson, 1993). All the associated plant species found in the *A. indica* populations were recorded and were identified following Flora of Pakistan, and The Plant List (TPL) (Nasir and Ali, 1980–1989).

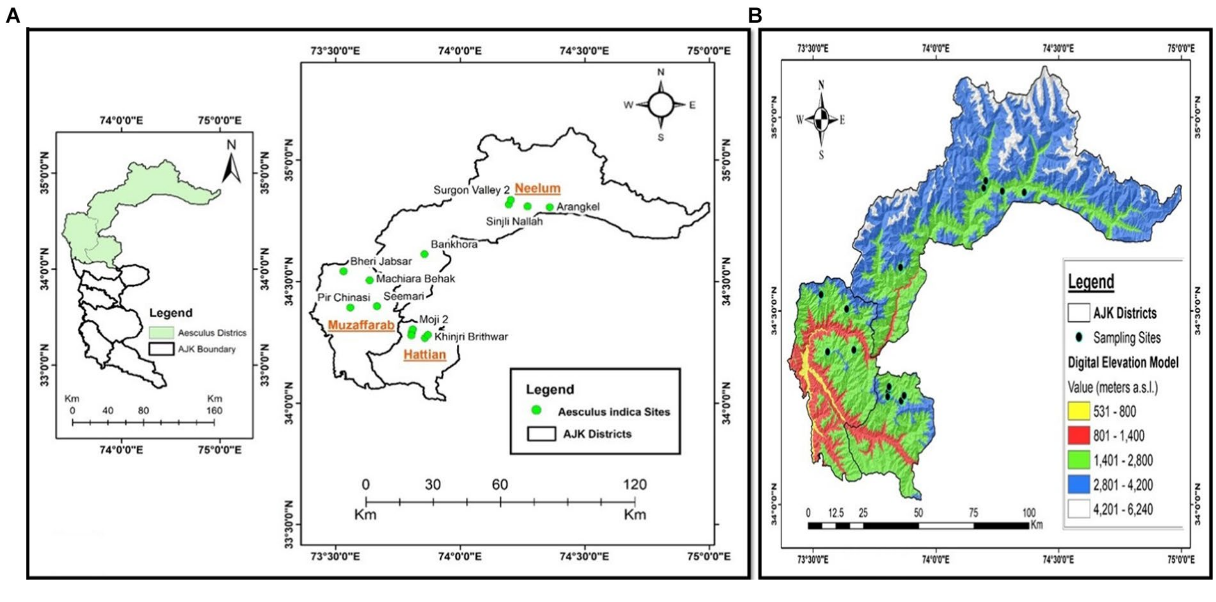

FIGURE 1
(A) Map of study area and location of the sampling sites in the state of Azad Jammu and Kashmir and **(B)** digital elevation model shows the altitudinal distribution of *Aesculus indica* in AJK.

The biological spectrum of the recorded flora including life form and leaf size, was determined following (Raunkiaer, 1934). Geographical coordinates such as altitude, longitude, and latitude of selected study sites were recorded by using the Global Positioning System (German GPS, Model Oregon 700). ArcGIS 10.8.2 was utilized for geospatial analysis of *A. indica* populations in AJK. This includes analyzing the spatial distribution of the *A. indica* populations along with creating digital elevation model (DEM) maps to reveal the altitudinal distribution of the species in the region. GPS data from each of the sampling plots were used to create the map of *A. indica* sampling locations. PALSAR/ALOS data with a resolution of 12.5 m were used to create the DEM.

2.3 Fuelwood properties

Fuelwood properties of *A. indica*, including moisture contents, ash contents, bulk density, volatile matter, calorific values, and fuelwood value index (FVI), were investigated to analyze the combustion characteristics of this woody plant species following standard protocols (Bhatt and Tomar, 2002). The evaluation of the calorific value of wood based on per unit was investigated by 2 gm oven-dried powdered wood samples in three replicates for each sample. For the determination of calorific value, an oxygen bomb calorimeter was used (Bhatt and Todaria, 1990). The FVI was calculated by the following method (Purohit and Nautiyal, 1987).

2.4 Diversity indices

Ecological attributes of *A. indica*-dominated forest communities were calculated using diversity indices. IVI was calculated for all recorded plant species as IVI = Relative density (RD) + relative frequency (RF) + relative cover (RC). Simpson's diversity index was calculated as $D = \sum ni\ (ni\text{-}1)/N\ (N\text{-}1)$ (Simpson, 1949), where ni = number of individuals of a single species and N = number of individuals of all species in a community. Shannon's diversity index was calculated as $H' = -\sum pi \log pi$ (Shannon, 1949), where pi = ni/N; ni = number of individuals of a species and N = number of individuals of all species. Species evenness was calculated as $J' = H'/\ln S$ (Pielou, 1969), where H′ = Shannon diversity index and S = Number of species. Species richness was calculated as $D = S/\sqrt{N}$ (Menhinick, 1964), where S = total number of species and N = number of individuals of all species. The community maturity index was calculated as MI = F/S (Pichi-Sermolli, 1948), where F = Frequency of all species and S = total number of species.

2.5 Data analysis

The species abundance data matrix was analyzed using multivariate ordination techniques such as Cluster analysis and Pearson's correlation test. Principal component analysis (PCA) was also applied to the species dataset to reveal the pattern of dominance and relative abundance of the species in the investigated *A. indica* populations. Ordination analysis was carried out using PAST Software (Version 4.05) and Origin Software, to find the notable patterns and correlations between structural and diversity parameters of the *A. indica* populations. Linear bivariate correlation models were used to analyze community attributes with investigated variables. This allowed for observing changes in the indices over time. We used Origin Pro version 10 to conduct the linear regression model.

2.6 Quantification of disturbances

Deforestation intensity in the *A. indica* populations was determined by counting the number of stumps/ha. Habitat disturbances, including Grazing intensity and soil erosion, were recorded at all the investigated sites by using visual indicators such as animal droppings, hoof marks, trampling, and browsed vegetation. The indicators were used to classify the studied sites into moderate, low, and overgrazed categories. Furthermore, soil erosion intensity classes were determined as high, moderate, and low-eroded categories (Shaheen et al., 2011).

3 Results

3.1 Population structure of *Aesculus indica*

The investigated *A. indica* populations showed an average tree density of 435.85 stem/ha, with a maximum value of 1,100 stem/ha at the Pirchanasi site and a minimum of 220 ha at the Bankhora site. An average basal cover value of 356.33 cm was determined for *A. indica* in the region, varying between a maximum of 1574.5 cm and a minimum of 52.5 cm (Table 1). The populations exhibited a regeneration value varying between 60 seedlings/ha and 340 seedlings/ha averaging, at 174.28 /ha. A deforestation intensity of 135.4 stumps/ha was recorded from the study area.

DEM revealed *that A. indica* populations were distributed in an altitudinal range of 1,400 m to 2,800 m in the study Most of the *A. indica* populations (64.29%) were distributed between the elevational range of 2,350 m and 2,850 m, which mainly comprises the upper temperate forest. Three sites (21.43%) were recorded in the 2050 m and 2,100 m ranges, whereas only two sites (14.29%) were recorded below 2000 m elevation in the lower temperate zone.

3.2 Associated flora in *Aesculus indica-dominated* populations

The floristic inventory revealed that the associated flora of *A. indica*-dominated forests comprised 168 species belonging to 131 Genera and 51 families. The vegetation communities recorded from Aesculus habitats were largely captivated by herbaceous flora, making a bulk of 89%. *A. indica* was recorded as the most dominant with an IVI value of 48.81, along with closely associated co-dominant species including *Viburnum grandiflorum* (23.35), *Fragaria nubicola* (12.19), *Abies pindrow* (11.57), *Oxalis corniculata* (11.06), and *Dryopteris stewartii* (8.81), respectively.

3.3 Biological spectrum of studied flora

Results of the biological spectrum showed that Microphylls were the dominant leaf size group in the study area, having 66 plant species

TABLE 1 Phytosociological attributes of *Aesculus indica*-dominated forest communities.

Sr. No.	Site names	Altitude (m)	Number of species	Species richness	Species evenness	Species maturity	Simpson diversity	Shannon diversity	Stem density	Basal cover
1.	Surgon valley 2	1960	34	2.46	0.90	47.60	0.95	3.16	220	61.28
2.	Surgon valley 1	2,100	47	3.21	0.92	42.00	0.97	3.55	360	63.65
3.	Moji 1	2095	35	2.61	0.94	48.60	0.96	3.33	420	195.18
4.	Arangkel	2,426	35	2.36	0.94	48.90	0.96	3.34	300	234.35
5.	Bankhora	2,379	26	1.99	0.89	48.70	0.94	2.91	220	52.5
6.	Brithwar Beli	2,807	57	4.13	0.90	31.50	0.97	3.64	240	68.57
7.	Moji 2	2,468	26	2.18	0.94	54.00	0.95	3.06	440	316.43
8.	Pir Chinasi	2,765	47	4.38	0.41	45.20	0.91	1.57	1,100	1574.89
9.	Sinjli Nallah	1965	35	2.65	0.91	43.50	0.95	3.25	520	101.39
10.	Khinjri Brithwar	2,354	30	2.39	0.86	48.80	0.93	2.93	260	161.51
11.	Daokhan	2,738	28	2.54	0.94	48.80	0.94	3.07	360	185.8
12.	Bheri Jabsar	2,536	40	3.66	0.28	47.10	0.94	1.02	1,037	1225.1
13.	Seemari	2,534	25	2.23	0.95	53.70	0.95	3.05	300	110.36
14.	Machiara Behak	2060	35	3.67	0.75	50.00	0.81	2.67	325	637.73

with a contribution of 39%, followed by Mesophylls (23%) and Nanophylls (19%) as co-dominant clusters. Leptophylls and Megaphylls comprise 11 and 5% as the least concerned leaf spectra, respectively (Figure 2A). Hemicryptophytes were the dominant life form, with 60 species constituting 38% of the flora, followed bytherophytes (31%) and geophytes (17%). Nanophanerophytes were represented with a share of 0.05%, whereas Megaphanerophytes (0.04%), Mesophanerophytes (0.2%), and Lianas (0.01%) were the least frequent life form classes (Figure 2B).

3.4 Phytosociological attributes

Phytosociological attributes of *Aesculus-dominated* vegetation communities showed significant levels of diversity and richness. The recorded plant communities were characterized by an average species number of 35.71 along with an average Simpson's diversity index of 0.94, fluctuating between 0.97 and 0.81. Average Shannon's diversity index of 2.90 ranges from 3.64 to 1.02, showing wide variations. The determined values of species richness, species evenness, and maturity index were averaged at 2.89, 0.82, and 47.03, respectively (Table 1).

3.5 Fuelwood combustion's characteristics

The average moisture contents determined in the wood of *A. indica* was recorded as 14.5%, average ash contents were recorded at 9%, and the average volatile matter was recorded as 23.8%. Results revealed that the highest values of ash contents (17%) and volatile matter (40%) were found in the bark of *A. indica* while moisture contents (21.4%) were present in greater amounts in the branch. Apart from this, *A. indica* exhibited a calorific value of 30.81 MJ/kg, while the calculated FVI of *A. indica* was 0.124, respectively.

3.6 Habitat disturbances in the *Aesculus indica* populations

Significant deforestation pressure was recorded in the *A. indica* forest stands, with an average value of 135 stumps/ha ranging from a maximum of 435 stumps/ha to a minimum of 41 stumps/ha. Approximately 71% of *A. indica* populations (10 out of 14) were recorded experiencing moderate to high grazing and trampling pressure, whereas only 4 populations showed non-significant grazing pressure. Six population sites (43%) were recorded with intense soil erosion intensity, followed by four sites each with moderate and low soil erosion.

3.7 Multivariate analysis

The PCA was applied to the species data matrix, representing 70% variance in its four axes. PCA illustration identified *A. indica* as the most dominant species and placed it separately on the x-axis. PCA biplot identified the dominant and most abundant plant taxa within the species dataset and placed them distinctly along the x-axis. *Viburnum grandiflorum, Oxalis corniculata, Abies pindrow, Fragaria nubicola, Viola odorata, and Poa alpina*, were identified as the most abundant and and closely associated species recorded from the *A. indica* populations. A second bunch of co-dominant species was also identified by the PCA analysis and placed along the y-axis. These species include *Dryopteris stewartii, Indigofera heterantha, Prunus cornuta, Podophyllum hexandrum, Skimmia laureola, Chenopodium album, Asplenium trichomanes, Strobilanthus glutinosus, and Plantago major*. The majority of the recorded herbaceous species were characterized by infrequent sporadic distribution and were not significantly associated with any of the sites. These species formed a clump in the center of the PCA biplot, indicating their indifferent behavior (Figure 3).

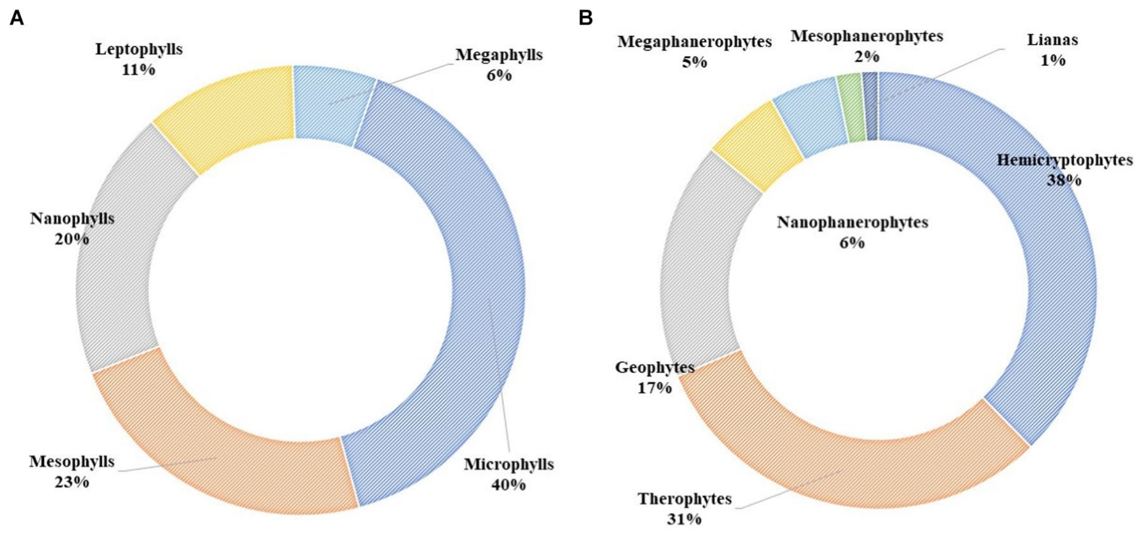

FIGURE 2
(A) Leaf size classes **(B)** life form recorded for *Aesculus-associated* flora of western Himalayan moist temperate forests.

Linear ordination analysis simplifies complex interactions between variables, providing useful insights into ecological datasets such as vegetation data from mountain regions. Linear ordination analysis offers an organized way to comprehend and demonstrate environmental as well as vegetation pattern gradients, which helps in managing and interpreting forest ecosystems. Pearson's correlation analysis of diversity index data and structural attributes revealed a significant ($p < 0.05$) strong positive correlation between the number of species with richness, species evenness with Shannon diversity, and stem density with basal cover. A strong negative correlation ($p < 0.05$) was recorded between basal cover and species evenness, basal cover and Shannon diversity, stem density, and species evenness, number of species and species maturity, and stem density and Shannon diversity. The rest showed a moderate positive and negative correlation between different data matrix indices (Figure 4).

Generalized linear regression model (GLM) revealed a strong correlation among the structural attributes of the *A. indica* stands. An increasing trend is reflected in stem density (stem/ha) with the basal cover (cm) values of the species (Figure 5). GLM also revealed a negative correlation of *A. indica* regeneration and deforestation values, indicating that the disturbed forest stands were showing poor and retarded recruitment. In contrast, a decreasing trend was observed between the variables such as regeneration (seedlings/ha) and deforestation (Stumps/ha) (Figure 6).

The cluster analysis based on Euclidean distance was performed on the phytosociological attributes of the *A. indica-dominated* vegetation communities. CA successfully separated and classified the investigated populations based on structural and diversity values. The healthiest *A. indica* populations at Pir Chinasi and Bher Jabser sites were distinctly separated in cluster A from the rest of the populations owing to the highest stem density (<1,000/ha) and basal cover (<1,200 cm) values, along with having the highest number of species (<40). Machiara Behak population separated from Cluster B as an outlier, apparently having higher values of structural attributes among the remaining 12 sites. Cluster B is comprised of nine sites further separated into two subgroups, B-1 having four sites with intermediate values of diversity and structural characteristics, whereas five populations characterized with lower values were grouped in B-2, representing the most disturbed *A. indica* populations in the region (Figure 7).

4 Discussion

The current study was carried out in the western Himalayan moist temperate forests to investigate the spatial distribution, population structure, associated flora, fuelwood properties, and conservation status of *A. indica*.

4.1 Population structure of *Aesculus indica*

Populations of dominant tree species exhibit variations attributed to differences in environmental variables, habitat quality, and land use practices (Ram et al., 2004). Investigated *A indica* populations showed an average density of 435.85 stems/ha with a very broad range of variation ranging from 1,100 stems/ha to a minimum of 220 stems/ha. More than 50% of the *Aesculus* populations showed disturbed population structure due to intense cutting pressure and disturbances. Only two sites showed considerably higher tree densities (>1,100/ha) that may be due to the high prevalence of smaller and younger trees (Svenning and Magård, 1999). The basal cover of *A. indica* was 356.33 cm across the region which is considerably high for a medium-sized deciduous tree. The better cover values suggest that *A. indica* plays a significant role in the canopy structure and composition of the Himalayan forests (Gairola et al., 2011). The variation in basal cover values could be indicative of differences in stand structure, age distribution, and competitive interactions with other tree species (Sharma and Samant, 2013).

The regeneration potential of *A. indica* assessed by determining the seedling density across the study sites revealed a regeneration value of 174.28 seedlings/ha. The relatively higher seedling density suggests that *A. indica* has a good regeneration potential in the

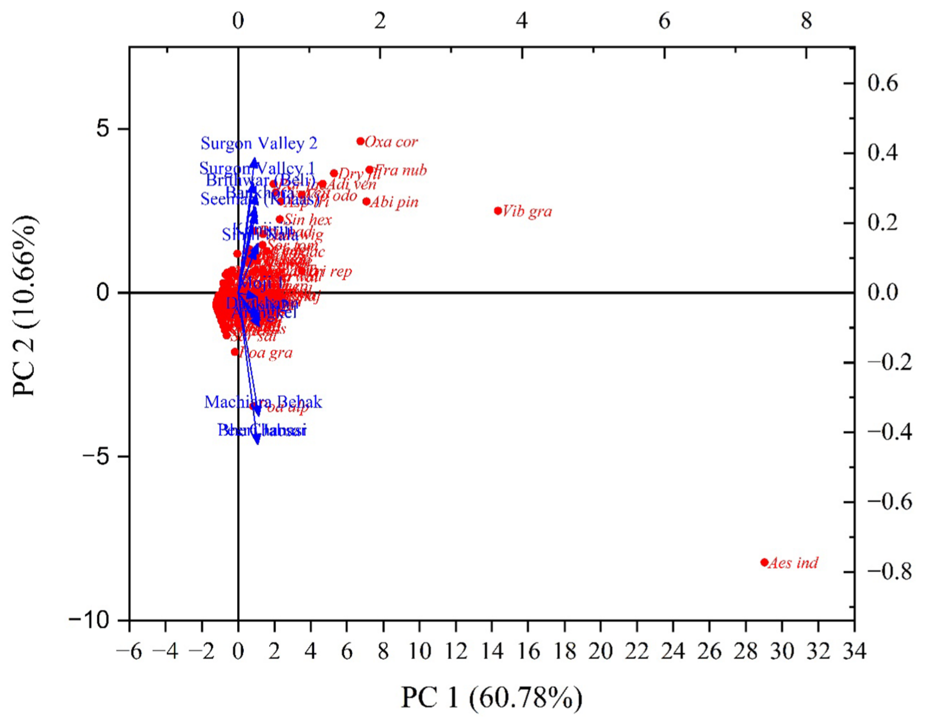

FIGURE 3
Principal component analysis shows the distribution of taxa based on the important value index. Species code: *Aes ind* (*Aesculus indica*), *Vib gra* (*Viburnum grandiflorum*), *Oxa cor* (*Oxalis corniculata*), *Fra nub* (*Fragaria nubicola*), *Abi pin* (*Abies pindrow*), *Poa alp* (*Poa alpina*), *Adi ven* (*Adiantum venustum*), *Dry fil* (*Dryopteris filix-mas*), *Poa gra* (*Poa gracilis*), and *Sin hex* (*Sinopodophyllum hexandrum*).

Himalayan forests, which is crucial for the long-term sustainability of the species (Sharma et al., 2018). However, the variation in seedling density across the study sites could be influenced by factors such as seed availability, microsite conditions, and herbivory (Gairola et al., 2011). Interestingly, the forest stands with significant deforestation pressure also showed better regeneration as open canopies due to low tree density provided better solar insolation which favors seedling growth in *A. indica* populations mostly occurring on north-facing aspects canopies (Singh and Negi, 2023). The population structure results provide valuable insights into the structure of *A. indica* forest stands in the western Himalayas. The high variation in structural attributes of the forest stands across the study sites underscores the importance of site-specific management strategies for *A. indica*.

4.2 Floristic diversity of *Aesculus indica* populations

Floristic analysis revealed that *A. indica* populations constituted a habitat for a large number of associated floral wealth comprised of 168 plant species indicating its ecological significance as a keystone structural species. The recorded flora revealed overwhelming dominance of five plants, i.e., Asteraceae, Lamiaceae, Rosaceae, Poaceae, and Polygonaceae families, which contributed 50% of the total recorded plant species. These dominant families mainly consisted of herbaceous species that exhibit widespread abundance and unique growth patterns in the Himalayan temperate forests due to morphological and genetic adaptations as well as broader ecological amplitude (Semwal et al., 2010).

Phytosociological investigations of *A. indica-dominated* temperate forest communities studied from diverse ecological localities showed the dominance of a few representative plant species. *A. indica* showed the highest IVI value of 48.81 followed by *Viburnum grandiflorum, Fragaria nubicola, Abies pindrow, Oxalis corniculata*, and *Dryopteris stewartii*. Similar types of vegetation in temperate forests were also reported by various researchers from the Himalayan region. The present study agreed with Alam et al. (2023), Haq et al. (2023), Haq et al. (2022), and Shaheen et al. (2024). Generally, these species have a wide niche and are distributed across temperate forests. These dominants are the indicators as well as keystone species of the temperate zone's vegetation (Khan S. M. et al., 2012; Khan W. et al., 2012; Cochard and Dar, 2014). Several studies in the western Himalayas have reported higher abundance values of *A. indica* which may be due to better conservation of forests (Sharma et al., 2014; Gairola et al., 2011).

Analysis of the biological spectrum of the flora, including leaf size and life form classification, demonstrates how the plants have adapted to the environmental factors and climate of their respective habitats (Khan et al., 2018). Hemicryptophytes were identified as the most prevalent floral life form in the *A. indica* populations, followed by therophytes and geophytes, respectively. It has been widely documented that the abundance of these life forms serves as a reliable indicator of the harsh environmental and mountainous conditions found in the temperate Himalayan forests (Haq et al., 2023). Microphylls were identified as the most abundant leaf size class in the *A. indica-associated* flora. Small leaves are reliable indicators of the cold and harsh environmental conditions of mountainous regions, ensuring

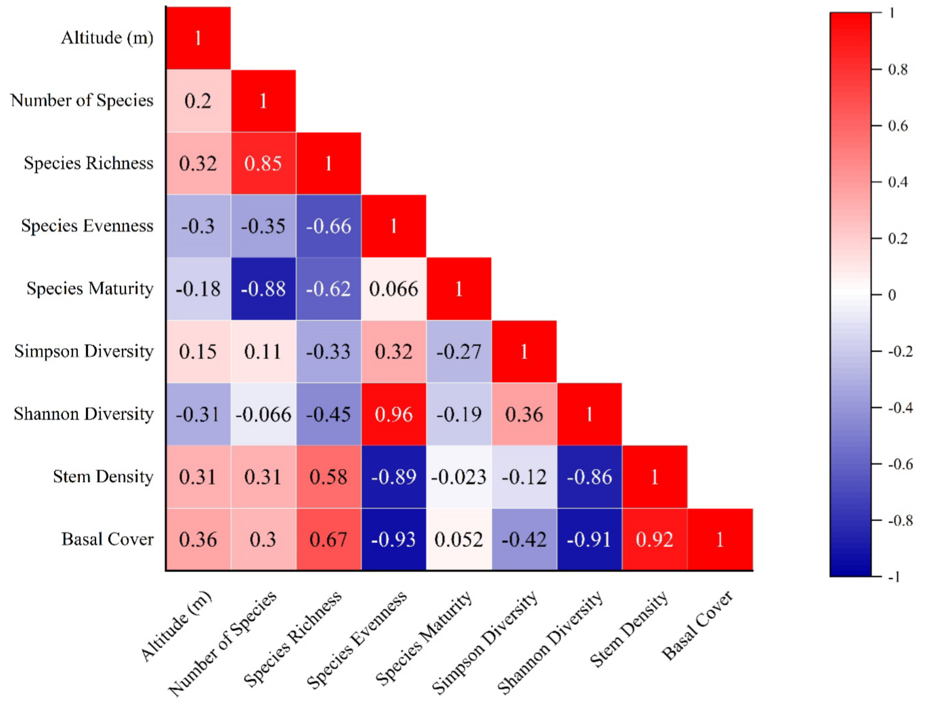

FIGURE 4
Pearson's linear correlation of the structural attributes and diversity values of the *Aesculus indica* populations.

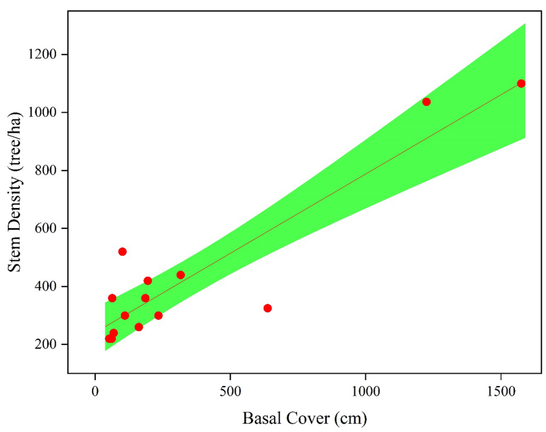

FIGURE 5
Linear bivariate regression analysis between stem density and basal cover.

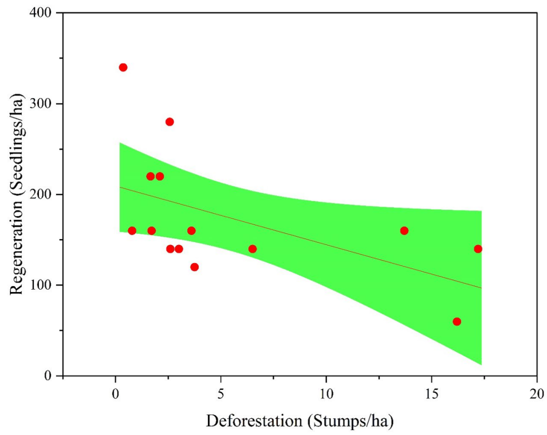

FIGURE 6
Linear bivariate regression analysis between regeneration and deforestation.

high moisture retention (Haq et al., 2020). The prevalence of hemicryptophytes and microphylls in the area might be due to broad ecological adaptations to environmental factors, including cold temperatures, abundant rainfall, and short growing seasons (Shaheen et al., 2024).

4.3 Phytosociological attributes of *Aesculus indica* forest communities

A. indica populations showed significant levels of diversity and richness in the investigated area. Environmental factors such as aspect, elevation, slope, soil, and microenvironmental habitats strongly influence the patterns of Species Richness and Diversity (Khan S. M. et al., 2012; Khan W. et al., 2012). Species richness values were recorded to be higher on north-facing slopes, attributed to more suitable habitat conditions in terms of higher soil moisture, favorable temperature, and solar insolation (Panthi et al., 2007). The values of Shannon's diversity recorded for the *A. indica* populations as 2.89 were in line with values recorded from eastern and middle Himalayan temperate forests of India, Nepal, and Bhutan (Gairola et al., 2011).

Species evenness is an important vegetation attribute that reflects the distribution pattern of plant species in any area ranging from 0 to 1, where the low value means unequal distribution and the highest value indicates

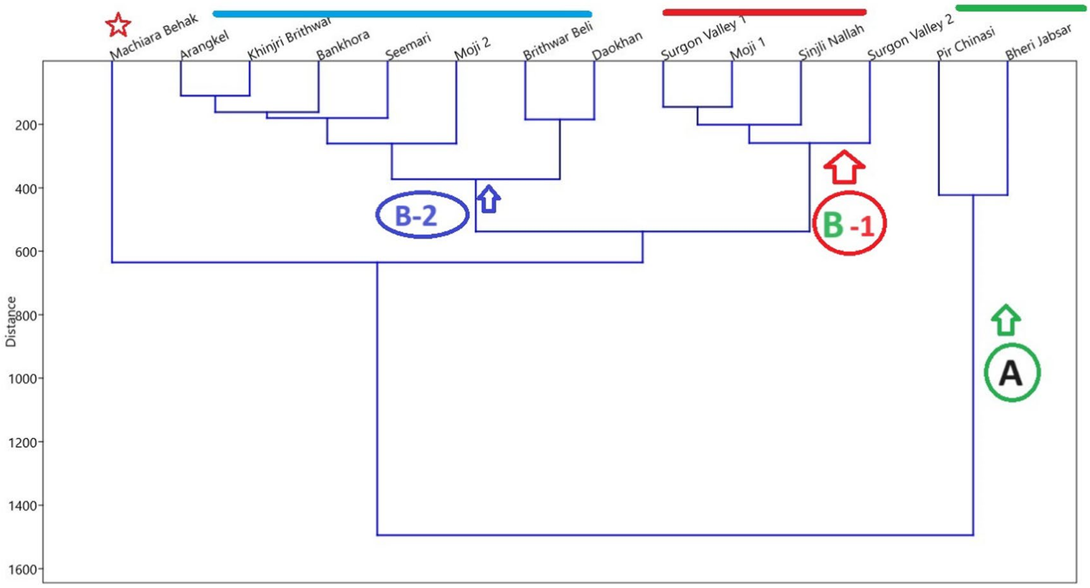

FIGURE 7
Cluster analysis dendrogram of sites dataset based on investigated *Aesculus indica* populations.

uniform and homogenous distribution pattern (Mitchell et al., 2023). Species evenness averaged 0.82 in the *A. indica-dominated* vegetation communities, reflecting a somewhat uniformly arranged species pattern. Populations showed a high Simpson's diversity value of 0.94, which reflects the striking dominance of few keystone taxa in the area constituting the majority of the temperate forests (Gairola et al., 2011). Little inter-site variation in Simpson's diversity values was observed owing to similar habitat conditions as well as species composition of the investigated *A. indica* populations. The populations exhibited a low value of maturity index (<60), which shows the impacts of anthropogenic disturbances that hinder the communities from developing to ecological climax (Singh et al., 2014). In addition, harsh climatic conditions of the Himalayan Mountain ecosystems, along with climate change impacts, are also exerting persistent pressure on the vegetation, testing its vigor and vitality to reach equilibrium (Panthi et al., 2007).

4.4 Habitat geography of *Aesculus indica* populations

The geographic variables, including altitude, slope, and aspect, significantly influence the distribution and habitat preference of *A. indica* in the western Himalayas (Duguid and Ashton, 2013). The combination of moderate to highly steep mountain slopes in the altitudinal range of 1,400–2,800 m located on north-facing aspects constituted the most preferred habitats for *A. indica* in the western Himalayas. This specific habitat preference can be attributed to the species' ecological requirements, including soil moisture, nutrient availability, and microclimate conditions (Singh and Negi, 2023).

The DEM analysis revealed that *A. indica* populations in the western Himalayas are primarily distributed in an altitudinal range of 1,400 m to 2,800 m. This altitudinal distribution is consistent with the species' preference for temperate climatic conditions and is indicative of its ecological niche in the Himalayan region (Singh and Negi, 2023). Most of the *A. indica* populations (64.29%) were found to be concentrated between the elevational range of 2,350 m and 2,850 m, which corresponds to the upper temperate forest zone. This finding aligns with previous studies indicating that *A. indica* predominantly occurs in the temperate regions of the Himalayas (Das et al., 2021; Shaheen et al., 2024).

The upper temperate forest zone, with its unique environmental conditions, appears to offer an optimal habitat for *A. indica* populations in the study region. The results of the current study revealed a clear preference for *A. indica* for north-facing aspects, with 90% of the populations recorded exclusively from north-facing slopes. This aspect preference suggests that *A. indica* exhibits specific adaptive strategies to optimize light interception, temperature regulation, and moisture retention, which are crucial for its growth and survival (Sharma and Samant, 2013). Aspects have a strong influence on the temperature as the north-facing slopes have dense canopy cover and less exposure to sunlight, the temperature is lower and remains shaded. Due to low temperatures and less intensity of light, north-facing areas have high moisture availability, making them suitable for *A. indica* growth (Bennie et al., 2008). The detailed analysis of geographic variables influencing *A. indica* distribution provides valuable insights for its conservation and management in the western Himalayas.

4.5 Anthropogenic disturbances and conservation status of *Aesculus indica* populations

A current study has revealed significant pressure on *A. indica* forests due to various disturbances such as the felling of trees for fuel and fodder, fire, extensive grazing, and soil erosion. These disturbances significantly alter the structure, composition, and abundance of *A. indica*, as well as associated floral diversity. Habitat loss is widely affecting the ecological functioning of temperate forest ecosystems in the Himalayas (Tiwari et al., 2019). A significant deforestation intensity has been recorded in the *A. indica-dominated* forests averaging 135 stumps/ha in the study area. Approximately 50% of sites showed higher values of deforestation intensity exceeding 300 stumps/ha. Local Himalayan rural populations heavily rely on forest stands for fuel and timber wood due to the unavailability of alternate fuel, electricity, and poverty, leading to devastated forest structure (Haq et al., 2021).

Overgrazing and trampling were also recorded as major threat to the *A. indica* seedlings in the region, as approximately 65% of investigated sites showed significant grazing disturbance. Seedlings are very vulnerable and grow only a few centimeters per year, prone to the damage caused by grazing and trampling (Aziz et al., 2019). Forest land encroachment for housing and cultivation also threatens the *A. indica* populations in the study area due to the scarcity of available space in the rugged mountain terraces (Shaheen et al., 2023).

It is feared that if these activities continue in temperate broad-leaved forests, it can lead to a potential loss of many other species found as associated flora along with *A. indica* (Pawar and Rothkar, 2015).

Climate change and anthropogenic disturbances pose serious threats to the viability of *A. indica* populations in the region. Conservation strategies should focus on a strict ban on deforestation, community-based conservation initiatives, a ban on road construction, educating communities to foster awareness, controlled grazing practices, restoration of degraded habitats, controlling invasive species, promoting reforestation initiatives, sustainable harvesting policies, and promoting alternative livelihoods that support local communities in the region. Additionally, the AJK Forest Department and local NGOs engage local communities to create awareness about temperate forest ecosystems through seminars, social media, and cultural events, which help in safeguarding temperate forest ecosystems. Monitoring programs that track *A. indica* population trends and their associated flora can inform adaptive management strategies. Conservation strategies should prioritize the protection and restoration of *A. indica* habitats, especially the upper temperate forest zones with north-facing slopes, to ensure the long-term sustainability of the species. The study emphasizes the urgent need for effective conservation measures to safeguard *A. indica* and its associated floral diversity in the western Himalayan region.

5 Conclusion

The present study provides comprehensive insights into the population structure, floral diversity, habitat geography, phytosociology, threats, and conservation status of *A. indica* in the western Himalayan region of Kashmir. *A. indica* populations exhibited an average density of 435.85 stems/ha with a high basal cover of 356.33 cm, indicating its significant role in the canopy structure of Himalayan forests. The study also highlighted the species' preference for north-facing aspects and an altitudinal range of 1,400–2,800 m, as the most suitable habitats. *A. indica,* as a keystone species, was recorded supporting a diverse floral community comprised of 168 plant species, dominated by the prevalence of hemicryptophytes and microphylls. The study identified significant anthropogenic disturbances, including deforestation, overgrazing, and forest land encroachment, as major threats to *A. indica* populations. It is recommended to formulate effective conservation measures such as a ban on deforestation, promoting sustainable forest practices, controlling invasive species, restoring degraded habitats, controlled grazing practices, community-based conservation initiatives, sustainable harvesting policies, educating local communities, and promoting alternative livelihoods that support local communities to ensure the preservation of *A. indica* populations as well as ecosystem health. Addressing the identified threats and implementing effective conservation strategies are crucial for the sustainable management and conservation of *A. indica* and its associated flora in the Himalayan temperate forests of the Kashmir region.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

UI: Investigation, Writing – original draft, Writing – review & editing. HS: Conceptualization, Supervision, Writing – original draft, Writing – review & editing. MM: Investigation, Methodology, Writing – original draft, Writing – review & editing. SN: Writing – review & editing, Data curation, Formal analysis. RK: Writing – review & editing, Investigation, Methodology, Visualization. SG: Writing – review & editing, Software, Visualization. AFA: Data curation, Formal analysis, Writing – review & editing. ArA: Investigation, Writing – original draft. AK: Data curation, Formal analysis, Writing – review & editing. SR: Data curation, Writing – review & editing. MR: Validation, Visualization, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. We extend our appreciation to the Researchers Supporting Project (no. RSP2025R218), King Saud University, Riyadh, Saudi Arabia.

Acknowledgments

We extend our appreciation to the Researchers Supporting Project (no. RSP2025R218), King Saud University, Riyadh, Saudi Arabia.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Alam, N. M., Shaheen, H., Manzoor, M., Tinghong, T., Arfan, M., and Idrees, M. (2023). Spatial distribution and population structure of Himalayan fir (*Abies pindrow* (Royle ex D. Don) Royle) in moist temperate forests of the Kashmir region. *Forests* 14:482. doi: 10.3390/f14030482

Aziz, S., Chughtai, F. M., Shaheen, H., Khan, R. W. A., and Dar, M. E. U. I. (2019). Biomass and soil carbon stocks assessment in western Himalayan alpine and subalpine vegetation zones of Kashmir. *Pak. J. Bot.* 51, 973–978. doi: 10.30848/PJB2019-3(18)

Bennie, J., Huntley, B., Wiltshire, A., Hill, M. O., and Baxter, R. (2008). Slope, aspect and climate: spatially explicit and implicit models of topographic microclimate in chalk grassland. *Ecol. Model.* 216, 47–59. doi: 10.1016/j.ecolmodel.2008.04.010

Bhatt, B. P., and Todaria, N. P. (1990). Fuelwood characteristics of some mountain trees and shrubs. *Biomass* 21, 233–238. doi: 10.1016/0144-4565(90)90067-T

Bhatt, B. P., and Tomar, J. M. S. (2002). Firewood properties of some Indian mountain tree and shrub species. *Bio* 23, 257–260. doi: 10.1016/S0961-9534(02)00057-0

Cochard, R., and Dar, M. E. U. I. (2014). Mountain farmers' livelihoods and perceptions of forest resource degradation at Machiara National Park, Pakistan-administered Kashmir. *Environ. Develop.* 10, 84–103. doi: 10.1016/j.envdev.2014.01.004

Cox, J. E., and Larson, D. W. (1993). Spatial heterogeneity of vegetation and environmental factors on talus slopes of the Niagara escarpment. *Canad. J. Bot.* 71, 323–332. doi: 10.1139/b93-034

Das, D. S., Dash, S. S., Maity, D., and Rawat, D. S. (2021). Population structure and regeneration status of tree species in old growth *Abies pindrow* dominant forest: a case study from western Himalaya, India. *Trees Forests People* 5:100101. doi: 10.1016/j.tfp.2021.100101

Duguid, M. C., and Ashton, M. S. (2013). A meta-analysis of the effect of forest management for timber on understory plant species diversity in temperate forests. *For. Ecol. Manag.* 303, 81–90. doi: 10.1016/j.foreco.2013.04.009

Gairola, S., Sharma, C. M., Suyalm, S., and Ghildiyal, S. K. (2011). Composition and diversity of five major forest types in moist temperate climate of the western Himalayas. *For. Stud. China* 13, 139–153. doi: 10.1007/s11632-011-0207-6

Haq, S. M., Amjad, M. S., Waheed, M., Bussmann, R. W., and Proćków, J. (2022). The floristic quality assessment index as ecological health indicator for forest vegetation: a case study from Zabarwan Mountain range. *Himalayas. Ecol. Ind.* 145:109670. doi: 10.1016/j.ecolind.2022.109670

Haq, S. M., Calixto, E. S., Rashid, I., and Khuroo, A. A. (2021). Human-driven disturbances change the vegetation characteristics of temperate forest stands: a case study from Pir Panchal mountain range in Kashmir Himalaya. *Trees. For. Peop.* 6:100134. doi: 10.1016/j.tfp.2021.100134

Haq, S. M., Khoja, A. A., Lone, F. A., Waheed, M., Bussmann, R. W., Mahmoud, E. A., et al. (2023). Floristic composition, life history traits and phytogeographic distribution of forest vegetation in the Western Himalaya. *Front. For. Glob. Chang.* 6:1169085. doi: 10.3389/ffgc.2023.1169085

Haq, S. M., Khuroo, A. A., Malik, A. H., Rashid, I., Ahmad, R., Hamid, M., et al. (2020). Forest ecosystems of Jammu and Kashmir state. *Biodiversity of the Himalaya: Jammu and Kashmir State*. 191–208. doi: 10.1007/978-981-32-9174-4_8

Jazib, M. J. (2023). Community composition, population structureand regeneration potential of tree species in oak-dominated mixed forests of Rajouri district in Jammu and Kashmir, India. *Sustain. Agri. Food Environ. Res* 11, 1–13. doi: 10.7770/safer-V11N1-art2210

Kaur, L., Joseph, L., and George, M. (2011). Phytochemical analysis of leaf extract of *Aesculus indica* L. *Internat. J. Pharm. Sci.* 3, 232–234.

Khan, W., Ahmad, H., Haq, F., Islam, M., and Bibi, F. (2012). Present status of moist temperate vegetation of Thandiani forests district Abbottabad Pakistan. *Internat. J. Biosci.* 10, 80–88.

Khan, W., Khan, S. M., Ahmad, H., Alqarawi, A. A., Shah, G. M., Hussain, M., et al. (2018). Life forms, leaf size spectra, regeneration capacity and diversity of plant species grown in the Thandiani forests, district Abbottabad, Khyber Pakhtunkhwa, Pakistan. *Saud. J. Biol. Sci.* 25, 94–100. doi: 10.1016/j.sjbs.2016.11.009

Khan, S. M., Page, S., Ahmad, H., Shaheen, H., and Harper, D. (2012). Vegetation dynamics in the Western Himalayas, diversity indices and climate change. *Sci. Tech. Develop. J.* 31, 232–243.

Lal, M., and Samant, S. S. (2020). Firewood species diversity and consumption pattern in kais wildlife sanctuary of Himachal Pradesh: implication for conservation. *Proc. Ind. Nat. Sci. Acad.* 86, 1411–1422. doi: 10.16943/ptinsa/2020/154984

Majeed, M., Khan, M. A., Bashir, A., and Qaisar, K. N. (2010). Maturity indices of Indian horse-chestnut (Aesculus indica Colebr.) seeds under temperate Kashmir conditions. *For. Stud. Chin.* 12, 45–48. doi: 10.1007/s11632-010-0007-4

Manzoor, M., Ahmad, M., Zafar, M., Gillani, S. W., Shaheen, H., Pieroni, A., et al. (2023). The local medicinal plant knowledge in Kashmir Western Himalaya: a way to foster ecological transition via community-centred health seeking strategies. *J. Ethnobio. Ethnomed.* 19:56. doi: 10.1186/s13002-023-00631-2

Menhinick, E. F. (1964). A comparison of some species-individuals diversity indices applied to samples of field insects. *Ecology* 45, 859–861. doi: 10.2307/1934933

Mitchell, B. A., Gorta, S. B., Callaghan, C. T., Kingsford, R. T., and Rowley, J. J. (2023). Fighting the flames: site-specific effects determine species richness of Australian frogs after fire. *Wildlife Res.* 51:22175. doi: 10.1071/WR22175

Nasir, Y. (1991). Threatened plants of Pakistan. *Plant life of South Asia.*, 229–234.

Nasir, E., and Ali, S. I. (1980–1989). Flora of Pakistan. No. 132-190. Islamabad, Karachi: Fakhri printing press Karachi.

Pandey, R., Rawat, M., Singh, V., Yousefpour, R., and Reshi, Z. A. (2023). Large scale field-based evaluation of niche breadth, niche overlap and interspecific association of Western Himalayan temperate forest tree species. *Ecol. Indic.* 146:109876. doi: 10.1016/j.ecolind.2023.109876

Pant, S., and Samant, S. S. (2012). Diversity and regeneration status of tree species in Khokhan wildlife sanctuary, north-western Himalaya. *Trop. Eco.* 53, 317–331.

Panthi, M. P., Chaudhary, R. P., and Vetaas, O. R. (2007). Plant species richness and composition in a trans-Himalayan inner valley of Manang district, Central Nepal. *Him. J. Sci.* 4, 57–64.

Pawar, K. V., and Rothkar, R. V. (2015). Forest conservation & environmental awareness. *Proced. Earth Planet. Sci.* 11, 212–215. doi: 10.1016/j.proeps.2015.06.027

Pichi-Sermolli, R. E. (1948). An index for establishing the degree of maturity in plant communities. *J. Ecol.* 36, 85–90. doi: 10.2307/2256647

Pielou, E. C. (1969). Ecological diversity and its measurement. *Intro Math Ecol.* 13, 221–235.

Purohit, A. N., and Nautiyal, A. R. (1987). Fuelwood value index of Indian mountain tree species. *Internat. Tree Crop J.* 4, 177–182. doi: 10.1080/01435698.1987.9752821

Rafiq, S. I., Singh, S., and Saxena, D. C. (2016). Physical, physicochemical and anti-nutritional properties of horse chestnut (*Aesculus indica*) seed. *J. Food Meas. Charact.* 10, 302–310. doi: 10.1007/s11694-016-9307-2

Ram, J., Kumar, A., and Bhatt, J. (2004). Plant diversity in six forest types of Uttaranchal, central Himalaya, India. *Cur. Sci.* 86, 975–978.

Rana, D., Bhatt, A., and Lal, B. (2019). Ethnobotanical knowledge among the semi-pastoral Gujjar tribe in the high altitude (Adhwari's) of Churah subdivision, district Chamba, Western Himalaya. *J. Ethnobiol. Ethnomed.* 15:10. doi: 10.1186/s13002-019-0286-3

Raunkiaer, C. (1934). The life forms of plants and statistical geographical. Oxford: Clarendon Press. 632.

Semwal, D. P., Uniyal, P. L., and Bhatt, A. B. (2010). Structure, composition and dominance–diversity relations in three forest types of a part of Kedarnath wildlife sanctuary, central Himalaya, India. *Not. Sci. Biol.* 2, 128–132. doi: 10.15835/nsb234655

Shaheen, H., Attique, A., Riaz, M. T., Manzoor, M., Khan, R. W. A., and Riaz, M. T. (2024). From biodiversity hotspot to conservation hotspot: assessing distribution, population structure, associated flora and habitat geography of threatened Himalayan yew in temperate forest ecosystems of Kashmir. *Biodivers. Conserv.* 33, 1–25. doi: 10.1007/s10531-023-02758-w

Shaheen, H., Aziz, S., Nasar, S., Waheed, M., Manzoor, M., Siddiqui, M. H., et al. (2023). Distribution patterns of alpine flora for long-term monitoring of global change along a wide elevational gradient in the Western Himalayas. *Global Ecol. Conserv.* 48:e02702. doi: 10.1016/j.gecco.2023.e02702

Shaheen, H., Qureshi, R. A., and Shinwari, Z. K. (2011). Structural diversity, vegetation dynamics and anthropogenic impact on lesser Himalayan subtropical forests of Bagh district, Kashmir. *Pak. J. Bot.* 43, 1861–1866.

Shannon, C. E. (1949). The mathematical theory of communication. By CE Shannon and Warren Weaver: Urbana.

Sharma, C., Mishra, A. K., Prakash, O., Dimri, S., and Baluni, P. (2014). Assessment of forest structure and woody plant regeneration on ridge tops at upper Bhagirathi basin in Garhwal Himalaya. *Trop. Plant Res.* 1, 62–71.

Sharma, C. M., Mishra, A. K., Tiwari, O. P., Krishan, R., and Rana, Y. S. (2018). Regeneration patterns of tree species along an elevational gradient in the Garhwal Himalaya. *Mount. Res. Develop.* 38, 211–219. doi: 10.1659/MRD-JOURNAL-D-15-00076.1

Sharma, A., and Samant, S. S. (2013). Diversity, structure and composition of forest communities in Hirb and Shoja catchments of Himachal Pradesh, north west Himalaya, India. *Int. J. Bot.* 9, 50–54. doi: 10.3923/ijb.2013.50.54

Simpson, E. H. (1949). Measurement of diversity. *Nature* 163:688. doi: 10.1038/163688a0

Singh, N., and Mittal, A. (2018). Response of Phenological events of Aesculus indica Colebr. To climate change along an altitudinal gradient in Kumaun Himalaya, Uttarakhand. *Int. J. Envir.* 8, 1–16. doi: 10.3126/ije.v8i1.22069

Singh, P., and Negi, G. C. S. (2023). "Phenological response of treeline ecotone tree species to global warming in Western Himalaya," in *Ecology of Himalayan treeline ecotone*. Singapore: Springer Nature Singapore. 377–393.

Singh, N., Tamta, K., Tewari, A., and Ram, J. (2014). Studies on vegetational analysis and regeneration status of *Pinus roxburghii*, Roxb. And *Quercus leucotrichophora* forests of Nainital Forest division. *Glob. J. Sci. Front. Res.* 14, 41–47.

Svenning, J. C., and Magård, E. (1999). Population ecology and conservation status of the last natural population of English yew *Taxus baccata* in Denmark. *Bio. Conserve.* 88, 173–182. doi: 10.1016/S0006-3207(98)00106-2

Syed, I. R., Sukhcharn, S., and Saxena, D. C. (2016). Evaluation of physical and compositional properties of horse-chestnut (*Aesculus indica*) seed. *J. Food. Proc. Tech.* 7, 561–562.

Tewari, A., Shah, S., Singh, N., and Mittal, A. (2018). Treeline species in Western Himalaya are not water stressed: a comparison with low elevation species. *Trop. Ecol.* 59, 313–325. Available at: https://www.tropecol.com/pdf/open/PDF_59_2/12%20Tewari%20et%20al.pdf

Tiwari, O. P., Sharma, C. M., Rana, Y. S., and Krishan, R. (2019). Disturbance, diversity, regeneration and composition in temperate forests of Western Himalaya, India. *J For Environ Sci* 35, 6–24. doi: 10.7747/JFES.2019.35.1.6

Verma, A., Arya, M. K., and Bisht, A. K. (2021). Increased insect pollinator service overcomes barriers in reproductive success of *Aesculus indica* Colebr. (Hippocastanaceae) in the temperate Himalaya. *Proc. Zool. Soc.* 74, 313–326. doi: 10.1007/s12595-021-00375-5

Zhang, Z., Li, S., and Lian, X. Y. (2010). An overview of genus *Aesculus* L.: ethnobotany, phytochemistry, and pharmacological activities. *Pharma. Crop* 1, 24–51. doi: 10.2174/2210290601001010024