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Tree species distributions in the Aravalli and Vindhya-Malwa regions of Gujarat and Rajasthan, India

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Abstract

The Aravalli and Vindhya-Malwa hills regions are known for their plant diversity. The plant species in these regions are affected by human threats and natural calamities. To understand the impacts on trees and their distribution along these regions, the present study was conducted. Five protected areas were selected in the southern, central Aravalli and Vindhya-Malwa regions of Gujarat and Rajasthan. The tree species were sampled during their seedling, sapling and mature tree stages. The nested plots method was used. Tree species in different growth stages were analysed and distribution specific to regions and across the landscapes were compared. Specific to regions, species richness was high in southern Aravalli compared to central Aravalli and Vindhya-Malwa regions. Across landscapes, the regions of southern Aravalli are significantly related to central Aravalli regions; the relationship between Aravalli and Vindhya-Malwa regions is not significant. Tree species distributions and establishment in these regions are affected by long-term threats like forest fire, selective removal of tree species and cutting and lopping at the time of flowering and fruiting, which create variations in tree species at the regional and landscape level. Recommendations were given to preserve the tree species.

Keywords

Aravalli; canopy fire; cutting; forest fire; lopping; long-term disturbance; tree dynamics; Vindhya-Malwa

Introduction

The Aravalli hills in north-west India comprising the states of Gujarat, Rajasthan, Haryana and the union territory of Delhi. It extends up to 670 km, with a few discontinuities, forest patches and gaps. Adequate forest stocks support the northern Indian drainage system. Many important streams, including Banas, Luni and Sabarmati, originate from these hills. The streams and rivers transport and distribute sediments, enriching the soil with all nutrients, thus supporting a good number of species in natural as well as man-made ecosystems (1). Vindhya range is a complex, discontinuous chain of mountain ridges and plateaus in west-central India. It extends from Rajasthan in the west to Bihar in the east, passing through Gujarat, Madhya Pradesh and Uttar Pradesh. Malwa Plateau generally refers to the volcanic upland region of the northern Vindhya range. The plateau includes districts of western Madhya Pradesh and parts of south-eastern Rajasthan. The climate is humid subtropical in the Vindhya-Malwa range (Rajasthan), arid and dry in central Aravalli (Rajasthan) and tropical wet and dry in southern Aravalli (Gujarat).

They display three distinct seasons - hot summer (Mar-Jun), monsoon (Jul-Oct) and cool winter (Nov-Feb). In these regions, the temperature can rise to 40° to 46° C in summer and decline to 1.5° to 4° C in winter. The average rainfall is 756 mm, with a maximum of 951 mm and a minimum of 517 mm. These specified ranges depend on the southwest monsoon that provides the maximum rainfall to this region. Thus, variations in climate in the Aravalli and Vindhya landscapes may transmute species richness and compositions in these regions.

The Aravalli hill range hosts diverse plant species, including trees, shrubs and herbs. In the hill regions of Haryana state, the studies have documented 92 tree species across 34 families and *Acacia arabica* is a dominant tree (2). Tree species composition was compared to different sites (3). In this study, influences of dominant trees, *Acacia tortilis*, *A. senegal* and *Eucalyptus camaldulensis* on understory vegetation were recorded. In southern Haryana's tropical dry deciduous forests, dominant tree species are *Ailanthus excelsa*, *Cassia fistula* and *Anogeissus pendula* (2). The studies conducted in the Vindhya-Malwa regions reveal significant seasonal variations in tree species phenology and ecological characteristics (4). Deciduous trees in dry tropical forests exhibit diverse leaf phenological patterns, with deciduousness durations ranging from a week to 7 months (5). Leaf flushing typically occurs during the hot, dry summer, prior to the rainy season, with species showing varying degrees of synchronicity (6). Furthermore, species composition, diversity and dominance fluctuate across seasons, with rainy season generally exhibiting higher diversity and evenness, while summer seasons show increased dominance of certain species and reduced overall diversity (7). These findings underscore the importance of seasonal adaptations in shaping forest ecosystems in the region. Disparity of tree species may also be skewed by biotic, abiotic and other environmental factors (8, 9). As reported, human threats like cutting, lopping, grazing, fuel wood collection, mining, forest fire and agricultural activities can affect the plant diversity of the Aravalli regions (10).

In the entire region of the Aravalli range, very few studies have explored the tree distribution at the regional level (2, 10, 11). The existing studies provide mere snapshots of forest composition (10) but do not track the distribution and regeneration patterns of tree species over greater extents of time and on a regional scale. The prevailing long-term threats are potential shifts in the ecosystem services resulting from changes in tree species types (10). Additionally, there is evidence of climate effects on tree species distribution and regeneration (12) and few separate studies on anthropogenic disturbances exist (13), but there is limited research integrating both factors. Studies from other regions have highlighted the relationship between climate and tree communities. Tree species establishments and their regeneration capability were studied by relating factors such as rainfall, persistent moisture and temperature patterns in the western and Garhwal Himalayas (14–16). Structural and floristic variation of tree species was reported from six locations of the old-growth wet evergreen forest of Nelliampathy hills (17). Variation in tree species composition was also reported in the eastern Himalaya (18), Garhwal Himalaya (19) and Himalayan moist temperate forests (20). Another study (21) reported that edaphic and environmental factors also change tree species richness, composition and regeneration in western Himalayan hills. Furthermore, natural and anthropogenic disturbances are critically affecting tree diversity, structure and regeneration in many forest ecosystems, sal forest (22), dry forest (23), sacred grove forest (24) and montane forest (25). The elevation of the mountain region plays a crucial role in determining the vegetative structure and composition of tree species in the Baihua mountain reserve (26). Forest fires also play a pivotal role as they mediate species richness, dominance and structural patterns (27). It acts as a driver of an ecosystem as climatological and geographical factors (28).

The Aravalli and Vindya-Malwa regions are ecologically significant regions and have varied morphological and geological characteristics (5, 7, 10). The regions with records of climate variability (12), temperature extremes (29), irregular rainfall patterns (30) and human disturbance activities like deforestation, grazing and mining (23, 30). The combined impacts of aforementioned factors on tree species are not documented well by any studies. Hence, there is a need for research that examines regional scale changes in trees and changes in tree growing stages. The existing studies might not sufficiently report the temporal aspects, particularly in relation to regional climate conditions and evolving human impacts on tree species. The present study was attempted to fill these knowledge gaps by providing a clear understanding of the spatial distribution of tree species in their growth stages (mature tree, seedling and sapling) in different areas of the Aravalli and Vindhya-Malwa regions. Further, edaphically, Vindhya-Malwa regions differ from Aravalli range. In some places, the Vindhya-Malwa region merges with the Aravalli hills. Therefore, the terrain, rock and soil factors differ in these regions, which also determines the richness and distribution of trees species. This present study will identify the multiple factors responsible for the richness and establishment (mature tree, seedlings and saplings) of tree species and the status of dominant families, genera and species in the regions of Aravalli and Vindhya-Malwa hills of Gujarat and Rajasthan.

Materials and Methods

Study area

In the present study, five protected areas covering the Aravalli and Vindhya-Malwa regions were selected. The southern Aravalli range Balaram Ambaji and Jessore Sloth Bear Wildlife Sanctuary; the central Aravalli Phulwari kinal and Kumbalgarh Wildlife Sanctuary; the Sitamata Wildlife Sanctuary located in Vindhya-Malwa region, was assessed in this study (Fig. 1).

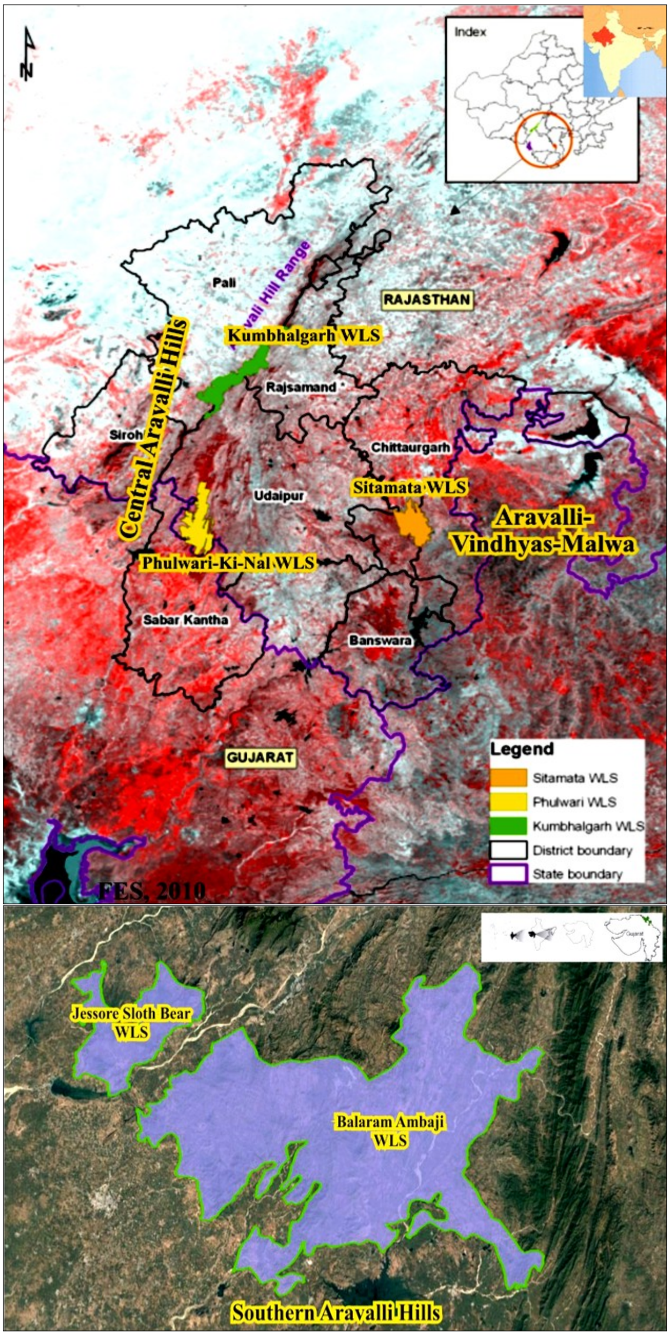


Fig. 1. Locations and distribution of protected areas in Aravalli and Vindhyas Malwa regions.

Southern Aravalli hills

The southern Aravalli region of Gujarat contains a large amount of dry deciduous and thorn forest, which prevents salt desert expansion. The Aravalli range of Gujarat is primarily marked as a protected area, such as the Jessore Sloth Bear Wildlife Sanctuary (24° 02' to 24° 31' N latitude and 72° 23' to 72° 37' E longitude) and the Balaram Ambaji wildlife sanctuary (24° 10' to 24° 30' N latitude and 72° 20' to 73° 00' E longitude) (31). Balaram Ambaji Wildlife Sanctuary contains a variety of forest types. There are dry and mixed deciduous woods (5A/C3), riverine forest (5/1S1), thorn forest (6B/C1), *Boswella* forest (5/E2), *Butea* forest (5/E5), *Acacia* forest (6/E2), *Zizphus* scrub forest (6B/DS1) and *Anogeissus* scrub forest (5E1). The Jessore Sloth Bear Wildlife Sanctuary is located on the hills of Mount Abu in Rajasthan (Fig. 1). This region's forest categorization is 5A/C3-southern dry mixed deciduous forest of tropical dry deciduous groups and 6B-tropical thorn forests with the subgroup desert thorn forest (6B/C1) (32). The sanctuary also includes a few minor patches of dry deciduous scrub forest containing *Zizyphus* (6B/DS1) and secondary dry deciduous degraded forest.

Central Aravalli hills

Many protected areas are in the Rajasthan's Aravalli. This study is focused on Phulwari-ki-nal (24° 00' to 24° 30' N latitude and 73° 07' to 73° 20' E longitude) and Kumbhalgarh Wildlife Sanctuary (20° 05' to 23° 03' N latitude and 73° 15' to 73° 45' E longitude) (Fig. 1). Phulwari -ki-nal Wildlife Sanctuary is a continuation of the Polo Forest in Gujarat's southern Aravalli range. It is one of the largest viable fragmented forests classified as II-dry tropical forest (32). This is further classed as 5B-northern tropical dry deciduous forest and C2-northern dry mixed deciduous woodland. The Wakal River, the main tributary of the Sabarmati, originates from this sanctuary. The river bisects the sanctuary into two unequal halves. The river basin is dotted with *Madhuca latifolia* groves, some of which cover up to 20 hectares. This sanctuary's deep woodland has provided shelter for some vulnerable and conservation-significant floral species, including *Anogeissus serecea, Chlorophytum borivilianum, Commiphora wightii, Gloriosa superba, Phoenix sylvestris, Streculia urens* and *Tecomella undulata* (33). Kumbhalgarh Wildlife Sanctuary is located north of Phulwari-ki-nal. It is significant because it forms an ecotone between the Aravalli hill forests and the Thar Desert in the west, acting as a barrier and preventing the desert from spreading eastward. However, vegetation on the hills has contributed to improving soil moisture retention capacity. The floral components are largely edaphic-climate climax type and the forests fall into the category II-tropical dry deciduous forests, further defined as 5B-northern tropical dry deciduous forest and C2-northern tropical dry mixed deciduous forest. Other subtypes include DS1-dry deciduous scrubs, DS1-*Anogeissus* scrub, E2-*Boswellia* forest, E5-*Butea* forests, E8-saline alkaline scrub savannah and E9-dry bamboo brakes (32). Some of the sanctuary's conservation-significant floral species are *Sterculia urens, Schrebera swietenoiodes, Toona ciliata, Jasminum grandiflorum* and *Caesalpinia decapatela.*

Vindhya-Malwa Plateau

Sitamata Wildlife Sanctuary (24° 04' to 24° 23' N latitude and 74° 25' to 74° 40' E longitude) is in the districts of Chittorgarh and Udaipur in the southwest area of Rajasthan (Fig. 1). It is outstanding in terms of habitat richness and interspersion, with teak stands, marshes, perennial streams, gently undulating mountains, deep natural canyons and beautiful grooves of mixed forests. The sanctuary's location at the intersection of the Aravalli-Vindhya hill and the Malwa Plateau makes it regionally significant and more distinctive floral features from both ranges may appear. This region's forest is classified as II-dry tropical forests, which are further divided into group 5-tropical dry deciduous forests, with 5A-southern tropical dry deciduous forest (including C1-dry teak bearing forest) and 5B-northern tropical dry deciduous forest (including C2-northern dry mixed deciduous forest) (32). The main feature of this sanctuary is its network of rivers (Jakham, Karmoi and Sitamata), which are complemented by riparian flora. All of this has resulted in unique micro and macro habitats that are home to several conservation-significant floral species, including *Sterculia urens, Dendrocalamus strictus, Chlorophytum tuberosum, Buchanania lanzan, Desmostachya bipinnata* and *Gloriosa superba*. Agricultural operations, combined with strong biotic pressure from domestic animals, illegal cutting of wood for timber, bamboo and other minor forest product gathering, put immense pressure on these regions. The forest is blessed with abundant natural resources, but it is also vulnerable to natural disasters and risks such as drought, fire, flood and storm (22).

Field methods

The study was carried out from 2005 to 2010. Geographic Information System (GIS) maps prepared by the GUIDE (2005) and FES (2007) are used to gather field data. Using a map, assessment plots were chosen and latitude and longitude points were marked for field travel. Plots were carefully placed throughout the whole protected area. Using nestled plots, five 1 x 1 m plots were used to measure the number of tree seedlings, 15 m radius circular plots were used to measure the mature trees and 8 m radius circular plots were used to measure the tree saplings. The criteria used to categorize the tree growth phases were as follows: seedlings (SE) of trees where height is <50 cm, saplings (SP) of trees where girth at breast height (GBH) <20 cm and >50 cm height. The >20 cm GBH of trees were classified as mature trees (MT). From each plot, the name and quantity of tree species were recorded. In all, 416 plots were constructed in Gujarat's southern Aravalli regions, 313 plots in Rajasthan's central Aravalli range and 168 plots in Rajasthan's Vindhya-Malwa region. The number of sampling plots was determined by the size of protected areas, types of forests and plant communities in each region.

Data analysis

Regional tree species richness is measured by counting the number of species, genera and families in MT, SE and SP stage. Families, genera and species were compared using Graph Builders tools of JMP Pro version 16. The numbers of individuals in different growth stages were converted into density/ha for further analysis using JMP Pro version 16. The distribution of trees in each region was tested using Bivariate Fit. The variance of trees in different regions was analyzed by Matched Pair (34).

Results

Tree species composition and dominance

Regional species richness showed that southern Aravalli supports 109 species, which fall under 36 families and 72 genera; central Aravalli has a richness of 86 tree species belongings to 36 families and 60 genera. Vindhya-Malwa ranges recorded 66 species from 33 families and 51 genera (Supplementary Table S1). Tree growth-wise, the southern Aravalli range showed the highest number of plant species, 95 species (35 families; 66 genera) in MT stage, 89 species (35 families; 60 genera) in SE stage and 80 species (34 families, 57 genera) in SP stage. Following this, the central Aravalli region had 76 species (33 families; 54 genera) in MT stage, 53 (27 families; 41 genera) in SE and 72 (35 families; 55 genera) in SP. Vindhya-Malwa ranges recorded 51 species (26 families; 40 genera) in MT stage, 51 (27 families; 43 genera) in the SE stage and 52 species (28 families; 42 genera) in the SP stage (Supplementary Table S1).

In MT, the dominant families in southern Aravalli were Apocyanaceae, Mimosaceae and Fabaceae; central Aravalli and Vindhya-Malwa ranges were dominated by Combretaceae, Mimosaceae and Fabaceae (Supplementary Fig. S1, S3 and Table S1). In the seedling stage, dominant families were Mimosaceae, Combretaceae and Caesalpiniaceae from the southern Aravalli; Mimosaceae, Combretaceae and Apocyanaceae from central Aravalli; and Vindhya-Malwa ranges were dominated by Combretaceae, Apocyanaceae and Fabaceae. In the sapling stage, southern and central Aravalli was dominated by Mimosaceae, Combretaceae and Fabaceae. The regions of Vindhya-Malwa were dominated by Apocyanaceae, Fabaceae and Combretaceae (Supplementary Fig. S1, S3 and Table S1).

In the southern Aravalli region, the dominant genera in the MT stage are *Acacia, Terminalia* and *Ficus*. The central Aravalli region was dominated by *Anogeissus, Acacia* and *Ficus*, while Vindhya-Malwa region were dominated by *Anogeissus, Terminalia* and *Syzygium*. In the SE stage, the southern Aravalli was dominated by *Acacia, Anogeissus* and *Ziziphus;* central Aravalli by *Anogeissus*, *Diospyros* and *Acacia* and Vindhya-Malwa region was dominated by *Anogeissus, Terminalia* and *Syzygium*. In the SP stage, *Wrightia, Acacia* and *Anogeissus* dominated in southern Aravalli; *Anogeissus, Diospyros* and *Wrightia* in central Aravalli; and *Anogeissus, Wrightia* and *Ziziphus* in Vindhya-Malwa region (Supplementary Fig. S2, S4 and Table S1).

Distributions and relationships in tree species

The tree species distribution in the Aravalli and Vindhya-Malwa regions of Gujarat and Rajasthan presented in Fig .2. A sum of 65 tree species is present in all three-growth stages of southern Aravalli hills, 13 tree species were present in the mature tree and seedling stages, 6 species were common in the mature tree and sapling and 6 species were present in the seedling and sapling stages. A total of 11, five and three species were present only in the mature tree, seedling and sapling stages. In the region of central Aravalli, 45 tree species were common in all three stages, 12, six and four species present only in mature tree, seedling and sapling stages. Two, six and 21 species were present on mature tree-seedling, seedling-sapling and mature tree-sapling stages respectively. In Vindhya-Malwa region, 37 species present in all three stages, three, four, seven species were present in mature tree-seedling, seedling-sapling and mature tree-sapling stages. Four species present in the mature tree, seven in seedling and four in sapling stages.

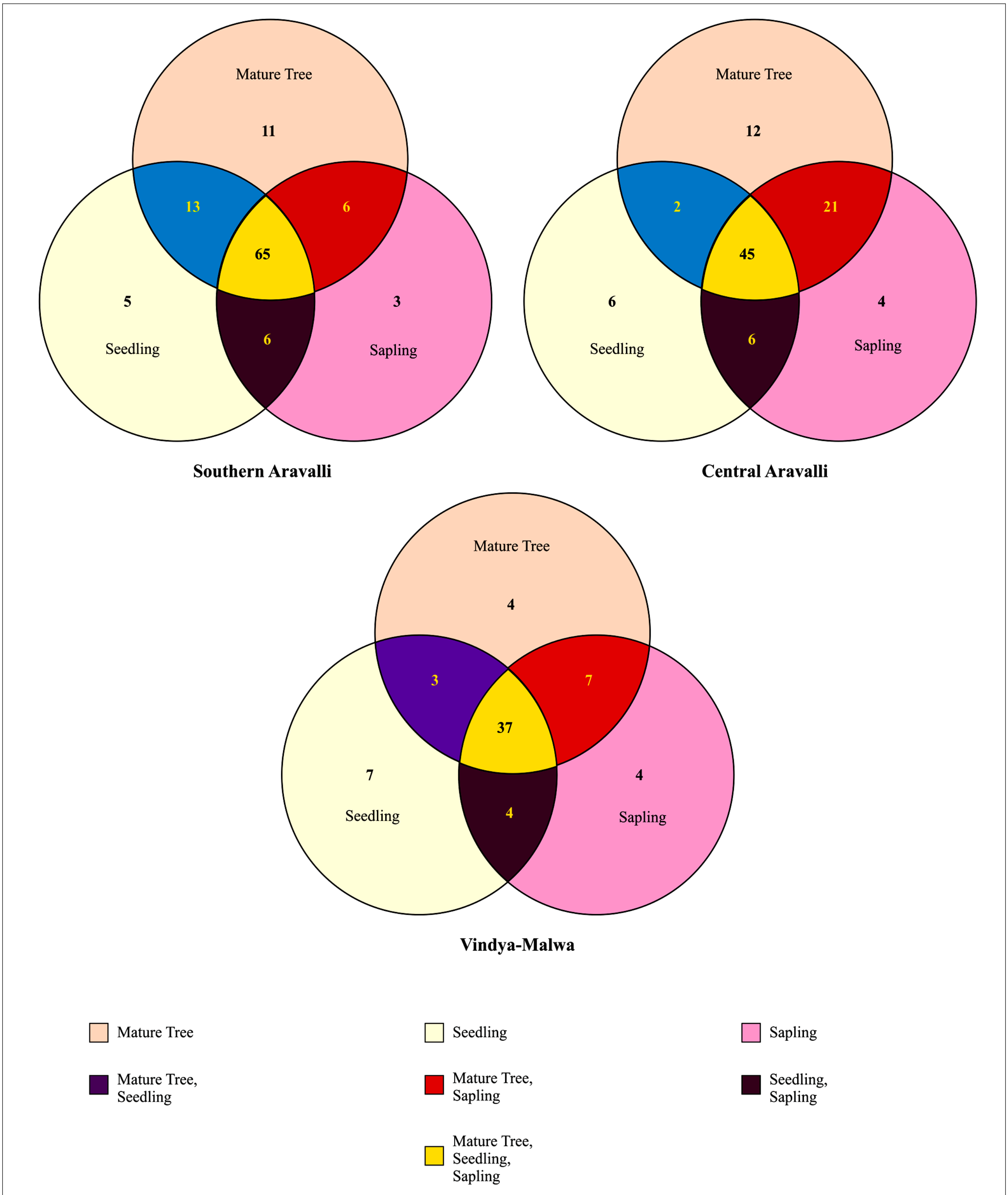
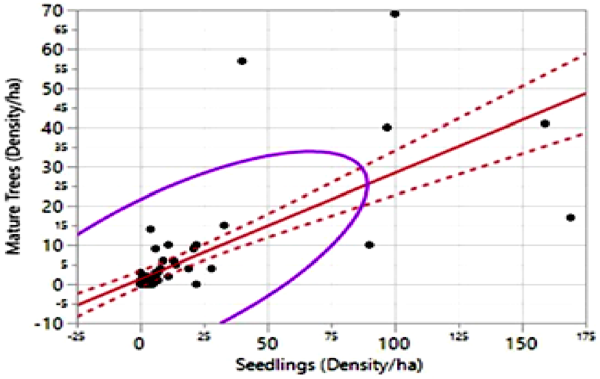


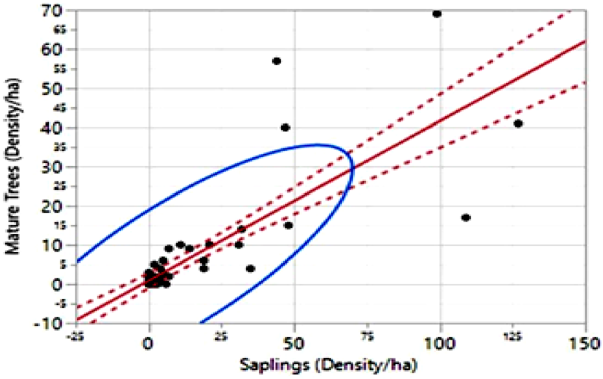
Fig. 2. Tree species distribution in Aravalli and Vindhya Malwa regions of Gujarat and Rajasthan.

Fig. 3 represented the relationship between density of MT, SE and SP in Aravalli and Vindhya-Malwa regions of Gujarat and Rajasthan. In Fig. 3a, shows the relationship between density of MT and SE in Gujarat's southern Aravalli region. The correlation value is r=0.711283 (p>0.0001), mean tree density of MT 3.83 (+10.95) and SE mean is 10.90 (+29.62). In Fig. 3b, the correlation was significant r=0.799308 (p>0.0001) between MT and SP and mean density of SP is 9.23 (+23.19). The relationship between density of MT, SE and SP were presented in Fig. 3c & 3d. Correlation between mature tree-seedling (r=0.698722; p>0.0001), mature tree-sapling (r=0.665129; p>0.0001), the mean density value of MT was 2.63 (+5.78), seedling was 200 (+381.88) and sapling was 16.61 (+44.95). Fig. 3e & 3f presents relationship in Vindhya-Malwa regions. There is no significant relationship between MT and SE (r=0.11; p<0.5074), but MT and SP showed significant relationships (r=0.874335; p<0.0001). The mean density of MT was 6.84 (+27.24), SE 284.86 (+501.87) and SP was 39.35 (+105.43).



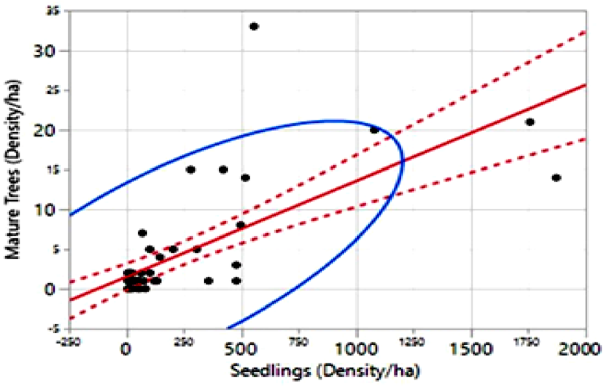
r=0.711283 (p=>.0001); Mature trees - mean 3.83; SD 10.95; Seedlings - mean 10.90; 29.62

Figure a: Relationship between mature trees and seedlings in southern Aravalli regions of Gujarat



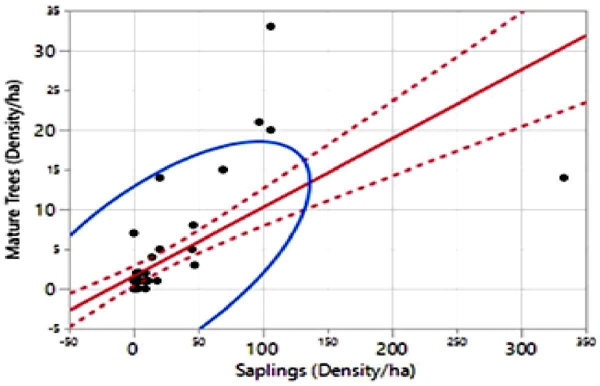
r=0.799308 (p=>.0001); Mature trees - mean 3.83; SD 10.95; Saplings - mean 9.23; 23.19

Figure b: Relationship between mature trees and saplings in southern Aravalli regions of Gujarat



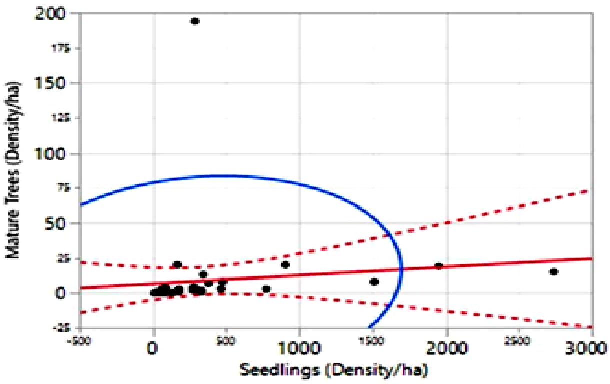
r=0.698722 (p=>.0001); Mature trees - mean 2.63; SD 5.78; Seedlings - mean 200; 381.88

Figure c: Relationship between mature trees and seedlings in central Aravalli regions of Rajasthan



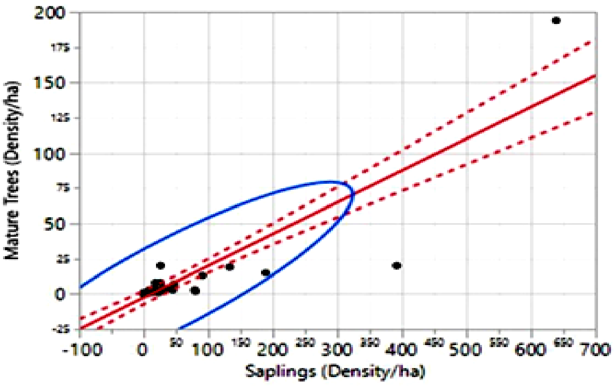
r=0.665129 (p=>.0001); Mature trees - mean 2.63; SD 5.78; Saplings - mean 16.61; 44.95

Figure d: Relationship between mature trees and seedlings in central Aravalli regions of Rajasthan



r=0.11 (p=<0.5074); Mature trees - mean 6.84; SD 27.24; Seedlings - mean 284.86; 501.87

Figure e: Relationship between mature trees and seedlings in Vindhya-Malwa regions of Rajasthan



r=0.874335 (p=>.0001); Mature trees - mean 6.84; SD 27.24; Saplings - mean 39.35; 105.43

Figure f: Relationship between mature trees and seedlings in Vindhya-Malwa regions of Rajasthan

Fig. 3. Relationship between mature trees seedlings and saplings in Aravalli, Vindhya-Malwa regions of Gujarat and Rajasthan.

Variations of trees species in Aravalli and Vindhya Malwa regions

Tree species composition were compared for three regions (Fig. 4). In the MT stage, 35 tree species were present in all three regions, 20 species were common to southern and central Aravalli regions, 5 species were common to southern Aravalli and Vindhya-Malwa regions, 8 species common to central Aravalli and Vindhya-Malwa regions. The distribution of SE showed 32 species in all three regions, nine species specific to southern and central regions of Aravalli and eight species belonged to southern Aravalli and Vindhya-Malwa and seven species were common to central Aravalli and Vindhya-Malwa regions (Fig. 4). In sapling stage, 31 species recorded from all three habitats, 18 species recorded from southern and central Aravalli regions and 12 species were present from central Aravalli and Vindhya-Malwa regions. Only one species is present in southern Aravalli and Vindhya -Malwa regions.

Comparative distribution of MT, SE and SP in the study area presented in Fig. 5. A correlation (r=0.91475) between MT in the southern Aravalli and the central Aravalli is given in Fig. 5a. However, the mean difference recorded is 2.06 ($p<0.1497$). Fig. 5b shows the relationship (r=0.33907) of MT in the southern Aravalli and the Vindhya-Malwa, with recorded mean difference of 2.74 ($p<0.2472$). The relationship of MT (r=0.42638) in central Aravalli and Vindhya-Malwa regions is presented in Fig. 5c and the mean difference recorded is 0.68 ($p<0.5875$). Fig. 5d shows a correlation of SE (r=0.67742) between the southern Aravalli and the central Aravalli with a mean difference of 267.19 ($p>0.0016$). Fig. 5e shows a correlation (r=0.28932) of SE between Gujarat's southern Aravalli and Rajasthan's Vindhya-Malwa and the mean difference is 345.34 ($p>0.0028$). Fig. 5f shows a relationship (r=0.34992) between SE distribution in the central Aravalli and Vindhya-Malwa areas of Rajasthan. The mean difference is 78.16 ($p<0.4865$). Fig. 5g demonstrates the correlation (r=0.77527) between SP in central Aravalli and southern Aravalli, the mean difference between the distribution in the two regions is 12($p<0.1371$). Fig. 5h shows a relationship (r=0.40542) between SP distributions in southern Aravalli and Vindhya-Malwa, the mean difference between the distributions is 39.32 ($p<0.0868$). Fig. 5i shows a correlation (r=0.44941) of SP distributions in Rajasthan's central Aravalli and Vindhya-Malwa regions. However, the mean difference between the distributions is 27.32 ($p<0.2119$).

Discussion

Tree dynamics

The study of tree species distribution in Gujarat and Rajasthan's Aravalli and Vindhya-Malwa areas provides insights into local ecological processes. Different environmental circumstances, historical impacts and human interventions are reflected in the distribution of tree species. Regional species richness was high in southern Aravalli. The high species richness in particular regions is due to the extent of area, diverse microhabitats and environmental/edaphic factors. Similar results are recorded in areas like protected areas of Sierra de Manantlan Biosphere Reserve in Jalisco, Mexico, Peru (35) and in Gebel Elba National Park, Egypt (36), Sergyemla Mountains (37) and Mexican Tropical Dry Forest (38). Climatic conditions, soil moisture, soil nutrients and solar radiations could be the factors that bring the variations in species richness. The biological factors (seed type, dispersal, germination time) and abiotic factors (rainfall pattern and surrounding environmental factors) could bring variations in richness (39). Topography, water regime, competitor effect and movement variables affect the spatial distribution of forest tree species in the Caucasus Mountain ranges (40) and edaphic factors in Chinese forests (41). The quantity of woody species in the Harana forest is greatly influenced by abiotic factors such as elevation, temperature, precipitation and soil organic matter (42).

In the case of central Aravalli and Vindhya hills, the tree species richness is low when compared to southern Aravalli regions. This is due to frequent drought and fire that prevents the establishment of seedlings. Frequent ground fire prevents species establishment in central Aravalli and Vindhya-Malwa regions. In Vindhya-Malwa region, 'canopy fire' is common, which reduces the species establishments greatly as well as it decreases the richness in tree growing stages. This disturbance determines the dominant tree species, *Tectona grandis* (Verbenaceae) and *Dendrocalamus strictus* (Bamboo grass, Poaceae) are dominant and susceptible to fire. The frequent fire incidents are due to leaf fall during the early stages of dry seasons, resulting in the accumulation of dried leaves (fuel) on the ground (43). It creates a condition, the incidence of fire repeats that reduces richness and a change in species compositions. Forest fire opens the tree canopy; small gap in tree canopy sufficiently allows sunlight to reach the ground, which brings a change in vegetation dynamics. Further incidents of fire change the soil composition, nutrient availability and germination process of ecosystems. It resulted in a dominance of a few species in an ecosystem, which are fire-tolerant species.

Species such as *Wrightia tinctoria, Holarrhena pubescent, Butea monosperma, Anogeissus pendula, Anogeissus latifolia* and *Diospyros melanoxylon* show rapid population growth, with species belonging to certain families (Apocynaceae, Miomosaceae, Combretaceae and Fabaceae in central Aravalli and Combretaceae, Miomosaceae, Fabaceae, Apocynaceae and Anacardiaceae in Vindhya-Malwa regions) being particularly dominant. At the same time, *Tectona grandis* (Verbenaceae) recorded as the dominant species; but its population affected by fire, showing less number in the SE stage and a relatively higher number in the SP stage. In addition, the *Tectona* genus and Verbenaceae family are not dominant at the general and family levels. Frequent forest fire, selective removal of species by cutting and lopping, especially during the flowering and fruiting periods, reduces the seed formation and dispersal. Furthermore, environmental factors, changes in rainfall and climatic factors affect seed germination. This creates a difference in the richness and growth pattern of tree species.

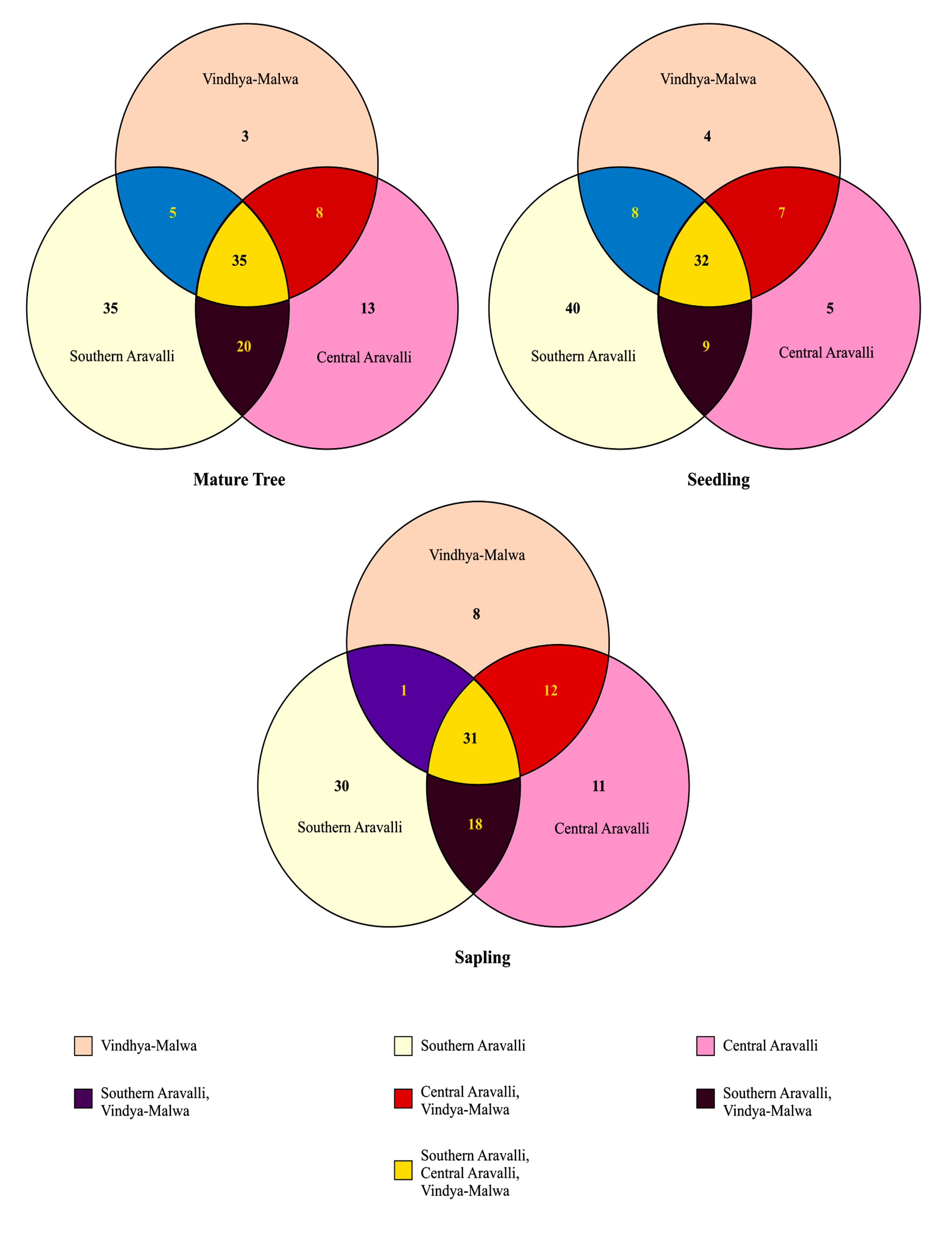
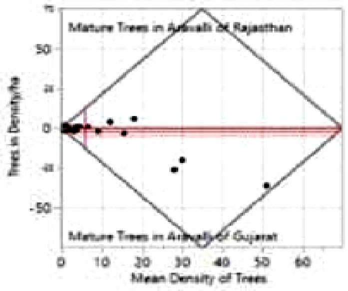
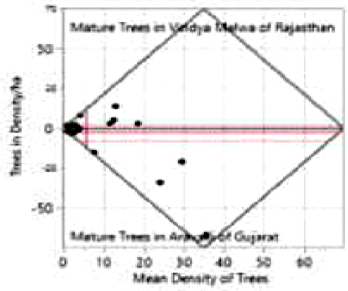


Fig. 4. Tree species variation in Aravalli and Vindhya Malwa regions of Gujarat and Rajasthan.



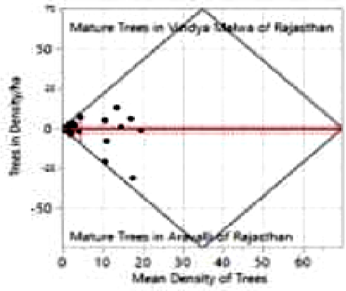
r=0.91475; mean difference – 2.06 (p=<0.1497)

Fig a: Mature trees distribution in southern Aravalli of Gujarat and central Aravalli of Rajasthan



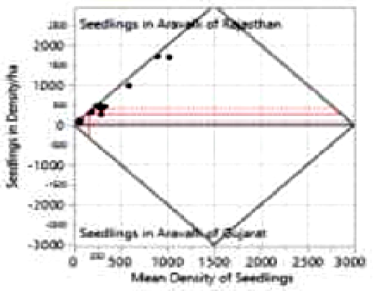
r=0.33907; mean difference – 2.74 (p=<0.2472)

Fig b: Mature trees distribution in southern Aravalli of Gujarat and Vindhya-Malwa of Rajasthan



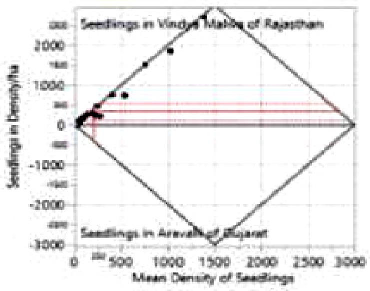
r=0.42638; mean difference – 0.68 (p=<0.5875)

Fig c: Mature trees distribution in central Aravalli and Vindhya-Malwa of Rajasthan



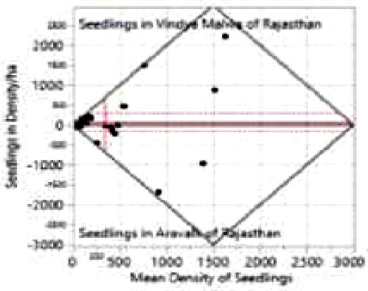
r=0.67742; mean difference – 267.19 (p=>0.0016)

Fig d: Seedlings distribution in southern Aravalli of Gujarat and central Aravalli of Rajasthan



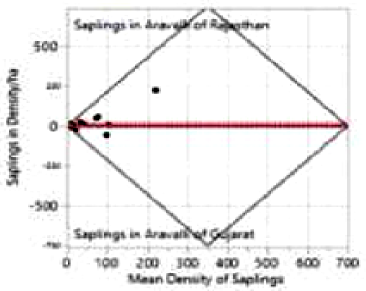
r=0.28932; mean difference – 345.34 (p=>0.0028)

Fig e: Seedlings distribution in southern Aravalli of Gujarat and Vindhya-Malwa of Rajasthan



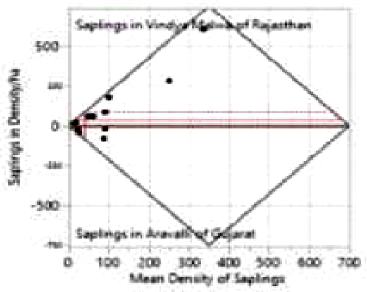
r=0.34992; mean difference – 78.16 (p=<0.4865)

Fig f: Seedlings distribution in central Aravalli and Vindhya-Malwa of Rajasthan



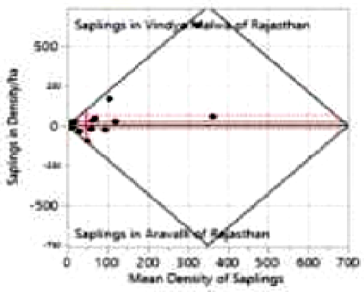
r=0.77527; mean difference – 12 (p=<0.1371)

Fig g: Saplings distribution in southern Aravalli of Gujarat and central Aravalli of Rajasthan



r=0.40542; mean difference – 39.32 (p=<0.0868)

Fig h: Saplings distribution in southern Aravalli of Gujarat and Vindhya-Malwa of Rajasthan



r=0.44941; mean difference – 27.32 (p=<0.2119)

Fig i: Saplings distributions in central Aravalli and Vindhya-Malwa of Rajasthan

Fig. 5. Comparative distribution of Mature Trees, Seedlings and Saplings in Aravalli and Vindhya-Malwa regions of Gujarat and Rajasthan.

Establishment of tree species

Our study recorded the distribution of MT, SE and SP in southern Aravalli, showing a significant relationship between all the stages. In central Aravalli, significant relationship was recorded, but the mean density of SE was high, which reduced the relationship between MT and SP. However, in the Vindhya regions, there is no significant relationship between MT and SE due to the high mean density of SE. At the same time, there is a significant relationship between MT and SP. Overall, in all three regions, the SE establishment was affected, with the intensity being highest in the Vindhya-Malwa and central Aravalli regions due to forest fire. In addition, the region-specific threats like frequency of cutting, lopping of tree species, utilisation of specific tree species by local communities and natural threats determine the distribution of tree species establishment in all three regions. The continuous long-term disturbance of tree elements affects their regeneration potential. Studies reported factors like forest type, altitude (44-46), change in the forest cover (45, 47-49) and inter-annual fluctuation in abiotic factors greatly influence the regeneration of tree species. Tree density, shrub cover and mean yearly temperature affect SE and SP survival rates (50) affecting the regeneration potential of tree species. The above-mentioned factors influence the establishment of MT, SE and SP within the regions.

Additionally, a study done in Ailao and Yulong Mountain in China found that, in small forest fragments, the herb layer, vegetation richness and composition impact trees, shrubs and seedlings establishments, affecting seed distribution and viability (51). Further, a study on the seasonal growth of ground layers and the richness of trees, seedlings and saplings showed positive and negative relationships in low, middle and high mountains. The long-term stressors, such as deer and introduced shrubs, are causing a shift in seedling communities toward fewer species (52), which is lowering the richness and diversity of seedling species. Seedling growths affected by fluctuations in temperature, moisture and sunlight (53). Their shallow root systems make them vulnerable to drought, frost and competition for resources, especially in dry or high-altitude environments (54). A study (37) recorded that soil moisture and nutrients play a critical role in determining seedling survival. In dense forests (55), light availability is a limiting factor for seedling growth. Another study (72) showed that seedling establishment influenced by canopy structure and light gaps. The author recorded the different tree seedling species adapting to different light intensities for their growth and establishment.

At the sapling stage, the species may experience competitive effects for resources such as light, nutrients and water (56). A study (53) recorded that saplings are more resilient to abiotic stresses compared to seedlings but still face significant threats from drought, temperature extremes and herbivory. Altitude and forest type play a vital role in SE and SP establishments; it determines the availability of resources, with saplings at higher altitudes or in drier regions often exhibiting slower growth due to harsher conditions (57). A study stated MT are well adapted due to extensive root systems; this allows them to access deeper water and nutrients more easily than SP and SE (37). In addition, MT utilize more resources for their reproduction and maintaining physiological processes; it limits the other forms of growth in the forest ecosystems (58). Another study (59) indicates that environmental stress can influence the reproductive success of seedlings and samplings, with drought and temperature extremes reducing seed production and viability of tree species. The type of forest ecosystem influences the establishment of trees, seedlings and saplings through differences in resource availability, such as light and nutrients (60). In deciduous forests (61), the seasonal shedding of leaves creates nutrient-rich litter layers that promote seedling and sapling growth. In contrast, evergreen forests (62) in nutrient-poor soils limit the growth due to less nutrient recycling. Dry forests characterized by prolonged periods of water scarcity, influencing the survival of seedlings and saplings more than that of mature trees (56). In contrast, wet forests may experience more competition for light, affecting species that are less shade-tolerant (62).

Altitude significantly impacts tree development stages through temperature gradients, air pressure and oxygen availability (57). Tree species at higher altitudes face lower temperatures and shorter growing seasons; these conditions affect seedling establishment and sapling growth (63). These species often exhibit slower growth rates and delayed maturation compared to those at lower elevations. Soil composition, including nutrient levels and drainage, can influence the growth rates and survival of tree species at all stages (64). Poorly drained or nutrient-poor soils are less conducive to seedling and sapling establishment, while mature trees with deep roots may be able to access subsurface nutrients (64). Another study (21) highlighted how soil properties in the western Himalayas influence species richness and regeneration success across different developmental stages. Different species respond uniquely to abiotic stresses based on their physiological traits. Further studies (65) identified species with greater drought resistance that tend to thrive in dry environments due to their deep root systems and efficient water-use strategies. On the other hand, species with shallow roots or higher water requirements may be restricted to more mesic environments.

Tree species distribution

The regional difference in species richness is reflected in the distribution of tree species in the Aravalli and Vindhya-Malwa regions. No major variations in the dominance of tree species were recorded in a MT, SE and SP stages. But tree species were significantly related between southern and central Aravalli regions and the central Aravalli and Vindhya Malwa regions. There was no significant relationship between southern Aravalli and Vindhya Malwa regions. This may be due to a shortage of SE, SP and low establishment due to continuous regional-specific threats that reduce connectivity. The long-term disturbance changes the ecosystem functions and this prevents the trees in all growing stages. Similar types of results were recorded in heavily as well as lightly logged-over sites in Mt Elgon lower montane forest in Western Kenya

(66) and pre and post-fire scenarios in Kibale National Park, Uganda (32). Because of interspecific competition due to disturbance, resource filtering creates variations (67). SE dispersal limitation and environmental heterogeneity may also be a factor for the spatial distribution of tree species in subtropical regions such as mixed broadleaf-conifer forests and broadleaf forests (68). Further, forest tree species affected by climate change (69). Climate change expected to affect diversity and richness in the temperate forests of Northern Iran by shifting and shrinking the climatically suitable habitats for major tree species (70). Change in climate plays a significant role in regional biodiversity patterns, although there is limited evidence that species interactions influence distribution patterns independently (71). Long-distance seed dispersal is a key factor in determining the distribution of trees and SE distributions across landscapes is depended on spatial pattern of seed arrival and spatial pattern of establishment (72).

The central Aravalli and Vindhya-Malwa regions fall under arid/semi-arid conditions. Frequent drought conditions limit the availability of soil moisture, leading to high seedling mortality rates (73). Another study highlighted that drought exacerbates competition among seedlings' growth in arid environments and favoured few species' growths (65). Further studies reported that prolonged droughts could slow tree growth by affecting photosynthesis and nutrient uptake (55). Drought can weaken trees, making them more susceptible to pests and diseases (65), drought-adapted (63) species often replace less resilient species under prolonged drought conditions. Apart from these, other studies reviewed frequent fires can destroy seedlings, preventing successful establishment (74). Some species have developed adaptations to survive or regenerate after fire. Fire -resistant bark and seed regeneration strategies help certain species persist in fire-prone areas (75). Frequent fires can directly damage or destroy seedlings and young trees, preventing successful establishment. Species that are not fire -resistant or lack fire-adapted traits are particularly affected. Environmental conditions, species identity and interactions with nearby saplings all affect seedling and sapling growth (76).

Conclusion

Disturbance in landscapes reduces less tolerant species and supports the growth of tolerant species. The process reflected in the landscapes of Aravalli Hill and the Vindhya-Malwa regions. Apart from climatic variations, biotic and abiotic disturbances significantly destroy tree species composition, growth and establishment patterns. In general, the landscapes of the Aravalli and Vindhya-Malwa regions are affected by a wide ranges of threats. The region wise assessment indicated a species compositional change, the disparity in richness, establishment deviations are due to long-term disturbance at regional level. The long-term disturbances of this region maltreat the species and change the functions of ecosystem. It reduces the richness and establishment of tree species in the central Aravalli and Vindhya-Malwa regions. The landscapes of this region suffered from fire. That decreases the richness and establishment of tree species. The relationship between tree development stages (seedling, sapling and mature tree) and abiotic factors like forest type, altitude and inter-annual environmental fluctuations is crucial for understanding tree species distributions in regions like the Aravalli and Vindhya-Malwa areas. These relationships are impacted by climate variability, soil properties and anthropogenic pressures like deforestation and fire. Enhancing species richness, promoting forest regeneration and ensuring long-term sustainability lies in developing targeted management strategies.

To maintain plant diversity, safeguard biodiversity following measures are recommended.

- Fire control measures can be implemented in this region.
- Species-specific conservation programs can be planned for important tree species and rare and endangered plants.
- Native fire and drought-resistant species can be promoted by plantation.

To control forest fires in the study area, the following management strategies can be implemented,

- To mitigate fire risks, early warning systems should be established, incorporating remote sensing technology and satellite imagery to monitor fire-prone areas.
- Create firebreaks - strips of land devoid of vegetation - to control the spread of wildfires. Buffer zones between forest areas and human settlements should also be established to reduce the risk of fire igniting due to human activities.
- Engage local communities in fire management by providing them with training and resources to implementing controlled burns under favorable conditions.

For habitat restoration and reforestation, there is a need to implement large-scale reforestation projects with species suited to local conditions. The choice of species should reflect an understanding of their resilience to specific abiotic stressors like drought, fire and soil conditions. Restoration efforts should include measures to improve soil quality and water retention, such as the use of organic mulching, terracing and the restoration of wetlands to ensure a consistent water supply during dry periods. Reconnecting fragmented habitats by creating ecological corridors allow for the movement of species across landscapes. This is particularly important for species that need to migrate to new areas in response to climate change.

The regions affected by any specific long term threats by cutting, lopping and selective removal of tree species influence the species compositions. It resulted in variation in the distribution of tree species and establishments. The following measures are recommended to address the long-term disturbance.

- Effective measures are needed to stop the cutting and lopping activity.

- Selective removal of species must be stopped.
- Species-specific conservation plan for the species should include both growing stages and aim to restore species by extensive plantation.
- Cutting and lopping must be banned during the flowing and fruiting period of the species.

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Authors' contributions

AK participated in data analysis and visualization and drafted the manuscript. SS participated in data analysis. PK participated in data analysis. SR carried out data collection and data curation, participated in data analysis, supervision and investigation, reviewed and edited the final draft. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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