ÉCOSCIENCE

Écoscience

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/teco20

Taxonomic estimates of climbing plants in India: how many species are out there?

Vivek Pandi, Kanda Naveen Babu, Munisamy Anbarashan, C. Sudhakar Reddy, Jishnu Borgohain, Khumukcham Shynyan, Anju Achamma Mathew, H. Rakshith, Jibin Joseph, Vishal Nandha Kennedy & Narayanaswamy Parthasarathy

To cite this article: Vivek Pandi, Kanda Naveen Babu, Munisamy Anbarashan, C. Sudhakar Reddy, Jishnu Borgohain, Khumukcham Shynyan, Anju Achamma Mathew, H. Rakshith, Jibin Joseph, Vishal Nandha Kennedy & Narayanaswamy Parthasarathy (2022): Taxonomic estimates of climbing plants in India: how many species are out there?, Écoscience, DOI: 10.1080/11956860.2022.2094631

To link to this article: https://doi.org/10.1080/11956860.2022.2094631

ÉCOSCIENCE
https://doi.org/10.1080/11956860.2022.2094631

Taylor & Francis
Taylor & Francis Group

Taxonomic estimates of climbing plants in India: how many species are out there?

Vivek Pandi[a], Kanda Naveen Babu[b,c], Munisamy Anbarashan[b], C. Sudhakar Reddy[d], Jishnu Borgohain[c], Khumukcham Shynyan[c], Anju Achamma Mathew[c], H. Rakshith[e], Jibin Joseph[f], Vishal Nandha Kennedy[a] and Narayanaswamy Parthasarathy[c]

[a]Manipal Centre for Natural Sciences, Centre of Excellence, Manipal Academy of Higher Education (MAHE), Karnataka, India; [b]Department of Ecology, French Institute of Pondicherry, Pondicherry, India; [c]Department of Ecology and Environmental Sciences, School of Life Sciences, Pondicherry University, Puducherry, India; [d]National Remote Sensing Centre, Indian Space Research Organization, Hyderabad, India; [e]JSS College, Karnatak University, Karnataka, India; [f]Forest Ecology Department, Kerala Forest Research Institute, Kerala, India

ABSTRACT

We present the first-ever attempt to estimate the taxonomic diversity of climbing plants in India, following the recent APG IV classification. We used more than 100 published and unpublished sources spanning more than a century to compile the extensive list of climbers. Our study revealed that the climbing plants in India are phylogenetically diverse, representing 2624 species radiated across 585 genera and 104 spermatophyte plant families. About two-thirds of the total climbers enumerated from the present study are lianas. Scramblers, in particular, are exclusively woody, unlike twiners and tendril climbers. The diversity of climbing mechanisms varied significantly across the 104 climber families. We also present the revised list of global climbing plant families, adding significantly to the existing dataset. We found that the climber diversity data collected exclusively from the ecological inventories or the taxonomic records underestimated the actual climber diversity by a significant margin. We discuss some of the key constraints in developing a climber database and recommend a replicable model, integrating ecology and taxonomy-based enumerations for the most precise estimate of climber diversity within a defined geographical area. The baseline data generated through our research will find applications in many ecological, taxonomic, phylogenetic, and evolutionary studies on climbers.

RÉSUMÉ

Nous présentons la première tentative d'estimation de la diversité taxonomique des plantes grimpantes en Inde, suivant la plus récente classification APG IV. Nous avons utilisé plus de 100 sources, publiées ou non, couvrant plus d'un siècle, afin de dresser la liste des plantes grimpantes. Notre étude a révélé que les plantes grimpantes en Inde sont phylogénétiquement diversifiées, représentant 2624 espèces parmi 585 genres et 104 familles de plantes spermatophytes. Environ les deux tiers de toutes les plantes grimpantes énumérées dans cette étude sont des lianes. Les plantes rampantes sont exclusivement ligneuses, contrairement aux plantes volubiles ou à vrilles. La diversité des mécanismes grimpants varie significativement parmi les 104 familles. Nous présentons aussi la liste mondiale révisée des familles de plantes grimpantes, en faisant des ajouts importants à la base de données. Nous avons découvert que les données sur la diversité des plantes grimpantes collectées exclusivement lors d'inventaires écologiques ou dans les archives taxonomiques sous-estiment significativement la diversité réelle. Nous discutons certaines des principales contraintes au développement d'une base de données des plantes grimpantes et nous recommandons un modèle réplicable, combinant les dénombrements écologiques et taxonomiques afin d'obtenir l'estimation la plus précise de la diversité des plantes grimpantes d'une région. Les données générées par notre étude seront utiles à plusieurs études écologiques, taxonomiques, phylogénétiques et de l'évolution des plantes grimpantes.

ARTICLE HISTORY
Received 6 March 2022
Accepted 23 June 2022

KEYWORDS
Lianas; phylogenetics; systematics; growth form; climbing mechanism; APG IV

Mots clés
Lianes; phylogénie; systématique; forme de croissance; mécanisme grimpant; APG IV

Introduction

Climbers are plants that lack autonomous vertical growth (Wyka et al. 2013). Although rooted in the ground, they often fail to attain the mechanical strength needed for self-supporting growth (Putz and Chai 1987). Therefore, they rely on external support to ascend the forest canopy (Gentry 1991). Climbers have evolved a variety of climbing mechanisms ranging from stem

CONTACT Vivek Pandi vivek.pandi@manipal.edu Manipal Centre for Natural Sciences, Centre of Excellence, Manipal Academy of Higher Education (MAHE), Madhava Nagar, Manipal, Udupi, Karnataka 576 104, India; Kanda Naveen Babu naveenbabu.k@ifpindia.org Department of Ecology, French Institute of Pondicherry, Pondicherry 605 001, India

Supplemental data for this article can be accessed online at https://doi.org/10.1080/11956860.2022.2094631

twining, tendril climbing, and producing adhesive roots that help them reach the forest canopy for better-lit environments (Muthuramkumar and Parthasarathy 2000; Muthumperumal and Parthasarathy 2010; Vivek and Parthasarathy 2015, 2017; Sperotto et al. 2020). Climbers are either woody (lianas) or non-woody (vines) plants that constitute one of the most conspicuous elements but are not limited to the tropical forest ecosystems (Emmons and Gentry 1983; Gentry 1991; Pérez-Salicrup et al. 2001). Woody climbers can comprise up to 30% of the woody plant diversity in many tropical forest ecosystems (Jongkind and Hawthorne 2005). Freeze-based embolism may limit their distribution within the tropics, but recent studies have shown their fair representation in temperate (Allen 2015) and subtropical ecosystems (Yuan et al. 2009; Malizia et al. 2015). Taxonomically, climbers are among the most diverse growth forms represented in 171 plant families of Gymnosperms, Pteridophytes, and Angiosperms (Gianoli 2015). There are families like Convolvulaceae (55 genera/~1850 species), Cucurbitaceae (97 genera/~ 990 species), and Menispermaceae (72 genera/~450 species) in angiosperms which are exclusively climbers. Nevertheless, Fabaceae is the most speciose climber family in the paleo-tropics by numbers (Putz and Chai 1987; Cai et al. 2009; Anbarashan and Parthasarathy 2013), while Apocynaceae and Fabaceae account for the most species-rich climber family in the Neotropics (Acevedo-Rodríguez et al. 2015 onwards).

Climbing plants have long attracted the interest of many ecologists and evolutionary biologists, owing to the peculiarities associated with this life form (Darwin 1875; Schenck 1892; Isnard and Silk 2009). Although research on climbers gained momentum in the last two decades (Schnitzer et al. 2012; Tang et al. 2012; da Cunha Vargas et al. 2021), the fundamental question of how many climbers are out there is still poorly understood. Firstly, climbers were neglected from many forest inventories because of the difficulties in taxonomical assertion and complexity in measurements, particularly in differentiating the ramets and genets. Further, the challenges in assigning the growth-form and climbing mechanisms among climbers often keep them off the census. For example, different terminologies such as climbing shrubs or scandent shrubs are used frequently in taxonomic surveys as an equivalent for what is otherwise known as a scrambler in ecological inventories. Many taxonomic surveys seldom consider scramblers as climbers however include them in the self-standing category as shrubs or small trees. Secondly, the limited ecological inventories focused on climbers are more inclined toward the lianas, leaving a substantial proportion of herbaceous climbers which may underestimate the global climber diversity by a significant margin. Overall, climbers are either not adequately documented in the ecological inventories or confused with different terminologies used in taxonomic surveys. As a result, we have lower estimates of climber diversity, which may hinder our understanding of their ecological and evolutionary significance.

The climbing plants play a crucial role in structuring and regulating tropical forest ecosystems worldwide (Schnitzer and Bongers 2002). From a structural perspective, climbers add considerably to species diversity and stem counts (Vivek and Parthasarathy 2015), and also provide food resources for the fauna that depend upon them (Parthasarathy et al. 2015). Moreover, they bind the canopy together and facilitate the movement of arboreal animals. Since climbers do not need to invest more in mechanical support, they devote most of their resources to producing leaf and reproductive parts. Thus, they compete aggressively with trees for aboveground and belowground resources, resulting in reduced tree growth and survival (Toledo-Aceves 2015). Growing evidence suggests an increase in the abundance and biomass of climbers, especially in the tropics (e.g., Schnitzer and Bongers 2011; Vivek and Parthasarathy 2018). While the underlying biological mechanisms remain unclear, it is a prerequisite to precisely estimate the climber diversity to comprehend the tangible ecological implications of the increased abundance and biomass of climbers.

India is one of the most biologically diverse countries in the world. The nature of diversity and heterogeneity in landscapes, coupled with the legacies of rich botanical literature in India offers one of the finest platforms to study the taxonomic diversity of climbers. In this study, we ask a simple question: How many species of climbers are there in India and how can we estimate them more precisely? In addition, this study aims to understand the diversity of climbing mechanisms among the Indian climbing flora. We also intend to update the global list of climbing plant families (Spermatophytes) represented at least by one climber species.

Methods

Life-form classification

The increased interest in climbers paralleled the number of terminologies used in literature. We adopted the following terms to be accepted as climbers in the present survey viz. lianas, climbers, woody climber, herbaceous climber, twiner, tendril climber, root climber, straggler, vines, scandent shrub, climbing shrub, semi-scandent, sub-scandent, climbing sarmentose shrub, rambling shrub, rambling climber, scrambling shrub,

scrambling climber, robust climber, hook climber, and branched climbers. However, based on their mode of climbing, we assigned all the climbers broadly under any of the six major climbing categories viz. armed-scramblers (SCR-A), unarmed-scramblers (SCR-UA), stem twiners (ST), tendril climbers (TC), root climbers (RC), and hook climbers (HC).

Data sources, validation, and curation

The present compilation of climbing plants of India is an outcome of an extensive up-to-date literature survey from the number of published sources between 1875 and 2021. We screened a total of 33 published Indian spermatophyte flora, scaling the entire geography, including the Islands of Andaman and Nicobar, for the presence/absence of climbers (Figure 1; Online Resource 1). In addition, we referred to a total of 70 research articles published from India that focused on qualitative and quantitative studies on climbers carried out to date (Online Resource 2). We retrieved the climber data from the national biodiversity characterization database (BIS – Biodiversity Information System (iirs.gov.in)) carried out across 3343 micro-plots (50 m^2 each). Records of the new species discoveries published by the Botanical Survey of India (BSI 2008-2020) were also verified for new species records on climbers in recent times (Plant discoveries (bsi.gov.in). The geo-coordinates reported for the new climber species record were taken from the original publication. The initial screening for climbers yielded 24,829 data points (pooled dataset). While assembling the database, the most time-consuming work was to determine the correctness of those plant species reported by previous workers under different synonyms. In such cases, we made all the nomenclatural changes as per the recent APG IV classification to recognize the valid scientific names (Chase et al. 2016). Though cumbersome, such an effort has removed the synonyms, which otherwise arbitrarily inflate the number of species. We used the WorldFlora R package (Kindt 2020) to match the plant names against the World Flora Online (WFO) taxonomic backbone data (Home (worldfloraonline.org)) as per the APG IV classification (Chase et al. 2016). WorldFlora offers a straightforward pipeline for semi-automatic plant name-checking, and the success rate of credible name matches ranged from 94.7% to 99.9%. Finally, the number of unique entries derived from WFO data was considered final for analysis. The geographical distribution of every species in the final list was verified using relevant sources (Nayar 1980; Nayar et al. 2014; Singh et al. 2015; Rao et al. 2019; Reddy et al. 2021), and those species endemic to India were enumerated. We executed a similar process to assign the conservation status for each species as per the revised IUCN criteria and categories (IUCN 2021). We used Hu et al. (2010), Gianoli's (2015), Acevedo-Rodríguez et al. (2015), Hu and Li (2015) and Gallagher (2015) to compare and update the global climbing plant family list as per the APG IV classification. The sequence of methods followed is in Figure 2 for easy adaptation and replication. We used Microsoft Excel, R Version 4.1.2 (R Core Team 2021), MEGA 11.0.10, and ArcGIS ver. 10.2. for data analysis.

Limitations of the data

Delineation of the geographical boundary

The classical taxonomy works like *The Flora of British India* (1875–97), and *The Flora of the Presidency of Bombay* (1901–03) was first published much before the bifurcation of India, which essentially include species from outside present-day India. However, firstly we filtered out the species unique to those two floras (not reported in any other modern Indian flora and research articles) and verified their distribution range as mentioned in the Flora. We considered species whose geographical distribution fell within the present-day political boundary of India and eliminated the rest.

Lack of precise data at the species-level for climbers (regional and global)

Species-level information was available/retrievable only from the ecological inventories, and comparisons based on such data may give biased results. Yet, we attempted to compare the taxonomic affinity of climbing Flora among different regions based on the family-level information (taxonomic origin) retrieved from the published sources.

Results

We enumerated a total of 2624 climber species that belonged to 585 genera and 104 families (40 orders) of Indian Spermatophyte flora (Table 1). Climbing plants are widely radiated in Indian Flora, representing ~12% of the total Angiosperms and ~13% of the Gymnosperms from 40 orders (62.5%) and 104 families (25% of the known Angiosperm families). Within Angiosperms, the eudicots represented the maximum number of climber species (84%), followed by the monocots (8%) and Magnoliids (7%) (Table 1; Figure 3). Gymnosperms constituted 11 climber species from the orders Gnetales and Ephedrales. Fabaceae was the species-rich climber family in the Indian spermatophyte flora, represented by 383 species (82 genera), followed by Apocynaceae (333 species/79 genera) and

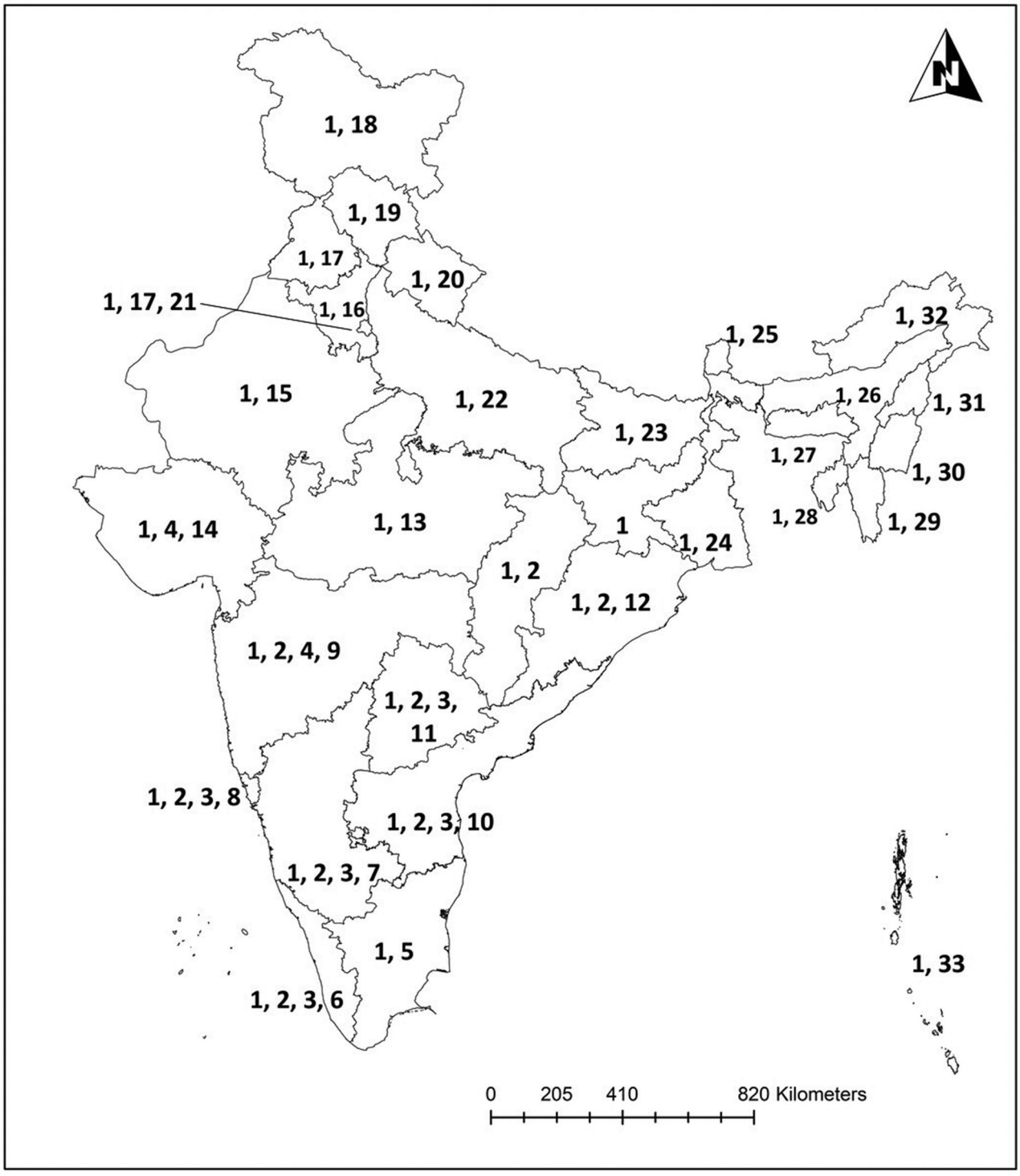

Figure 1. List of floras (1–33) referred to for each state in India. Multiple reference numbers separated by a comma indicate more than one reference. 1 – Flora of British India, 2 – Flora of Peninsular India, 3 – Flora of the Presidency of Madras, 4 – Flora of the Presidency of Bombay, 5 – Flora of the Tamil Nādu Carnatic & Flowering plants of Tamil Nadu, A compendium, 6 – Flora of Kerala 7 – Flora of Karnataka, 8 – Flora of Goa, 9 – Flora of Maharashtra, 10 – Flora of Andhra Pradesh, 11 – Flora of Telangana, 12 – Flora of Odisha, 13 – Flora of Madhya Pradesh, 14 – e-flora of Gujarat, 15 – Flora of Rajasthan, 16 – Flora of Haryana, 17 – Flora of Punjab with Hazra & Delhi, 18 – Flowers of the Himalaya, 19 – Flora of Himachal Pradesh, 20 – Flora of Uttarakhand, 21 – The Flora of Delhi & Flora of Punjab with Hazra & Delhi, 22 – Flora of Uttar Pradesh, 23 – Botany of Bihar and Odisha, 24 – Flora of West Bengal, 25 – Flora of Sikkim, 26 – Flora of Assam, 27 – Flora of Meghalaya, 28 – Flora of Tripura, 29 – Flora of Mizoram, 30 – Flora of Manipur, 31 – Flora of Nagaland, 32 – Flora of Arunachal Pradesh, 33 – Flora of Andaman & Nicobar Islands.

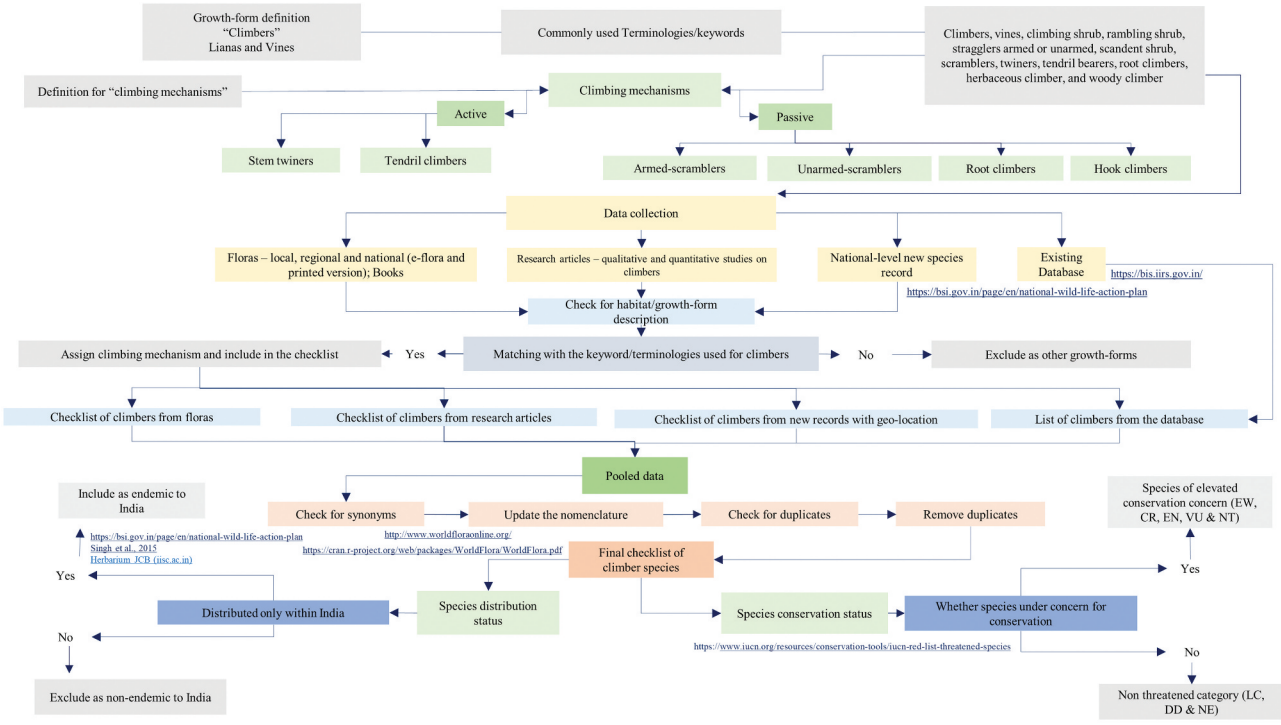

Figure 2. Method followed for the taxonomic estimation of climbing plants in India. Reference links provided for the existing database and new species records are exclusive to India. Commonly used terminologies and keywords for climbers are based on the extensive survey of research articles, flora books, and taxonomical monographs. Additional keywords/terminologies can be considered based on the locally available references.

Convolvulaceae (220 species/26 genera) (Table 1; Figure 4). *Piper*, the root climber, is the most radiated climber genus (80 species), followed by *Ipomoea* (75 species) (Figure 5). Among the six major categories, the majority of the species were stem twiners (1102 species), followed by the unarmed scramblers (741 species) (Figure 6). Fabaceae evolved the maximum diversity of climbing mechanisms (5 types) among the 106 plant families (Table 1). Bignoniaceae and Araliaceae also exhibited diverse climbing strategies (4) with relatively fewer species representations. Only 40% of the families evolved to display multiple climbing strategies (more than one climbing mechanism), while 60% exclusively exhibited one of the six climbing mechanisms (Table 1). Woody climbers (lianas) comprised 63% of the total species diversity, whereas the herbaceous climbers (vines) added 37% to the species richness of climbers in India (Figure 7). The passive climbers (scramblers and hook climbers) in the present survey were exclusively woody, while the active climbers had both woody and herbaceous growth habits. (Figure 8) Over the last decade, a total of 51 climbers were discovered in India at an average of 4.25 ± 2.6 species per year and contributed up to 10% of the total species discoveries (Figure 9; Table 2). Most of the climber species discovered appeared exclusively in the Western Ghats and the Eastern Himalayas (Figure 10). Among 2624 climbers, 520 species (19.8%) were endemic to India, particularly the Western Ghats and the Eastern Himalayas (Figure 11; Online Resource 3). Only twenty-seven climber species from the present survey feature under the IUCN red list category (Table 3). Comparing our dataset with the other major studies, we estimated 196 Spermatophyte plant families globally with at least a single climber representation (Online Resource 4). The Climbing Flora of India showed a greater taxonomic affinity with the Chinese dataset, sharing 54 plant families (Figure 12). The number of shared families decreased from China, Eurasia & North Africa, the Neotropics, and Australia (Figure 12). The number of species added from the taxonomic references (Flora) represented ~90% of the total species richness, whereas data compiled exclusively from the research articles and the species discovery records comprised only 38.26% of the diversity. A comprehensive survey of global climber families yielded 194 flowering plant families (~50% of the Angiosperms) and 196 seed plant families, with 34 new additions to the previous dataset (Online Resource 4).

Table 1. Taxonomic estimate of climber species diversity in the Indian spermatophyte flora. The orders, families, and species are presented following the APG IV classification.

Class	Order	Family	Number of genera	Number of species	Diversity of climbing mechanism
Gymnosperms	Ephedrales	Ephedraceae	1	3	1
	Gnetales	Gnetaceae	1	8	1
ANA grade	Austrobaileyales	Schisandraceae	2	7	1
Magnoliids	Piperales	Aristolochiaceae	2	22	2
		Piperaceae	2	88	1
	Laurales	Hernandiaceae	1	4	1
		Lauraceae	1	2	1
	Magnoliales	Annonaceae	14	73	1
Monocot	Alismatales	Araceae	5	31	3
	Dioscoreales	Dioscoreaceae	1	34	1
	Pandanales	Pandanaceae	1	1	1
		Stemonaceae	1	1	1
	Liliales	Alstroemeriaceae	1	1	1
		Colchicaceae	1	1	1
		Smilacaceae	2	25	1
	Asparagales	Asparagaceae	1	17	1
		Orchidaceae	1	2	1
	Arecales	Arecaceae	4	86	2
	Poales	Flagellariaceae	1	1	1
		Poaceae	6	10	2
	Commelinales	Commelinaceae	1	1	1
Eudicots	Ranunculales	Berberidaceae	1	1	1
		Lardizabalaceae	2	5	1
		Menispermaceae	21	59	2
		Papaveraceae	1	5	1
		Ranunculaceae	4	45	2
	Proteales	Sabiaceae	1	8	2
Core Eudicots	Dilleniales	Dilleniaceae	3	6	1
	Vitales	Vitaceae	11	115	1
	Celastrales	Celastraceae	12	67	3
	Oxalidales	Connaraceae	6	19	2
	Malphighiales	Dichapetalaceae	1	4	1
		Euphorbiaceae	9	23	2
		Linaceae	2	4	1
		Lophopyxidaceae	1	1	1
		Malpighiaceae	6	28	2
		Passifloraceae	4	35	2
		Peraceae	1	1	1
		Phyllanthaceae	4	9	1
		Salicaceae	1	1	1
	Fabales	Fabaceae	82	383	5
		Polygalaceae	2	2	1
	Rosales	Cannabaceae	1	1	1
		Elaeagnaceae	1	4	2
		Moraceae	6	25	3
		Rhamnaceae	10	45	4
		Rosaceae	4	64	1
		Urticaceae	6	7	1
	Cucurbitales	Begoniaceae	1	1	1
		Cucurbitaceae	40	115	1
	Geraniales	Geraniaceae	1	1	1
	Myrtales	Combretaceae	3	32	4
		Melastomataceae	8	13	2
	Sapindales	Anacardiaceae	1	1	1
		Rutaceae	8	27	2
		Sapindaceae	2	8	2

(*Continued*)

Table 1. (Continued).

Class	Order	Family	Number of genera	Number of species	Diversity of climbing mechanism
	Malvales	Malvaceae	9	32	2
		Thymelaeaceae	2	3	1
	Brassicales	Capparaceae	6	39	2
		Resedaceae	1	2	1
		Salvadoraceae	1	2	1
		Tropaeolaceae	1	2	1
	Santalales	Olacaceae	2	5	2
		Opiliaceae	1	3	1
	Caryophyllales	Amaranthaceae	3	3	2
		Ancistrocladaceae	1	6	2
		Basellaceae	2	3	1
		Cactaceae	1	1	1
		Caryophyllaceae	1	1	1
		Nepenthaceae	1	3	1
		Nyctaginaceae	2	5	1
		Phytolaccaceae	1	1	1
		Polygonaceae	5	8	3
	Cornales	Hydrangeaceae	2	2	2
		Cornaceae	1	1	1
	Ericales	Actinidiaceae	1	2	1
		Ericaceae	2	4	1
		Polemoniaceae	1	1	1
		Primulaceae	3	21	1
	Icacinales	Icacinaceae	7	13	3
	Solanales	Convolvulaceae	26	220	1
		Solanaceae	4	14	2
	Gentianales	Apocynaceae	79	333	4
		Gelsemiaceae	1	1	1
		Gentianaceae	4	12	1
		Loganiaceae	2	26	3
		Rubiaceae	21	62	4
	Lamiales	Acanthaceae	8	24	2
		Bignoniaceae	16	25	4
		Gesneriaceae	1	1	1
		Lamiaceae	12	36	2
		Oleaceae	2	51	2
		Orobanchaceae	2	3	2
		Plantaginaceae	3	5	2
		Scrophulariaceae	1	2	1
		Verbenaceae	2	4	2
	Boraginales	Boraginaceae	3	11	1
	Aquifoliales	Cardiopteridaceae	1	1	1
		Stemonuraceae	1	1	1
	Asterales	Asteraceae	12	25	2
		Campanulaceae	2	6	1
	Apiales	Araliaceae	4	14	4
	Dipsacales	Caprifoliaceae	3	16	1
		Viburnaceae	1	1	1

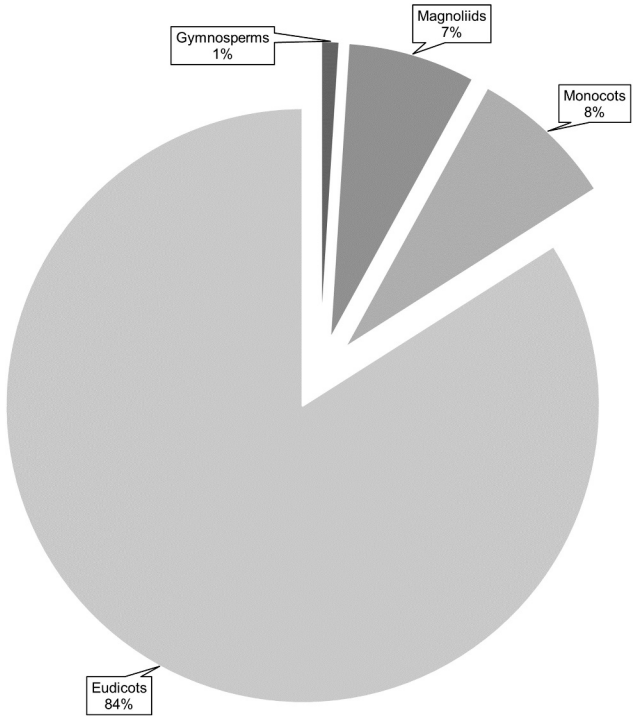

Figure 3. Contribution of various groups within Angiosperms to the climbing plant families distributed in India.

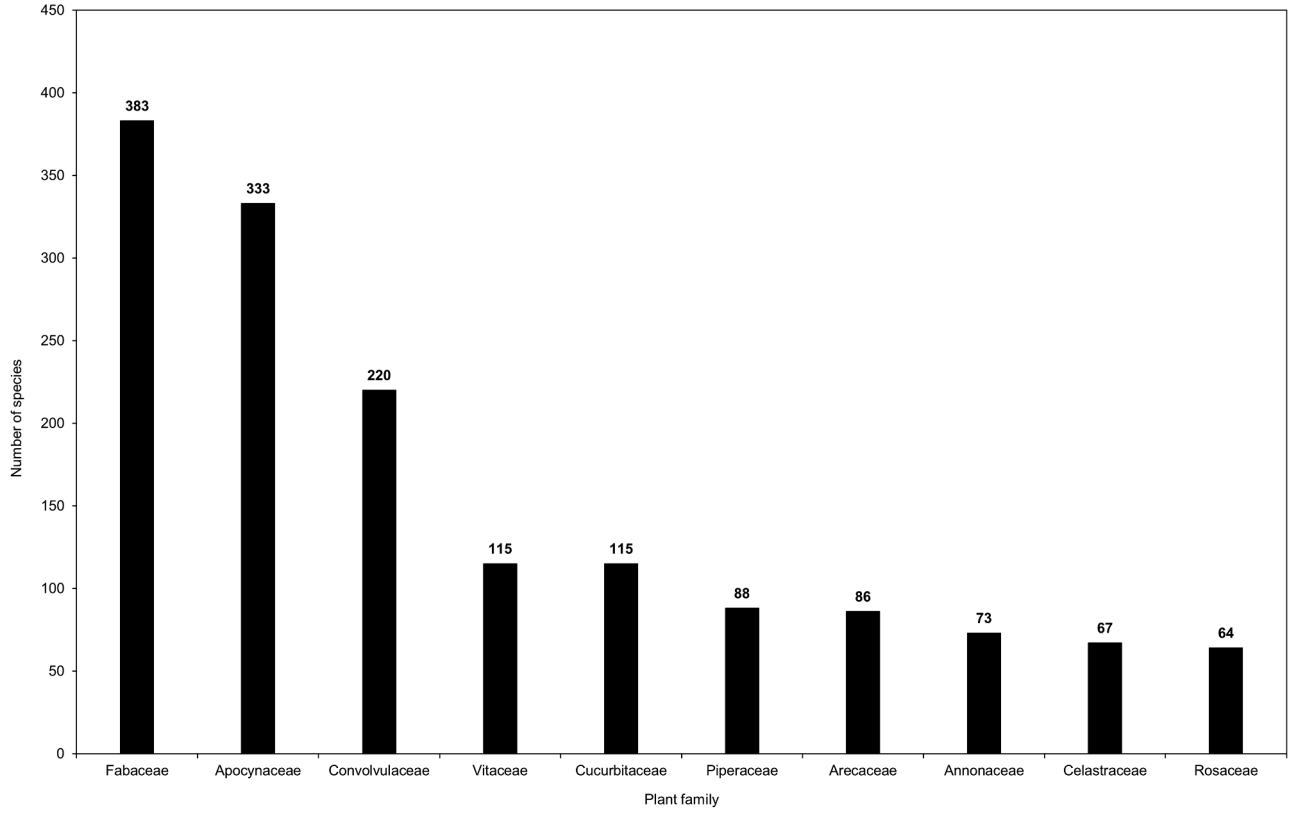

Figure 4. Top-ten species-rich climber families in India with their species representation.

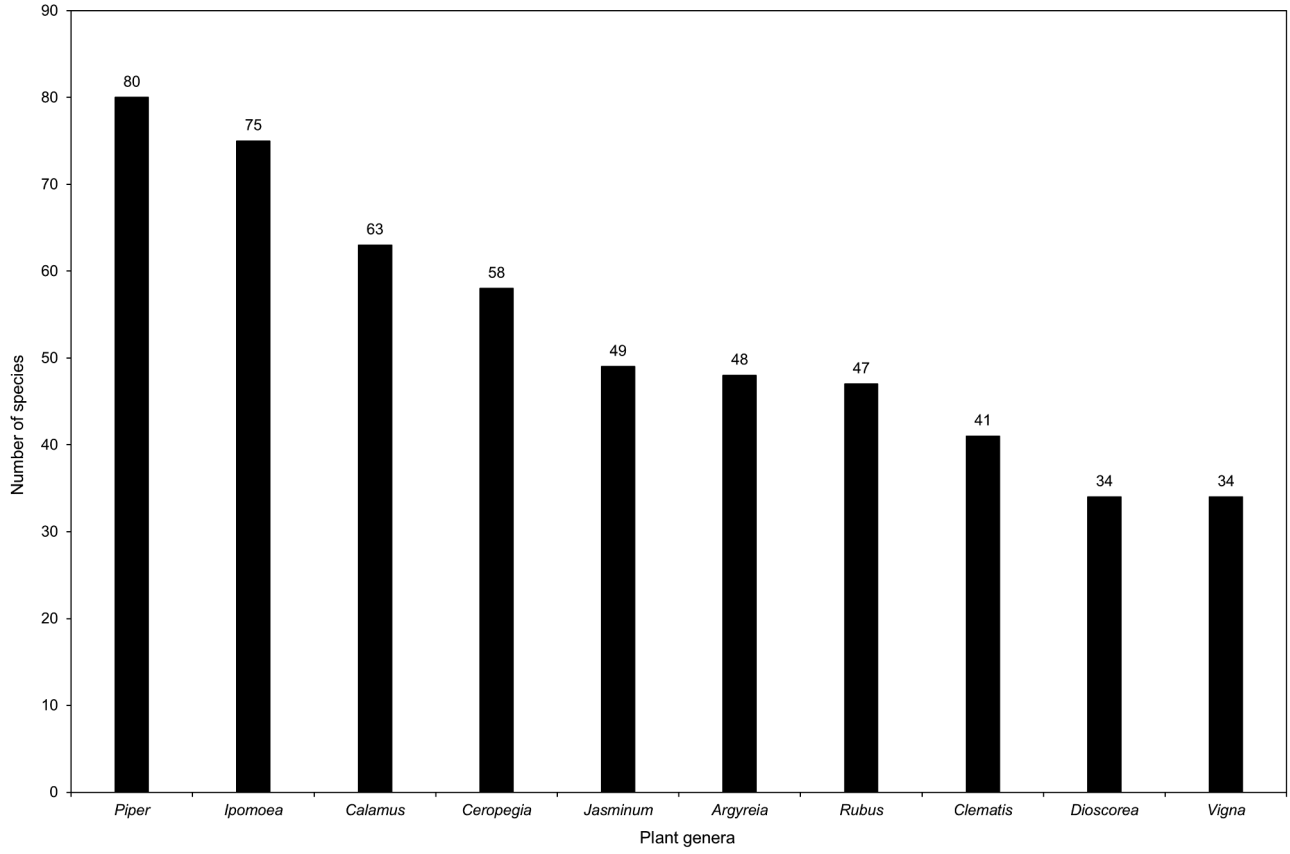

Figure 5. Ten most speciose climber genera in India with their species richness.

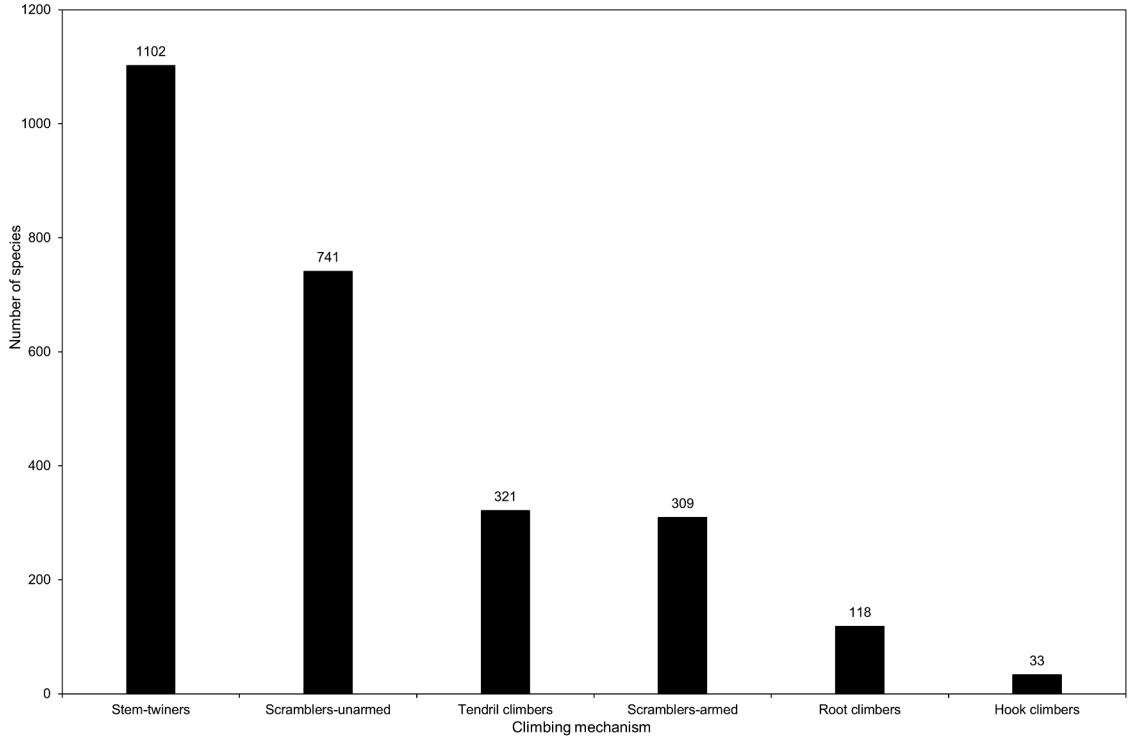

Figure 6. The six major climbing categories and their species representation in the Indian spermatophyte flora.

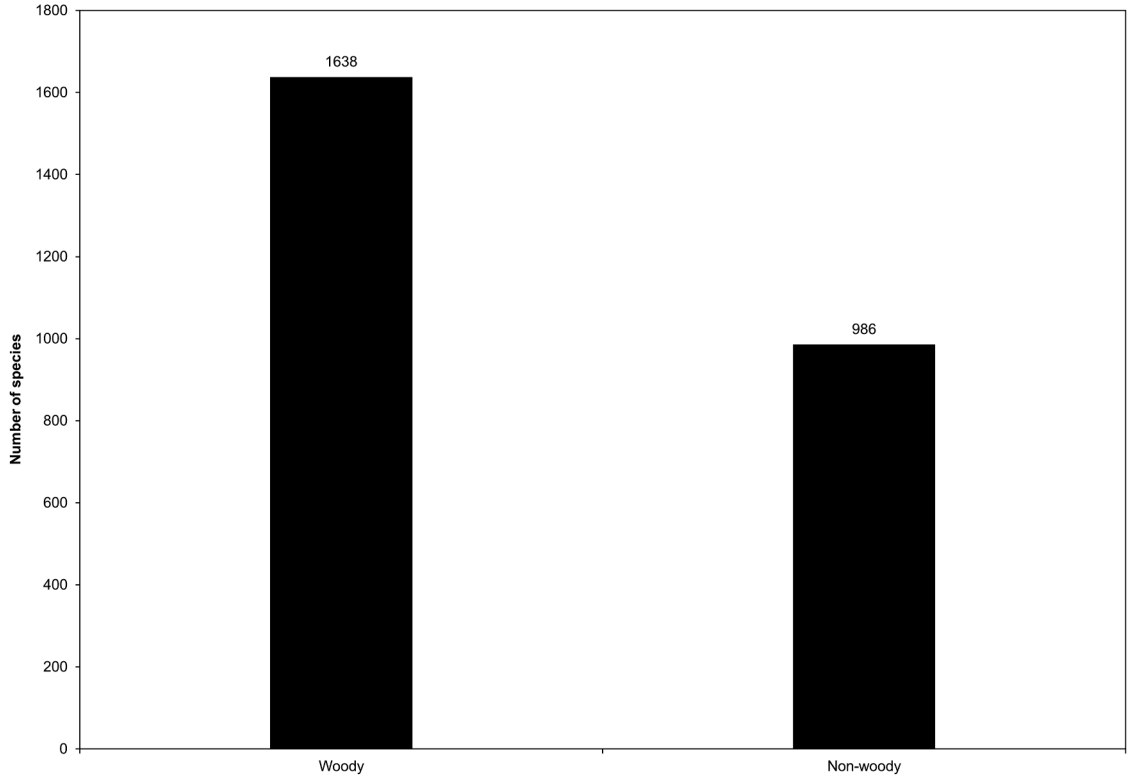

Figure 7. Proportion of woody and non-woody climbers in the Indian spermatophyte flora.

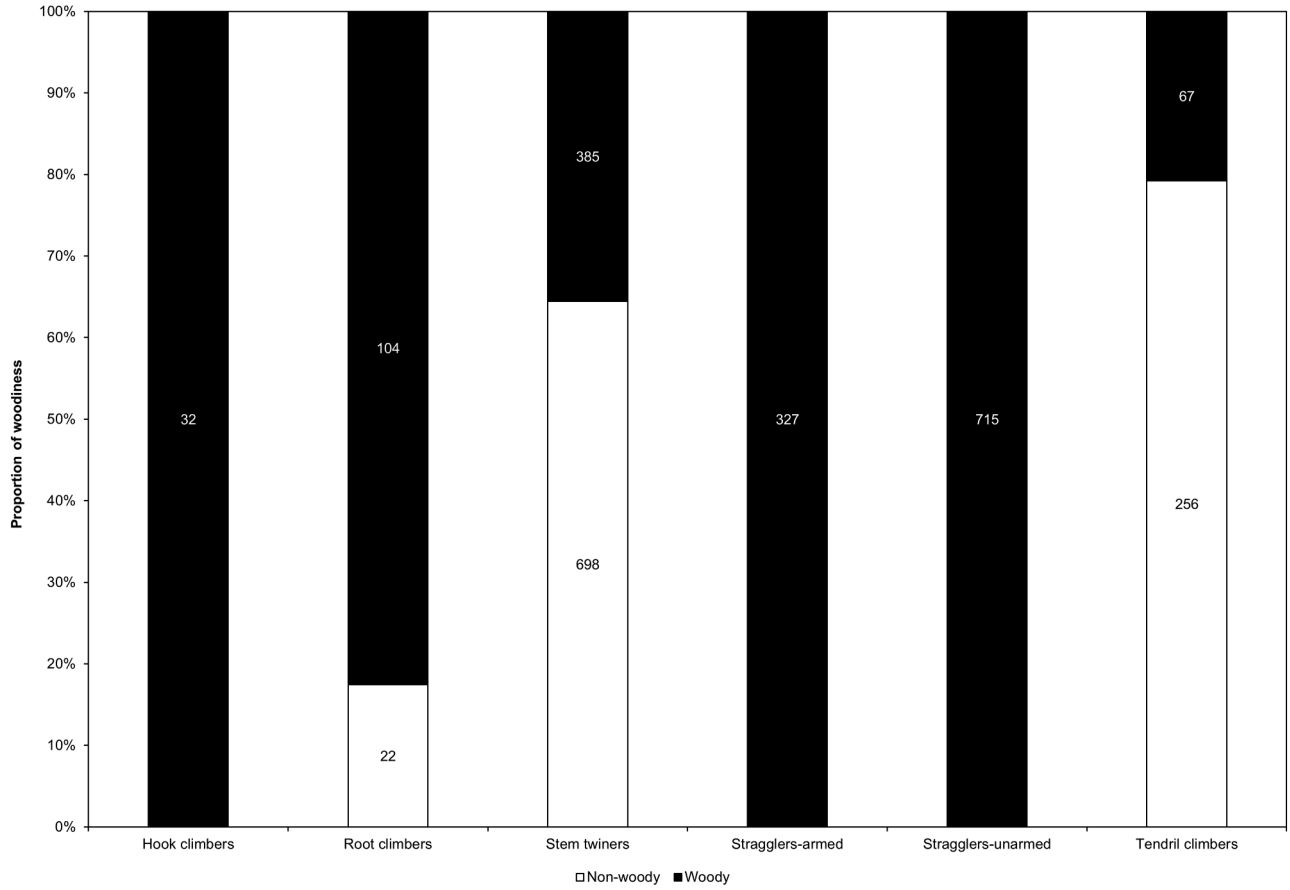

Figure 8. Proportion of woody and non-woody climbers among different climbing mechanisms of the Indian spermatophyte flora.

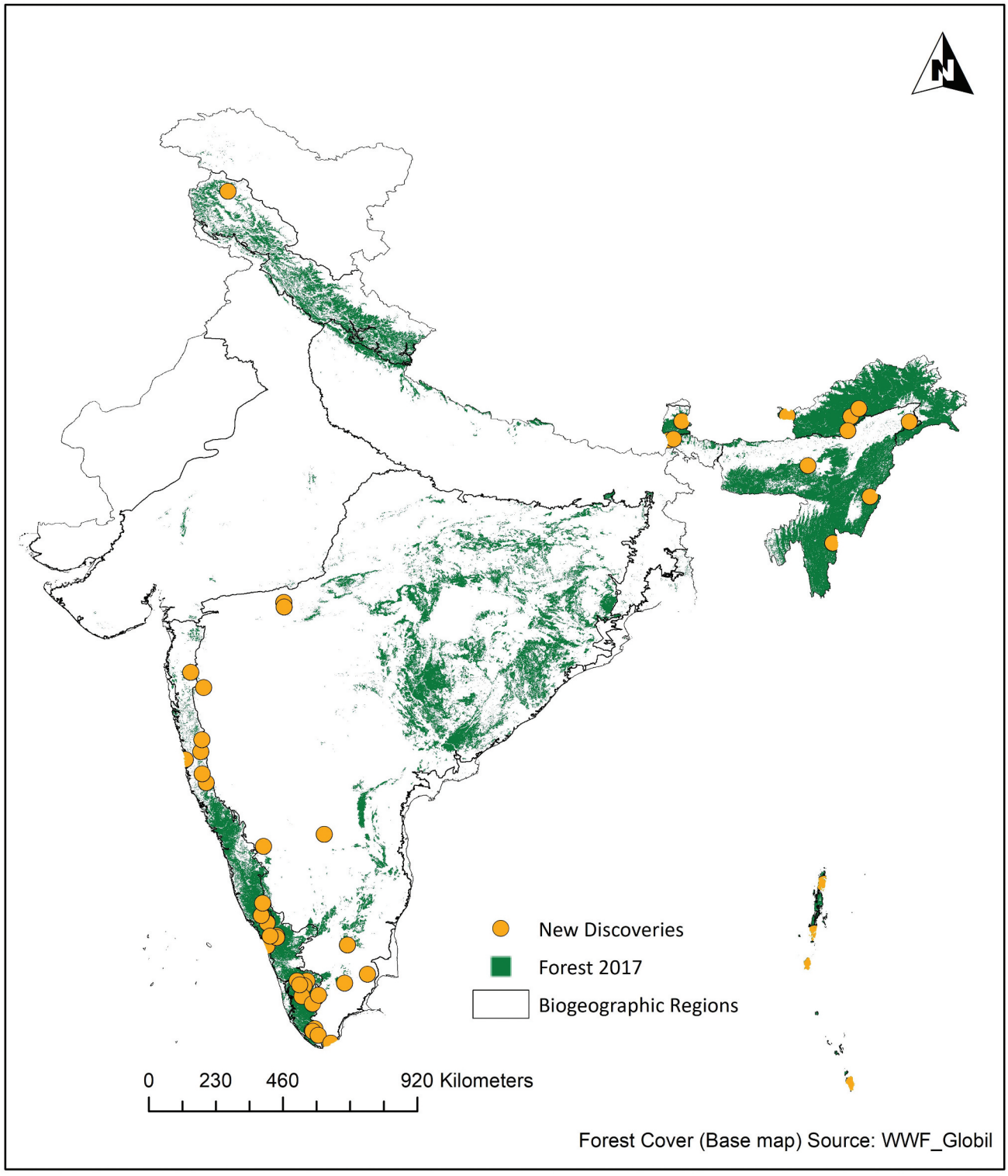

Figure 9. Geographical locations of the new climber species in India discovered over the last decade (2009–2020). Geo-locations for the 51 new species discovery records were taken from the original research articles and .Reddy et al. (2021)

Discussion

Different plant growth forms will have adaptations for ecological and evolutionary significance (Rowe and Speck 2005; Asner et al. 2012). Many, perhaps most of the plant's structural and functional traits are associated with their life forms. For example, whether a plant is a tree or a climber determines its anatomy, physiology, mechanical property, and overall architecture (Rowe and

Table 2. Proportion of climbers in the new species discovery of angiosperms in India over the last decade (2009–2020). Other functional groups include herbs, trees, shrubs, epiphytes, and parasites.

	New species record Angiosperms			
Year	Total records	Climbers	Other functional groups	Proportion of climbers (%)
2009	62	2	60	3.23
2010	69	0	69	0.00
2011	56	1	55	1.79
2012	76	1	75	1.32
2013	68	5	63	7.35
2014	82	4	78	4.88
2015	73	7	66	9.59
2016	101	4	97	3.96
2017	129	8	121	6.20
2018	103	6	97	5.83
2019	85	5	80	5.88
2020	91	8	83	8.79

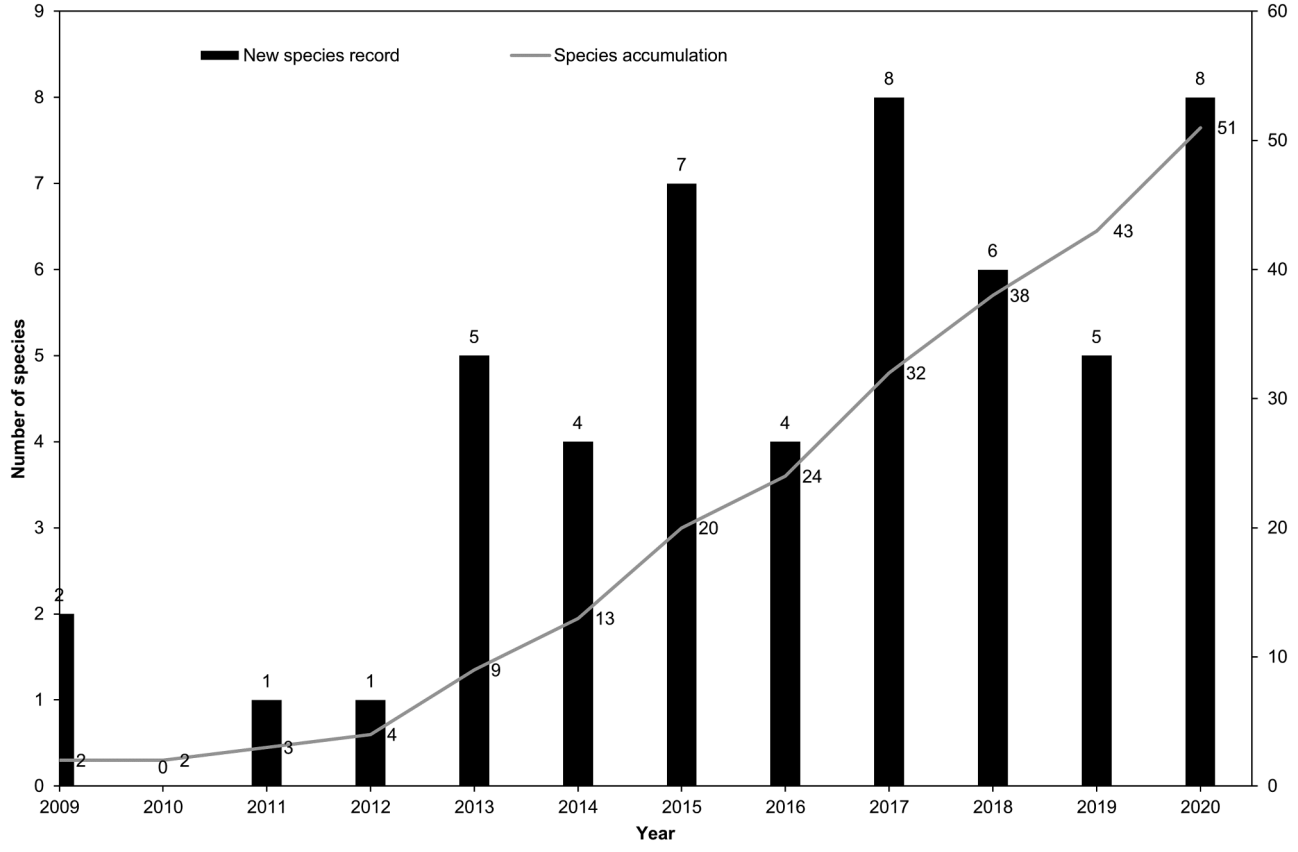

Figure 10. Species discovery and accumulation rates of climbers over the last decade (2009–2020) in India. Data is based on new species records published by the Botanical Survey of India (2009–2020) and Reddy et al. (2021)

Speck 2005). Therefore, understanding the precise growth form is a prerequisite for any ecological or evolutionary studies. Climbers are one of the principal plant growth forms (Wyka et al. 2013), yet neglected in several ecological inventories despite their pivotal role in the tropical forest ecosystems (Schnitzer and Bongers 2002; Bowling and Vaughn 2009). The difficulties in identifying, measuring, and assigning a suitable life-form among climbers are associated with the dense entanglement they form and the exhibition of growth-form plasticity,

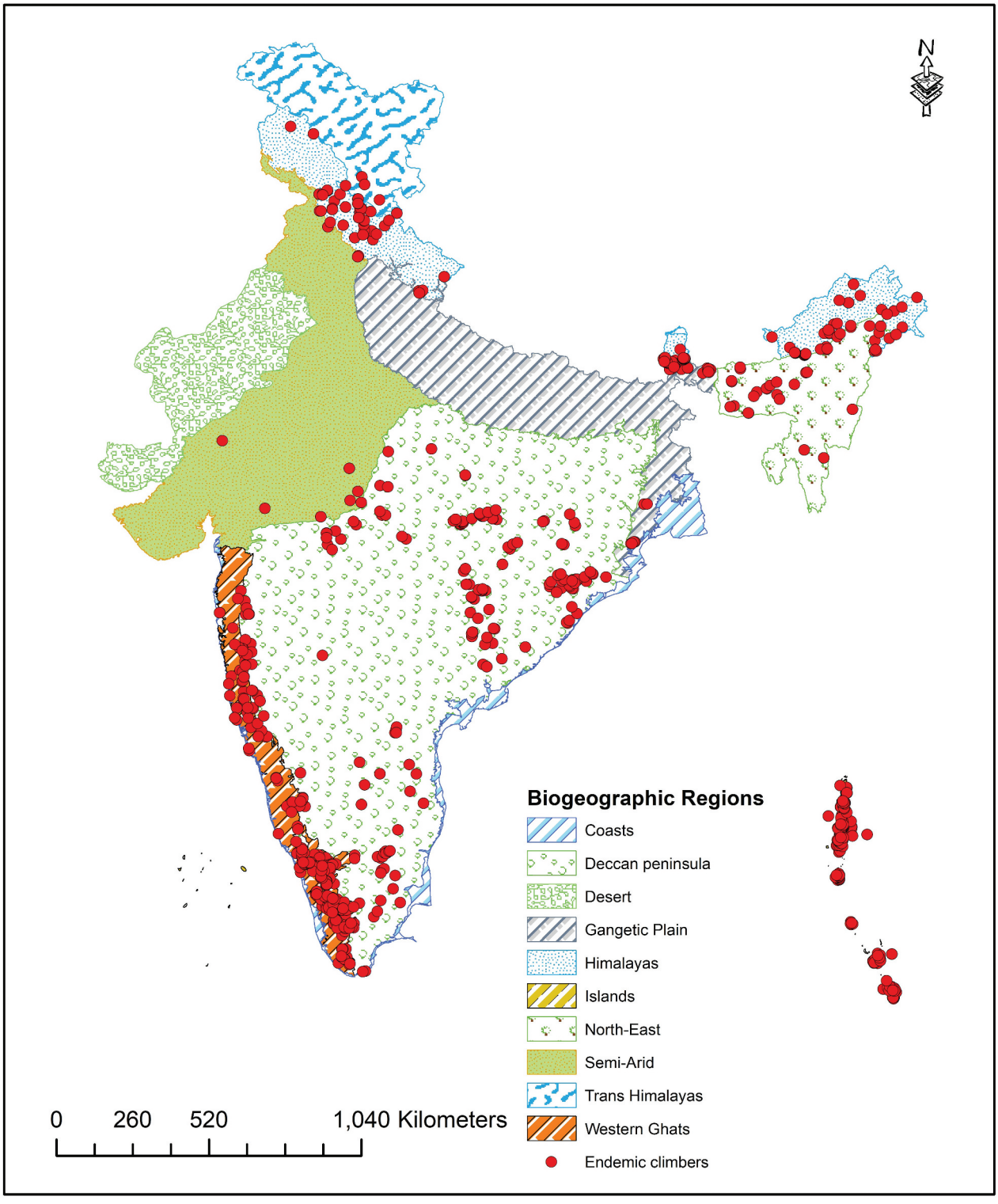

Figure 11. Distribution of endemic climbers in India. Coordinates from Reddy et al. (2021)

which lead to complexities in designating the precise growth-form (Gerwing et al. 2006). In particular, many scramblers are considered climbers in some, while free-standing shrubs in other studies. For instance, *Ziziphus oenoplia*, one of the widespread scramblers in India, has been considered a shrub or small tree or a climber across different studies, leading to the complexity in assigning the growth form Similarly, scramblers like the members of the genus *Capparis* (Capparaceae) are extremely strenuous to classify neatly into a single growth form

Table 3. List of climber species in India of elevated conservation concern according to the IUCN. NT = near threatened; VU = vulnerable; EN = endangered; CR = critically endangered.

Sl. No	Species	Family	Conservation status
1	*Bauhinia diphylla* Buch.-Ham.	Fabaceae	NT
2	*Cayratia pedata* (Lam.) Gagnep.	Vitaceae	VU
3	*Ceropegia anjanerica* Malpure, M.Y. Kamble & S.R.Yadav	Apocynaceae	EN
4	*Ceropegia odorata* Nimmo	Apocynaceae	CR
5	*Dalbergia congesta* Wight &Arn.	Fabaceae	EN
6	*Decalepis hamiltonii* Wight &Arn.	Apocynaceae	EN
7	*Dimorphocalyx balakrishnanii* Chakrab. & Premanath	Euphorbiaceae	EN
8	*Dimorphocalyx beddomei* (Benth.) Airy Shaw	Euphorbiaceae	EN
9	*Dioscorea hamiltonii* Hook. f.	Dioscoreaceae	NT
10	*Eleiotis rottleri* Wight &Arn.	Fabaceae	VU
11	*Gymnema khandalense* Santapau	Apocynaceae	EN
12	*Jasminum azoricum* L.	Oleaceae	CR
13	*Lathyrus odoratus* L.	Fabaceae	CR
14	*Marsdenia floribunda* (Brongn.) Schltr.	Apocynaceae	VU
15	*Microtropis densiflora* Wight	Celastraceae	EN
16	*Nepenthes distillatoria* L.	Nepenthaceae	VU
17	*Nepenthes khasiana* Hook. f.	Nepenthaceae	EN
18	*Olax psittacorum* (Lam.) Vahl	Olacaceae	CR
19	*Piper barberi* Gamble	Piperaceae	EN
20	*Piper pedicellatum* C.DC.	Piperaceae	VU
21	*Rhynchosia heynei* Wight &Arn.	Fabaceae	VU
22	*Salacia oblonga* Wall.	Celastraceae	VU
23	*Salacia talbotii* Baker f.	Celastraceae	NT
24	*Strychnos benthami* C.B. Clarke	Loganiaceae	VU
25	*Utleria salicifolia* Bedd. ex Hook .f.	Apocynaceae	CR
26	*Vigna khandalensis* (Santapau) Raghavan &Wadhwa	Fabaceae	NT
27	*Willughbeia cirrhifera* Abeyw.	Apocynaceae	VU

because of their ability to grow as a bush or as a trailing liana as dictated by the environment. In the present study, for those species designated more than one growth form, we considered the habit described from the Flora with broader geographical coverage, as it would offer a better description of the species based on the multiple occurrences across different habitats. The increased interest in climbers elevated the number of terminologies (Gerwing et al. 2006; Sperotto et al. 2020) and novel methods in classifying them based on their climbing mechanisms (Hegarty 1991). While earlier researchers considered only the twiners and tendril-bearers (Darwin 1865; Schenck 1892), modern studies consider a maximum of nine climbing strategies (e.g., Addo-Fordjour and Rahmad 2015). Since we surveyed and compiled climbers from some of the classical taxonomy works carried out in India, we assigned the climbing mechanisms for those species by referring to the recent manuals including, Floras and pertinent research articles.

Traditionally climbers are considered single functional groups irrespective of the differences in climbing strategies Dias et al. (2021). However, recent studies have reported the divergence of some of the structural and functional traits among the woody climbers with different climbing strategies (e.g., Dias et al. 2021; Vivek and Babu MS unpublished results). Therefore, assigning a suitable climbing mechanism might play a crucial role with the growing consensus on decentralized research on climbers, however, adopting a standard definition and description for climbing mechanisms across the studies Sperotto et al. (2020). Another difficulty encountered during data compilation was the species repetition either because of the synonyms or references from multiple sources published over a time interval of more than 100 years. The nomenclature and family names change over time, where some families are subsumed into one, while some are segregated into many. Therefore, we carried out a thorough systematic revision, following the recent APG IV classification. We removed more than 20,000 entries either as synonyms or duplicates, which otherwise may over-predict the species richness. With about 2600 species, the diversity of climbers in India is vast such that 12% of the Indian angiosperms are climbers against 4% reported from the Australian Flora (Gallagher 2015). However, Hu et al. (2010) reported 2,900 odd species of climbers in China, and

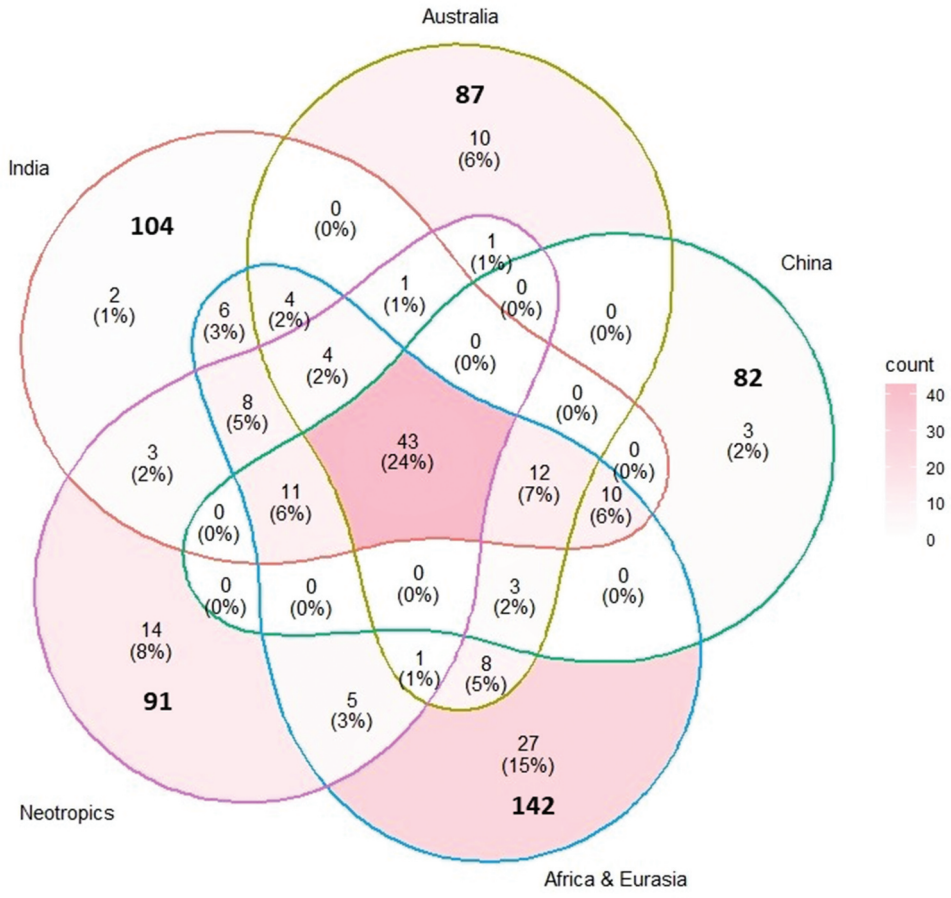

Figure 12. Taxonomic affinity between the climbing plant families of India, Australia, China, Eurasia & North Africa, and the Neotropics. Bold numbers represent the total number of climber families in each region.

Acevedo-Rodríguez et al. (2015) estimated the presence of 10,000 climber species in the Neotropics comprising 10% of the Tracheophytes flora. Though slightly inferior in numbers, the higher levels of endemism depict the uniqueness of Indian climbing flora. In total, 520 species of climbers are endemic to India, which constitute ~20% of the total recorded diversity. Hu et al. (2010) reported 87 species endemic to China. The biogeographical and landscape diversity across India and within Eastern Himalayas (EH) and the Western Ghats (WG) serve as local diversification centres. Further, the different elevation, topographical and bioclimatic gradients of EH and WG offer unique phytogeographical systems to harbour endemic species (Behera et al. 2002; Puyravaud et al. 2003; Muthuramkumar et al. 2006; Gore et al. 2014; Manish et al. 2017). The discovery of climber species at an average of little above four species per year from India supports the unequivocal claim of the global increase in climber species richness (BSI 2009–2020). A spike in recent discovery rates of climbers can be credited with the increased interest and recognition of climbers in many ecological inventories and phytosociological and ethnobotanical studies. The higher endemism and the extent of discoveries in the Eastern Himalayas and the Western Ghats biodiversity hotspot justify the need for special conservation efforts through proper planning and management.

Almost 50% of the total genera of Cucurbitaceae and Convolvulaceae are present in India. Likewise, more than 70% of the genera under Vitaceae constituted the Indian Flora of climbing plants. Although families like Cucurbitaceae and Menispermaceae are exclusively climbers, Fabaceae had the maximum number of species from the present study. Our results are on par with the earlier findings that Fabaceae is the most climber-rich family in the paleo-tropics (e.g., Hu et al. 2010; Anbarashan and Parthasarathy 2013).

We surveyed the list of climbers from the floras based on taxonomic surveys and manuscripts based on the ecological inventories. We found that the estimates based on ecological surveys may under-represent the climber flora of any region depending on the scale of research and whether or not the non-woody climbers are studied. In the current study, a database of climbers

created only from the ecological studies estimated less than 40% of the total climber species richness. The reduced coverage of local climber diversity in ecological inventories is either because of the higher DBH (diameter at breast height) threshold considered during the survey or the limited number of focused studies on climbers, unlike the trees. Most quantitative plant diversity inventories often neglect the non-woody climbers and some woody climbers with legacies of their thin stem, thus reducing the local climber representation from the sample plots. For instance, herbaceous climbers constituted 37% of the overall diversity in the present study, and those species might never qualify for the ecological inventories, thus readily ignoring a minimum of one-third of the actual richness. Excluding the vines, the climber diversity may comprise only the large-bodied lianas, mostly twiners, hook climbers, and scramblers. The size constraints, coupled with the higher proportion of non-woody species, often keep tendril climbers off the census. Overall, going only with the ecological dataset comprising only the woody climbers would underestimate the climber richness by up to 30%. Likewise, the direct climber records sourced from the published Floras of taxonomic origin are incomplete without many scramblers and new species records. Therefore, it is essential to integrate the taxonomic and ecological studies to precisely estimate the diversity of climbers as in the present study.

Interestingly, the scramblers and hook climbers from the present study are exclusively woody, while the twiners and tendril climbers are herbaceous and woody. However, we are unsure if this trend is universal. According to the Fossil climber record database (FRC), the earliest known liana record (398 – 385 mya), *Tetraxylopteris* (Progymnosperms), is a scrambler (Burnham 2015). Progymnosperm-scramblers were also the earliest known plants to develop bifacial cambium (Burnham 2015). Is the present observation of the degree of woodiness among the scramblers somehow related to the origin and evolution of climbing behaviour in plants? Because some of the scramblers in the present compilation reported having dual growth strategies as lianescent and self-supporting plants (Vivek et al. unpublished results). This observation is beyond the scope of this research yet, phylogenetic and molecular studies may provide more insights.

Less than 0.1% of climbers are on the IUCN list under species of elevated conservation concern. Climbers generally perform better under drought and anthropogenic disturbances (Schnitzer 2005, 2015; Cai et al. 2009; Balch et al. 2011). Their ability to do vegetative reproduction, greater fecundity and rigorous germination capacities make them one of the highly competitive life forms in forest ecosystems (Schnitzer and Bongers 2002). However, there are several climber species including *Aganosma cymosa, Ampelocissus latifolia, Aristolochia tagala, Asparagus racemosus, Hemidesmus indicus*, and the endemic species like *Cayratia pedata* that are locally threatened but have not been listed (IUCN), rather not evaluated. Similarly, species such as *Asparagus racemosus, Ichnocarpus frutescens* and *Tylophora indica* are among the most exploited species for their medicinal uses (Pandian and Ravichandran, 2019), which are not evaluated. Although the majority of the economically valuable climbers are available as cultivars, the continued and non-sustainable extraction may make them vulnerable over the long run. For example, *Jasminum azoricum* has been harvested in large quantities for essential oil production and extracts for its medicinal properties (Salim 2016; Hari and Nair 2018), beyond its regeneration potential, placing them under the NT category. We, therefore, recommend evaluating/re-examining the status of a number of threatened/economically valuable climber species based on quantitative methods as a priority.

Gentry (1991) estimated the representation of climbers in at least 131 plant families before three decades. Later, Gianoli (2015) estimated a total of 171 families of Angiosperms, Gymnosperms, and Pteridophytes to have at least one climber species. We updated the list of global climbing plant families with a significant addition of 34 new Angiosperm families, including two unique additions from the present study. A total of 194 flowering plant families roughly constitute 50% of the globally known angiosperm families. These numbers, however, might increase provided we have a similar dataset with extensive coverage of climbers from other regions. The data presented might help link the growth-form evolution within and across many tropical plant families. Climbers and the climbing mechanisms have evolved multiple times within Angiosperms (Gentry 1991; Gianoli 2004). However, our results revealed that climbers have radiated into more families than expected. Families like Fabaceae have evolved five different climbing mechanisms within closely related species. Contrastingly, some families such as Menispermaceae, Piperaceae, and Vitaceae have a single and specific climbing mechanism. According to Gianoli (2015), the macro-evolutionary pattern of association between climbing mode and diversification has not received quantitative attention. These findings may serve as the platform to check Gentry's hypothesis (Gentry 1991; Gianoli 2015), linking climbing mechanisms' diversity to the enhanced diversification potential. The lack of precise climber data at the species level constrained our comparisons at the family level. Indian climbing flora

had a greater taxonomic affinity towards Chinese Flora, with many families overlapping. However, it diminished gradually towards the Neotropics and Australia, revealing the role of geographical proximity in determining species similarity (Leiva et al. 1997). The Eurasian and North-African regions with many unique climber families signify a higher rate of local diversification at the family level. Climbers are diverse geographically and phylogenetically, which merit more attention like trees to have a deeper insight into their role in the forest, origin, evolution, phylogenetic position, and diversification. Thus, it is essential to have precise estimates of climbers' diversity and richness.

Conclusion

Historically climbers have attracted relatively lesser attention when compared to the trees. The present study revealed the taxonomic and phylogenetic diversity of climbers in India. We found that the estimation of climbing plant diversity using a dataset exclusively derived from ecological inventories may underestimate the climber diversity by a significant margin. Likewise, pure taxonomic studies may readily exclude several scramblers. Therefore, we recommend integrating the ecological inventory dataset with the taxonomic records to unambiguously estimate the climber species richness and assign a suitable climbing mechanism. The methodology employed in the present study for reckoning the climber species richness within a defined geographical boundary is one of the most precise and extensive methods carried out to date, and it is replicable with modifications that best suit the region. The updated list of climbing plant families signifies that climbers have radiated into more families than was expected. The observed level of endemism among the Indian climbing flora demonstrated the role of local diversification in promoting species richness. The exhibition of various climbing mechanisms within the confamilials calls for dedicated research. It would be interesting to see how some families have evolved multiple climbing mechanisms while some adopted a specific mode for climbing. Also, is the diversification of climbing mechanisms in the dominant families somehow linked to species diversification? Likewise, the exclusive woodiness among the scramblers from the present study poses a serious question of its universality. Overall, this effort is the first-ever in India and the most precise estimate of climber diversity to date. More contributions from global climber researchers, following similar considerations, will enable the accurate estimation of the world's climbing Flora. When the climbers continue to grow in abundance and diversity globally, this work is a precursor for our efforts towards reaching the global climber database.

Acknowledgments

We thank the reviewers for their valuable comments and suggestions that improved the quality of the manuscript. VP thanks Dr. Prithviraj for his comments on improving this manuscript. KNB thanks the library team, the French Institute of Pondicherry, for providing resources (floras). We thank Siddhi Panchal, Tarangini, Gayathri, Abhinav, Afzal, Alida, Ansa, Finsha, Indushree, Madesh Ram, Mahida, Sameema, Shonima, Swikruti, and Vishal for helping in exporting the list of species from the published articles.

Data availability statement

The datasets used and analysed in this study are available from the corresponding authors on reasonable request.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

Funding was provided by the Manipal Centre for Natural Sciences, Centre of Excellence, Manipal Academy of Higher Education, Manipal, Karnataka, India.

ORCID

Vivek Pandi http://orcid.org/0000-0001-8141-2522
Kanda Naveen Babu http://orcid.org/0000-0001-8134-5024
Munisamy Anbarashan http://orcid.org/0000-0002-0595-1978
C. Sudhakar Reddy http://orcid.org/0000-0002-5979-1412
Narayanaswamy Parthasarathy http://orcid.org/0000-0002-4172-5441

References

Acevedo-Rodríguez P, Ackerman JD, Anderson C, Austin D, Biral L, Calvo J, Delprete P, Dressler S, Feuillet C, Liede-Schumann S, et al. 2015. Lianas and climbing plants of the Neotropics. Washington (DC (USA)): National Museum of Natural History; [accessed 2022 Mar 6]. https://naturalhistory.si.edu/research/botany/research/lianas-and-climbing-plants-neotropics.

Addo-Fordjour P, Rahmad ZB. 2015. Patterns of liana abundance, reproductive traits and liana-tree relationships in relation to forest management in a tropical forest in Ghana. J Sustain Forest. 34(8):832–857. doi:10.1080/10549811.2015.1062783.

Allen BP. 2015. Patterns of liana abundance, diversity and distribution in temperate forests. In: Parthasarathy N, editor. Biodiversity of lianas. New York: Springer; p. 7–15.

Anbarashan M, Parthasarathy N. 2013. Diversity and ecology of lianas in tropical dry evergreen forests on the Coromandel Coast of India under various disturbance regimes. Flora. 208 (1):22–32. doi:10.1016/j.flora.2012.12.004.

Asner GP, Martin RE, Penuelas J. 2012. Contrasting leaf chemical traits in tropical lianas and trees implications for future forest composition. Ecol Lett. 15(9):1001–1007. doi:10.1111/j.1461-0248.2012.01821.x.

Balch JK, Nepstad DC, Curran LM, Brando PM, Portela O, Guilherme P, de Carvalho O Jr, de Carvalho O. 2011. Size, species, and fire behaviour predict tree and liana mortality from experimental burns in the Brazilian Amazon. Forest Ecol Manag. 261(1):68–77. doi:10.1016/j.foreco.2010.09.029.

Behera MD, Kushwaha SPS, Roy PS. 2002. High plant endemism in an Indian hotspot–eastern Himalaya. Biodivers Conserv. 11(4):669–682. doi:10.1023/A:1015596309833.

Bowling AJ, Vaughn KC. 2009. Gelatinous fibres are widespread in coiling tendrils and twining vines. Am J Bot. 96 (4):719–727. doi:10.3732/ajb.0800373.

BSI. 2008-2020. Plant discoveries: new genera, species, and new records. Kolkata (India): Botanical Survey of India; [accessed 2022 March 6]. http://bis.iirs.gov.in/.

Burnham RJ. 2015. Climbing plants in the fossil record: paleozoic to present. In: Schnitzer SA, Bongers F, Burnham RJ, Putz FE, editors. Ecology of lianas. London (UK): Wiley; p. 203–220.

Cai ZQ, Schnitzer SA, Wen B, Chen YJ, Bongers F. 2009. Liana communities in three tropical forest types in Xishuangbanna, South-West China. J Trop For Sci. 21(3):252–264.

Chase MW, Christenhusz MJM, Fay MF, Byng JW, Judd WS, Soltis DE, Stevens PF. 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. Bot J Linn Soc. 181(1):1–20.

da Cunha Vargas B, Grombone-Guaratini MT, Morellato LPC. 2021. Lianas research in the Neotropics: overview, interaction with trees, and future perspectives. J Tree Sci. 35 (2):333–345. doi:10.1007/s00468-020-02056-w.

Darwin C. 1875. The movements and habits of climbing plants. London (UK): John Murray.

Dias AS, Oliveira R, Martins F, Bongers F, Anten N, Sterck F. 2021. Climbing mechanisms as a central trait to understand the ecology of lianas-a global synthesis. Authorea Preprints. doi:10.22541/au.162004148.87250667/v1

Emmons LH, Gentry AH. 1983. Tropical forest structure and the distribution of gliding and prehensile-tailed vertebrates. Am Nat. 121(4):513–524. doi:10.1086/284079.

Gallagher RV. 2015. Climbing plant diversity in Australia: taxonomy, biogeography and functional traits. In: Schnitzer SA, Bongers F, Burnham RJ, Putz FE, editors. Ecology of lianas. London (UK): Wiley; p. 104–115.

Gentry AH. 1991. The distribution and evolution of climbing plants. In: Putz FE, Mooney HA, editors. The biology of vines. Cambridge (UK): Cambridge University Press; p. 3–50.

Gerwing JJ, Schnitzer SA, Burnham RJ, Bongers F, Chave J, DeWalt SJ, Thomas DW. 2006. A standard protocol for liana censuses. Biol Conserv. 38(2):256–261.

Gianoli E. 2004. Evolution of a climbing habit promotes diversification in flowering plants. P Roy Soc Lond B Bio. 271 (1552):2011–2015. doi:10.1098/rspb.2004.2827.

Gianoli E. 2015. Evolutionary implications of the climbing habit in plants. In: Schnitzer SA, Bongers F, Burnham RJ, Putz FE, editors. Ecology of lianas. London (UK): Wiley; p. 239–250.

Gore R, Garad K, Gaikwad S, Gaikwad S. 2014. Endemic flowering plants of northern Western Ghats (Sahyadri Ranges) of India: a checklist. Check List. 10(3):461–472. doi:10.15560/10.3.461.

Hari N, Nair VP. 2018. FTIR spectroscopic analysis of leaf extract in hexane in *Jasminum azoricum* L. Int J S Res Sci Tech. 4 (8):170–172.

Hegarty EE. 1991. Vine-host interactions. In: Putz FE, Mooney HA, editors. The biology of vines. Cambridge (UK): Cambridge University Press; p. 357–375.

Hu L, Li M, Li Z. 2010. The diversity of climbing plants in the spermatophyte flora of China. Biodivers Sci. 18(2):198–207.

Hu L, Li M. 2015. Diversity and distribution of climbing plants in Eurasia and North Africa. In: Parthasarathy N, editor. Biodiversity of lianas. New York (USA): Springer; p. 57–79.

Isnard S, Silk WK. 2009. Moving with climbing plants from Charles Darwin's time into the 21st century. Am J Bot. 96 (7):1205–1221. doi:10.3732/ajb.0900045.

IUCN. 2021. The IUCN Red List of threatened species. Version 2021-2. Gland (Switzerland): International Union for Conservation of Nature; [accessed 2021 November 26] http://www.iucnredlist.org.

Jongkind CCH, Hawthorne WD. 2005. A botanical synopsis of the lianas and other forest climbers. In: Bongers F, Parre MPE, Traore D, editors. Forest climbing plants of West Africa: diversity, ecology and management. Wallingford (UK): CAB International; p. 19–39.

Kindt R. 2020. WorldFlora: an R package for exact and fuzzy matching of plant names against the World Flora Online taxonomic backbone data. Appl Plant Sci. 8(9):e11388. doi:10.1002/aps3.11388.

Leiva MJ, Chapin FS, Ales RF. 1997. Differences in species composition and diversity among Mediterranean grasslands with different history–the case of California and Spain. Ecography. 20(2):97–106. doi:10.1111/j.1600-0587.1997.tb00351.x.

Malizia A, Campanello PI, Villagra M, Ceballos S. 2015. Geographical, taxonomical and ecological aspects of lianas in subtropical forests of Argentina. In: Parthasarathy N, editor. Biodiversity of lianas. New York: Springer; p. 17–42.

Manish K, Pandit MK, Telwala Y, Nautiyal DC, Koh LP, Tiwari S. 2017. Elevational plant species richness patterns and their drivers across non-endemics, endemics and growth forms in the Eastern Himalaya. J Plant Res. 130(5):829–844. doi:10.1007/s10265-017-0946-0.

Muthumperumal C, Parthasarathy N. 2010. A large-scale inventory of liana diversity in tropical forests of South Eastern Ghats, India. Syst Biodivers. 8(2):289–300. doi:10.1080/14772001003723546.

Muthuramkumar S, Parthasarathy N. 2000. Alpha diversity of lianas in a tropical evergreen forest in the Anamalais, Western Ghats, India. Divers Distrib. 6(1):1–14. doi:10.1046/j.1472-4642.2000.00057.x.

Muthuramkumar S, Ayyappan N, Parthasarathy N, Mudappa D, Raman TS, Selwyn MA, Pragasan LA. 2006. Plant community structure in tropical rain forest fragments of the Western Ghats, India. Biotropica. 38(2):143–160. doi:10.1111/j.1744-7429.2006.00118.x.

Nayar MP. 1980. Endemic flora of peninsular India and its significance. Bull Bot Surv India. 22(1–4):12–23.

Nayar TS, Sibi M, Beegam AR. 2014. Flowering plants of the Western Ghats, India, Vols 1,2. Kerala (India): Jawaharlal Nehru Tropical Botanic Garden and Research Institute.

Pandian E, and Ravichandran P. 2019. Diversity and Threatened Climber Plants in Tropical Forests of Courtallam Hills, Southern Western Ghats, India. J Trop for Env. 9(2).

Parthasarathy N, Vivek P, Anil K. 2015. Liana diversity and their ecosystem services in tropical dry evergreen forest on the Coromandel Coast of India. In: Parthasarathy N, editor. Biodiversity of lianas. New York: Springer; p. 17–42.

Pérez-Salicrup DR, Sork VL, Putz FE. 2001. Lianas and trees in a Liana Forest of Amazonian Bolivia. Biotropica. 33(1):34–47. doi:10.1111/j.1744-7429.2001.tb00155.x.

Putz FE, Chai P. 1987. Ecological studies of lianas in Lambir national park, Sarawak, Malaysia. J Ecol. 75(2):523–531. doi:10.2307/2260431.

Puyravaud JP, Davidar P, Pascal JP, Ramesh BR. 2003. Analysis of threatened endemic trees of the Western Ghats of India sheds new light on the Red Data Book of Indian Plants. Biodivers Conserv. 12(10):2091–2106. doi:10.1023/A:1024184814545.

R Core Team. 2021. R: a language and environment for statistical computing. Vienna (Austria): R Foundation for Statistical Computing. https://www.R-project.org/.

Rao K, Raja K, Swamy DK, Arun Singh R, and Gopalakrishna Bhat K. 2019. Flora of peninsular India. Bengaluru (Karnataka (India)): Indian Institute of Science; [accessed 2022 March 6] http://flora-peninsula-indica.ces.iisc.ac.in/ .

Reddy CS, Joseph A, Abraham GA, Sabu MM. 2021. Patterns of animal and plant discoveries, distribution and endemism in India—implications on the effectiveness of the protected area network. Environ Monit Assess. 193(2):62. doi:10.1007/s10661-020-08820-2.

Rowe N, Speck T. 2005. Plant growth forms: an ecological and evolutionary perspective. New Phytol. 166(1):61–72. doi:10.1111/j.1469-8137.2004.01309.x.

Salim SAA. 2016. In Vitro regeneration of *Jasminum azoricum* L: an important ornamental and medicinal plant. Int J Pharm Sci Res. 2(3):122–127.

Schenck H. 1892. Beiträge zur biologie und anatomie der lianen im besonderen der in Brasilien einheimischen arten. In: Schimper AFW, editor. Botanische mittheilungen aus den tropen. Jena (Germany): Verlag von Gustav Fischer; p. 1–253.

Schnitzer SA, Bongers F. 2002. The ecology of lianas and their role in forests. Trends Ecol Evol. 17(5):223–230. doi:10.1016/S0169-5347(02)02491-6.

Schnitzer SA. 2005. A mechanistic explanation for global patterns of liana abundance and distribution. Am Nat. 166 (2):262–276. doi:10.1086/431250.

Schnitzer SA, Bongers F. 2011. Increasing liana abundance and biomass in tropical forests: emerging patterns and putative mechanisms. Ecol Lett. 14(4):397–406. doi:10.1111/j.1461-0248.2011.01590.x.

Schnitzer SA, Mangan SA, Dalling JW, Baldeck CA, Hubbell SP, Ledo A, Yorke SR, Tobin MF, Aguilar S, Brassfield D. 2012. Liana abundance, diversity, and distribution on Barro Colorado Island, Panama. PLoS ONE. 7(12):e52114. doi:10.1371/journal.pone.0052114.

Schnitzer SA. 2015. Lianas in forest ecosystems. In: Peh KSH, Corlett RT, Bergeron Y, editors. Routledge handbook of forest ecology. New York: Routledge; p. 201–213.

Singh P, Karthigeyan K, Lakshminarsimhan P, Dash SS. 2015. Endemic vascular plants of India. Kolkata (India): Botanical Survey of India.

Sperotto P, Acevedo-Rodríguez P, Vasconcelos TN, Roque N. 2020. Towards a standardization of terminology of the climbing habit in plants. Bot Rev. 86(3–4):180–210. doi:10.1007/s12229-020-09218-y.

Tang Y, Kitching RL, Cao M. 2012. Lianas as structural parasites: a re-evaluation. Sci Bull. 57(4):307–312. doi:10.1007/s11434-011-4690-x.

Toledo-Aceves T. 2015. Above and belowground competition between lianas and trees. In: Schnitzer SA, Bongers F, Burnham RJ, Putz FE, editors. Ecology of lianas. London (UK): Wiley; p. 147–163.

Vivek P, Parthasarathy N. 2015. Liana community and functional trait analysis in the tropical dry evergreen forest of India. J Plant Ecol. 8(5):501–512. doi:10.1093/jpe/rtu031.

Vivek P, Parthasarathy N. 2017. Patterns of tree-liana interactions: distribution and host preference of lianas in a tropical dry evergreen forest in India. Trop Ecol. 58(3):591–603.

Vivek P, Parthasarathy N. 2018. Contrasting leaf-trait strategies in dominant liana and tree species of Indian tropical dry evergreen forest. Flora. 249:143–149. doi:10.1016/j.flora.2018.11.002.

Wyka TP, Oleksyn J, Karolewski P, Schnitzer SA. 2013. Phenotypic correlates of the lianescent growth form: a review. Ann Bot. 112(9):1667–1681. doi:10.1093/aob/mct236.

Yuan CM, Liu WY, Tang CQ, Li XS. 2009. Species composition, diversity, and abundance of lianas in different secondary and primary forests in a subtropical mountainous area, SW China. Ecol Res. 24(6):1361–1370. doi:10.1007/s11284-009-0620-7.