Indian Arachnology (order: Araneae) in the 21st century: trends, gaps and future prospects

Irina Das Sarkar*, Manju Siliwal and V. P. Uniyal

Wildlife Institute of India, Dehradun 248 001, India

Although Indian Araneae research over the last 20 years has provided insights into spatio-temporal diversity patterns, we lack a methodical synthesis of the work, resulting in knowledge blind spots for answering more pressing questions of ecology and conservation for the taxon. In this study, we present a comprehensive review of the status of Indian arachnological research spanning the 21st century. We find a systematic bias in research (>80%) towards inventories and taxonomic descriptions, with little work on aspects of ecology, biogeography and phylogeny, thereby impairing conservation efforts. Compared to global research advancements, much of the Indian data seems to be qualitative with under-documentation from several important ecozones, highlighting an urgent need to initiate systematic research to achieve a more comprehensive understanding of the Araneae fauna of the country for inclusion in conservation and policy-making.

Keywords: Arachnology, conservation and policy-making, current trend, ecology, future perspectives.

INVERTEBRATES dominate terrestrial biodiversity, accounting for more than 80% of the extant species[1]. The variation of invertebrates in global distribution, body morphology, habitat selection, and vital ecosystem roles (serving as prey and predator across trophic levels) makes them ecologically and economically indispensable[1,2]. However, despite their pivotal role, invertebrates often remain neglected in conservation and biodiversity policies[3,4], primarily owing to the common perception that insects and spiders are potential pests and threats to general well-being[1]. Acknowledging that 'arachnology' refers to the study of all arachnids (spiders, scorpions, ticks, mites and harvestmen), within the scope of this article, the term is restricted to the study of spiders (order Araneae).

Among invertebrates, spiders are widely established as a successful predatory group[5] represented by 49,525 species globally[6]. They constitute the seventh largest order in the animal kingdom and are of considerable research interest due to their high diversity and wide generalist predatory preferences[7]. Their abundance and prey regulation in agricultural and natural terrestrial ecosystems make them an effective model group to assess patterns of ecosystem services[8,9]. Spiders have been empirically used as indicators of changes in habitat structure and properties[10–15]. The voracious feeding habits of spiders, cumulating to large quantities of prey masses within, but not limited to agricultural settings[8], make them efficient pest control agents (e.g. *Phyllloneta impressum* (L. Koch, 1881) preferentially feed on aphids, while *Philodromus* spp. feed on ciccadelids or caterpillars)[9,16]. They also serve as key elements in predator–prey interactions, providing a significant prey-base to higher fauna, while exhibiting broad feeding strategies. The multitrophic roles of spiders make them critical elements in terrestrial ecosystems. In addition to their agronomic and ecological values, spider venom has shown potential as a candidate for medicinal drug research, bioinsecticides and antimicrobial agents[17–21]. Notwithstanding their crucial role in ecosystem functioning, the taxon has seldom been included in conservation strategies in the Indian context. The required prioritization of this group is impeded by the limitation of knowledge with respect to their true diversities, distribution, variability across temporal and spatial gradients, and ecological sensitivity to habitat changes[1]. These information gaps coupled with the lack of systematic assessments and corroborative data of tropical species hinder conservation strategies leading to a disproportionate representation of the group[1].

Taxonomic arachnological study at the national level was initiated as early as 1864 by Blackwall[22], followed closely by Stoliczka[23], and the field has since then been furthered by several prominent researchers[24–28]. Taxonomic knowledge of Indian spiders in the 20th century was furthered by various studies[29–39]. Narayan[40], Mukerjee[41] and Bhattacharya[42–46] were among the first Indians to further the field of arachnology, primarily enlisting common spiders of the country. Contributions in the second half of the century were prominently made by other researchers[47–57]. This was followed by the major contributions by Tikader[58–69], documenting spider diversity across the subcontinent cumulating in an expansive taxonomic literature collection for the country. He described several new species, both to science and India, alongside detailing species from well-defined geographic zones[60–63,65,67,68]. Tikader[70] also published the first comprehensive checklist of Indian spiders. Several researchers contributed to western, central, and North Indian spider records, along with some sporadic records from South India[71–104]. Vijayalakshmi and Ahimaz[105] also contributed to drawing common, though not necessarily scientific, attention to the field of Indian arachnology.

*For correspondence. (e-mail: irina.dassarkar@gmail.com)

Arachnological studies of the 21st century thus far (2000–20) have been furthered by several prominent institutions and laboratories, independently and in collaboration, contributing to much of the contemporary literature, and an overall inclusion of the faunal group into mainstream scientific forums. Despite the existence of more than 400 published research articles on spiders, it is unclear how these studies relate to broader research thematics. This essentially points to a knowledge blind spot wherein, although we possess field-based information on species diversity, there is little to no comprehensive information on the ecological translation of the data from a larger perspective.

The primary aim of this study is to present a comprehensive review of the status of arachnological knowledge of the current century across India's spatial width within a bi-decadal timeframe (2000–20). By a thorough collation of scientific arachnological literature, we assess the nature of the thematic, spatial and temporal distribution of arachnological research across the Indian states and Union Territories (UTs), and identify evident gaps and information blind spots that need further systematic evaluation.

Methods

An extensive keyword-based literature survey of the available arachnological literature was undertaken using Google Scholar and World Spider Catalog to collate arachnological data published between 1 January 2000 and 31 December 2020. The following keywords pertaining to the field were searched in exhaustive combinations to identify the relevant literature: Araneae/spider diversity, checklist, taxonomy, community assemblages, traditional knowledge, ethnozoology, genetics, evolution, biological indication/control, integrated pest management (IPM), silk, India. Academic theses and media articles were excluded owing to a lack of homogenous digitization. Each identified publication was then filtered by: (1) the broad thematic research category; (2) the states/UTs that the research pertains to and (3) the publication year. For the first cataloguing, articles were clubbed under one of the seven broad categories: taxonomy, diversity, behaviour, community ecology, conservation, ethnozoology, and miscellaneous. For the second, states/UTs represented in the literature were accounted for. Several studies on arachnological knowledge of the country as a whole were pooled together rather than considering them as state-specific records.

All publications pertaining to new/first reports of any species/genera/family along with a taxonomic revision of any of them were clubbed under the category of 'taxonomy'; these papers included reports of species described as new to science and/or new records for the country. All the literature pertaining to spatial and temporal Araneae diversity, including but not limited to bio-inventories, were clubbed under 'diversity'. All the literature that elaborated on species or group-specific behavioural aspects, including annotations of natural histories were categorized as 'behaviour'. The class of 'community ecology' included the literature that viewed community assemblages across various spatial scales along with studies that aimed to establish the group as bio-indicators and natural pest control agents. 'Conservation' studies highlighted the need to include the taxon in conservation initiatives or described the species of conservational importance. The literature that described the involvement of spiders in local traditional medicinal usage and/or for zootherapeutic uses was grouped under 'ethnozoology'. All studies that did not directly and/or indirectly fall under the purview of the above-mentioned categories were clubbed as 'miscellaneous' for ease of comprehension. The unpublished literature entailing doctoral or dissertation reports was not considered in the current list. Details of the recorded literature with spatial, temporal and thematic categorization have been provided as supplementary material.

Results

A total of 421 arachnological studies were identified through an extensive literature survey over a bi-decadal timeframe (2000–20), across various research categories ranging from taxonomic advances to pharmacological aspects. The literature pertaining to diversity and taxonomic research accounted for 175 (42%) and 172 (41%) articles respectively, thereby constituting the majority (83%) of the focal work in India (Figure 1). Research relating to community ecology accounted for 31 articles representing 7.4% of the data, behavioural studies were represented by 23 publications (5.5%), research pertaining to ethnozoology and conservation accounted for five publications each (1%), and miscellaneous research accounted for 10 publications (2%) (Figure 1).

Temporally, there was a gradual increase in arachnological publications in the country. The second-half of the bi-decadal frame (2010–20) accounted for 315 publications (75%) compared to only 106 (25%) articles between 2000 and 2009 (Figure 2). The recent decade also represents 78% of the total diversity (137) and 77% of the taxonomic (132) studies, in addition to accounting for 55% of community ecology (17) and 78% of behavioural (18) research (Figure 3). The year 2020 represents the most published year with 70 articles, of which diversity and taxonomic studies accounted for 25 (36%) and 32 (46%) publications respectively (Figure 2). However, ethnozoological and conservational studies have declined in the recent decade, with only four and three published literature respectively, in the former decade from a total pool of five publications each (Figure 3).

Taxonomic and diversity studies in India followed a synergistic pattern for most of the study timeframe, with one category preceding the others quantitatively, with a few exceptions (e.g. 2002) (Figure 4). These dominant categories exhibited an accelerating trend in publication frequency throughout most of the timeline. Research assessing

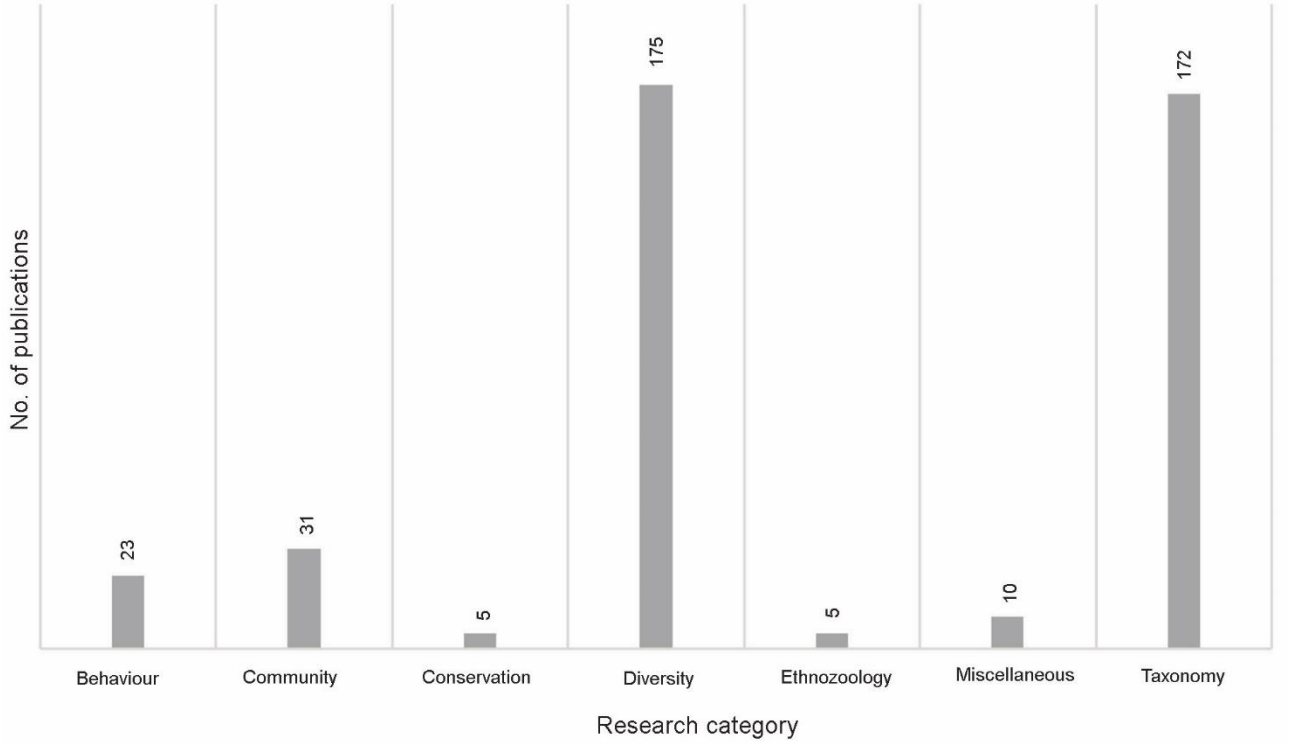

Figure 1. Category-wise publication trend highlighting the total number of publications under each thematic category from 2000 to 2020.

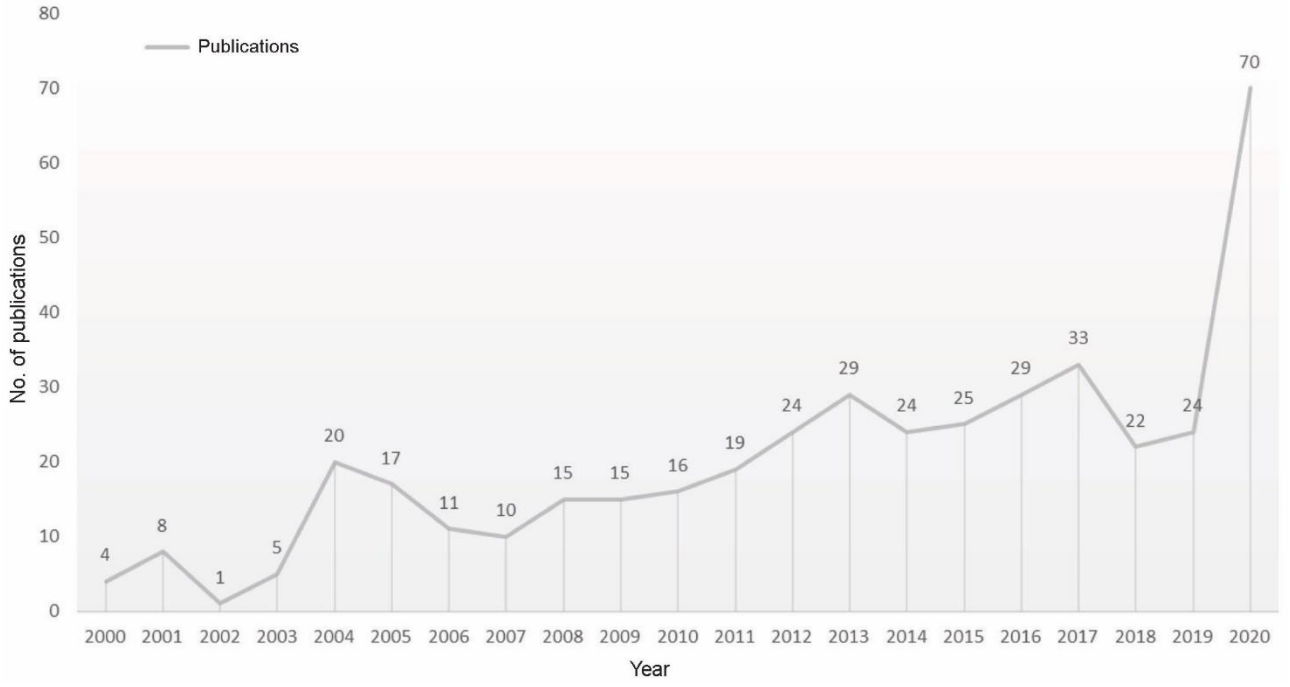

Figure 2. Temporal publication trend highlighting the total number of publications per year from 2000 to 2020.

community ecology followed a staggered trend peaking in 2008 ($n = 5$) while being absent for 33% of the timeframe (Figure 5). Spider behavioural studies were found to alternate between 0 and 2 articles from 2000 to 2016, followed by a categorical peak post-2017, with the highest number of publications in 2020 ($n = 7$). Studies pertaining to conservational aspects were represented in only five temporal bursts, highlighting the complete absence of the category for 76% of the timeframe. Similarly, ethnozoological and other miscellaneous studies appeared thrice and four times

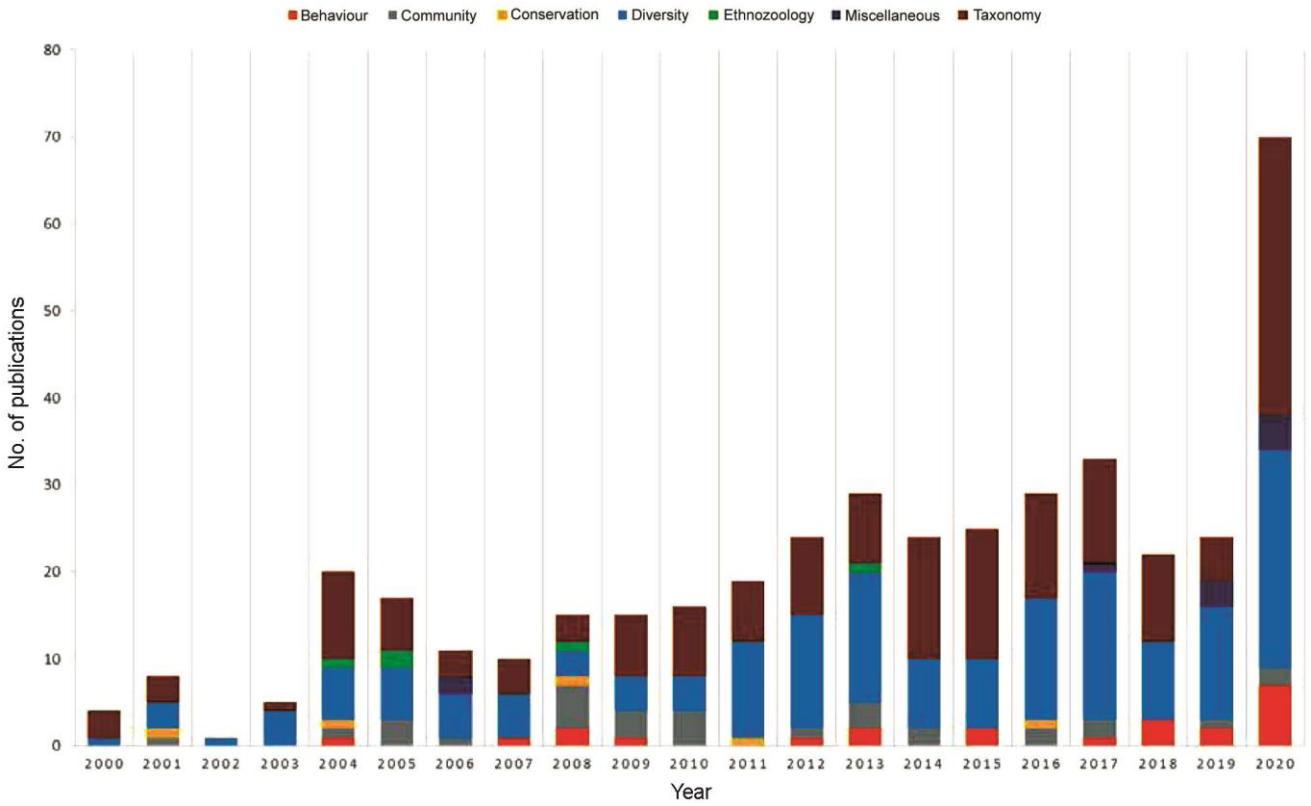

Figure 3. Trend highlighting the total number of publications under each thematic category per year from 2000 to 2020.

Figure 4. Trend highlighting the total number of publications under the dominant categories (diversity and taxonomy) published per year from 2000 to 2020.

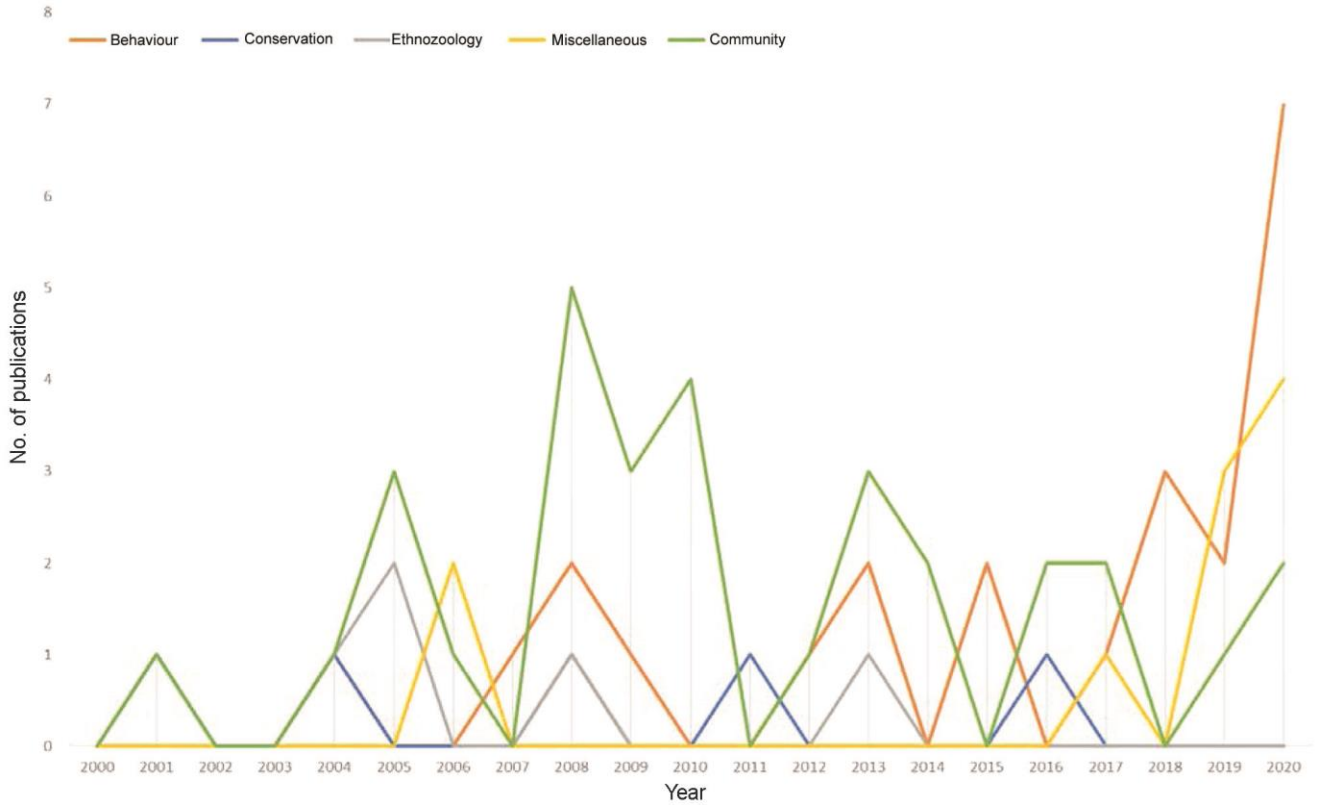

Figure 5. Trend highlighting the total number of publications under other categories published per year from 2000 to 2020.

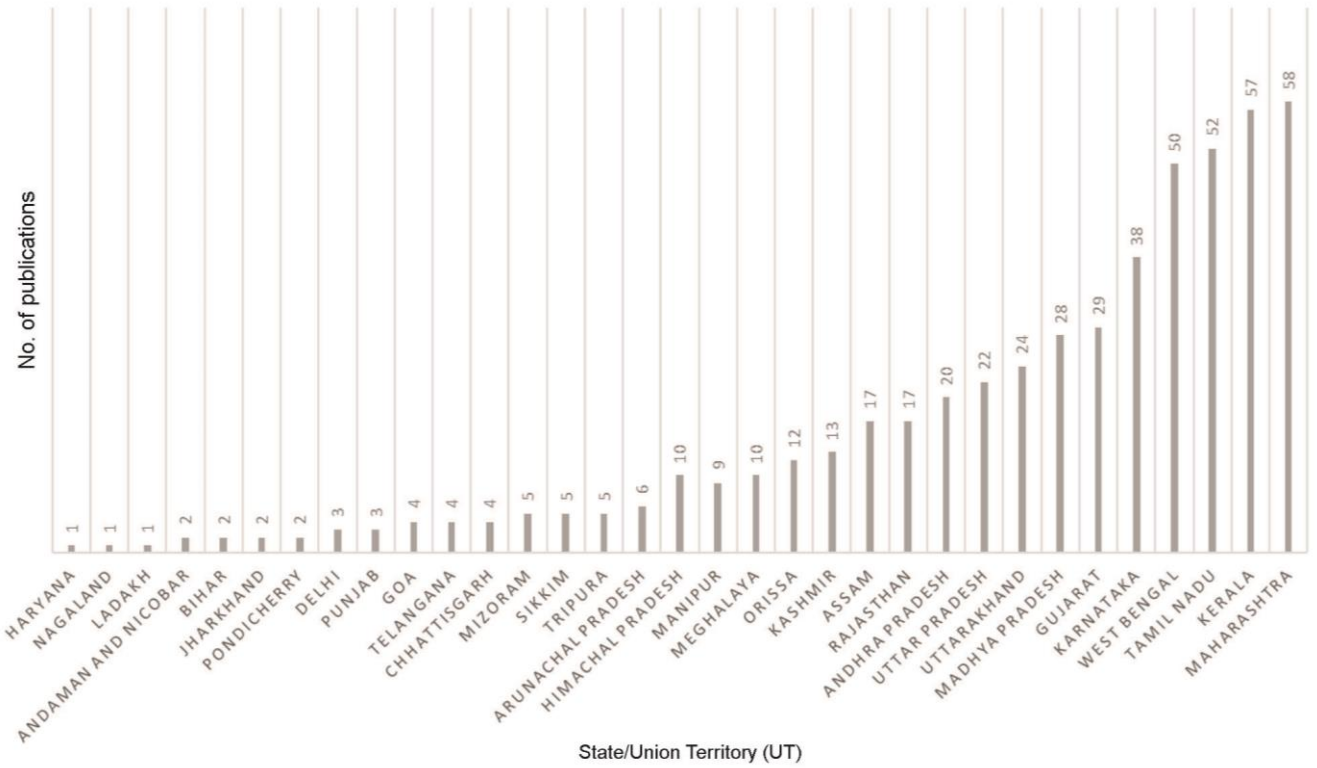

Figure 6. Spatial trend highlighting the total number of publications furnished per Indian state/Union Territory (UT).

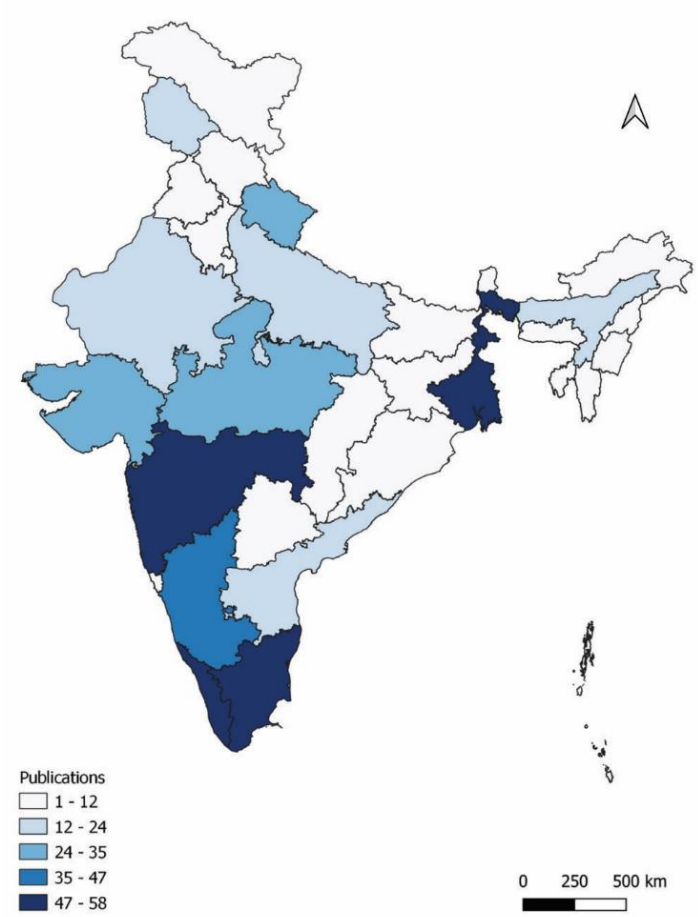

Figure 7. Overview of arachnological (Araneae) research conducted in India from 2000 to 2020.

respectively, indicating a representational absence for 86% and 81% of the timeframe respectively. With the exception of conservation and ethnozoological research, all other categories seemed to follow an increasing trend after 2019 (Figure 5).

Araneae data across India's spatial width accounts for representation from 33 out of 36 states and UTs. Five states, Maharashtra (11%), Kerala (11%), Tamil Nadu (10%), West Bengal (10%) and Karnataka (7%) accounted for almost half the total national data (Figures 6 and 7). Category-wise, these dominant states also accounted for 52%, 41%, 52% and 50% of taxonomic, diversity, community and behavioural studies in the country respectively (Figure 8 and Table 1). Among these states, only West Bengal accounted for ethnozoological research representation, while Karnataka represented 29% of the conducted behavioural research. Haryana, Jharkhand, Ladakh and Nagaland comprised the most data-deficient regions represented by one publication each, with Nagaland remaining the only Indian state with no preliminary Araneae diversity record (Figure 8). The dominating synchroneity of taxonomic and diversity studies is also reflected when viewed at independent state levels, with a steady distribution of the two categories in the more comprehensively worked spatial zones. Additionally, seven states and two UTs, viz. Bihar, Haryana, Jharkhand, Ladakh, Nagaland, Goa, Telangana, Punjab, and Andaman and Nicobar Islands did not account for any taxonomic reference literature (Figure 7). Twenty-three states (70%) remained devoid of studies pertaining to community ecology, while 25 states (76%) had no contribution to behavioural research (Table 1). Overall, research relating to community ecology, behavioural studies, ethnozoology and other works remained limited to a few states, highlighting the spatial and categorical disproportions in systematic initiatives. All publications relating to conservational initiatives were clubbed together under a national bracket owing to their holistic, rather than state-specific applicability.

Discussion

This study represents a country-wide assessment of spatio-temporal and thematic research trends in an unconventional taxon. Araneae research of the current century has fed into a wide reservoir of knowledge despite limited popularization and prioritization within conservation frameworks.

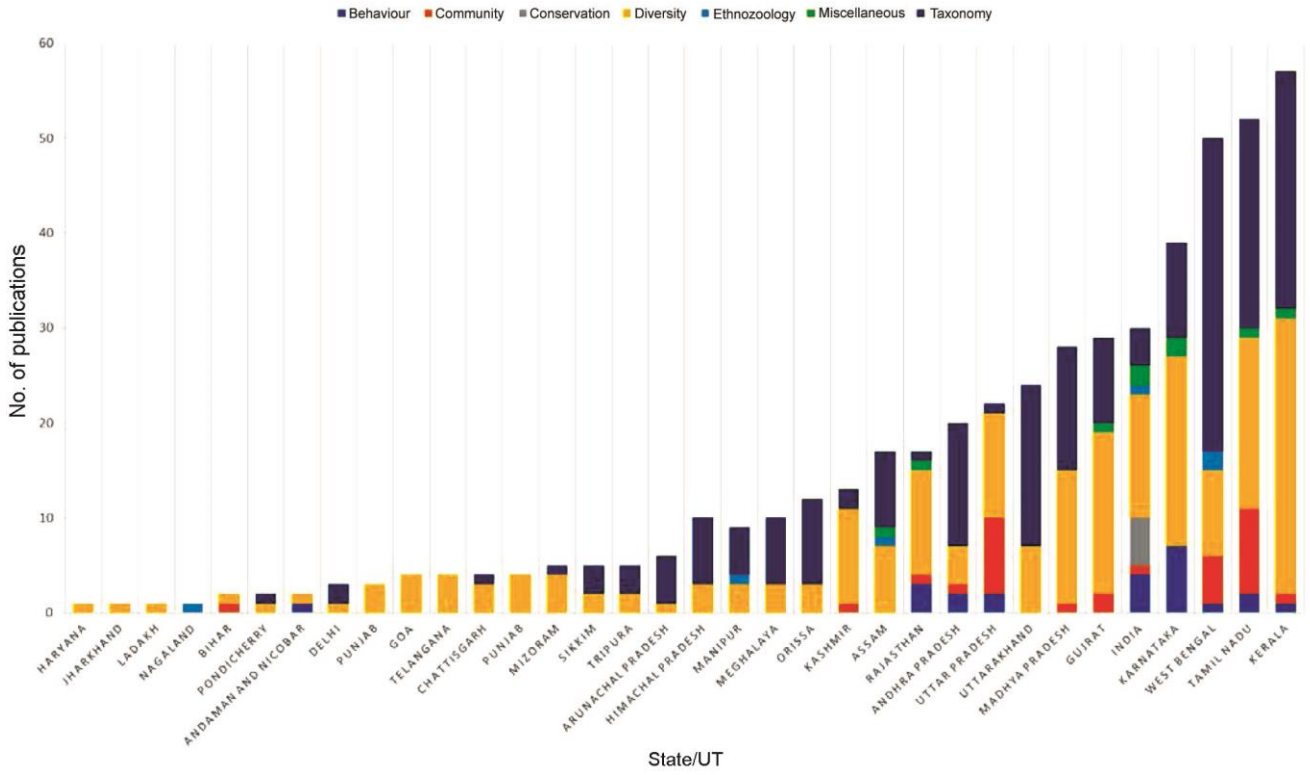

Figure 8. Spatio-temporal trend highlighting the total number of publications per Indian State/UT per year from 2000 to 2020.

However, there seems to be a disconnect in synergizing available records to establish a meaningful ecological and distributional understanding of Indian spiders. The results from this study can help bridge existing and identified limitations of arachnological research through converging efforts on regions and themes that remain particularly understudied. The outcome can also aid effective policy interventions in biodiversity management, public engagement and scientific communication.

Taxonomic and diversity databases have helped establish extensive alpha diversity records, constituting 82% of the total literature. The majority of these reports emerge from five states, viz. Maharashtra, Kerala, Tamil Nadu, West Bengal and Karnataka, represent almost 50% of the national data. Among these, with the exception of West Bengal, a significant fraction of data remains represented from the Western Ghats (Figures 1, 6 and 8; Table 1). In contrast, other biodiversity hotspots, i.e. the Himalaya, Indo-Burma and Sundaland regions, remain under severe information blind spots. Araneae records from the Indian Himalaya represent a fractional 10% of the literature, while the trans-Himalayan region represents only 5% (Figures 6 and 8 and Table 1). This decrease in baseline data from climate-vulnerable regions may lead to unmonitored catastrophic changes in critical community properties of undocumented biota in the absence of appropriate research, monitoring, and conservation strategies[106–110]. Sebastian *et al.*[111] in their overview of spiders of the Western Ghats, highlighted similar fractional gaps in the state-specific literature that fail to represent the diversity of important eco-regions in their entirety. Among the states and UTs of India, three UTs, viz. Dadra and Nagar Haveli and Daman and Diu, Chandigarh, and Lakshadweep, remained arachnologically unrepresented till 2020.

Although quantitative disproportions of state-specific data require more methodical efforts of focused research initiatives, qualitative skewness of the available knowledge also demands similar indicatives. Despite the relative availability of checklists, the larger and predictably more ecologically meaningful aspects of species distribution patterns and drivers across these inventoried regions remain unclear. Although community ecology accounted for the third most researched category for taxon (7%), the literature assessing patterns of community assemblages remains inadequate, representing <2% of the total pool. This further impedes ecological interpretations from an otherwise abundant alpha dataset. Furthermore, insights into assemblage patterns remain predominantly restricted to the states of Uttar Pradesh and Tamil Nadu (Figure 8 and Table 1). Additionally, notwithstanding abundant local (22 records from the present study) and global evidences of spiders being effective pest-control agents, indicators of natural heterogeneity, fragmentation and micro-climate variations[9,112–116], their inclusion in IPM and long-term habitat monitoring initiatives are yet to be implemented in India. This is further impeded by the lack of information pertaining to the natural history, behavioural

Table 1. Publications: Thematic categories for each state/Union Territory (UT) in India

State/UT	Behaviour	Community	Conservation	Diversity	Ethnozoology	Miscellaneous	Taxonomy	Total
India	4	1	5	13	1	2	4	30
Haryana	0	0	0	1	0	0	0	1
Jharkhand	0	0	0	1	0	0	0	1
Ladakh	0	0	0	1	0	0	0	1
Nagaland	0	0	0	0	1	0	0	1
Bihar	0	1	0	1	0	0	0	2
Puducherry	0	0	0	1	0	0	1	2
Andaman and Nicobar Islands	1	0	0	1	0	0	0	2
Delhi	0	0	0	1	0	0	2	3
Punjab	0	0	0	3	0	0	0	3
Goa	0	0	0	4	0	0	0	4
Telangana	0	0	0	4	0	0	0	4
Chhattisgarh	0	0	0	3	0	0	1	4
Punjab	0	0	0	4	0	0	0	4
Mizoram	0	0	0	4	0	0	1	5
Sikkim	0	0	0	2	0	0	3	5
Tripura	0	0	0	2	0	0	3	5
Arunachal Pradesh	0	0	0	1	0	0	5	6
Himachal Pradesh	0	0	0	3	0	0	7	10
Manipur	0	0	0	3	1	0	5	9
Meghalaya	0	0	0	3	0	0	7	10
Odisha	0	0	0	3	0	0	9	12
Jammu and Kashmir	0	1	0	10	0	0	2	13
Assam	0	0	0	7	1	1	8	17
Rajasthan	3	1	0	11	0	1	1	17
Andhra Pradesh	2	1	0	4	0	0	13	20
Uttar Pradesh	2	8	0	11	0	0	1	22
Uttarakhand	0	0	0	7	0	0	17	24
Madhya Pradesh	0	1	0	14	0	0	13	28
Gujarat	0	2	0	17	0	1	9	29
Karnataka	7	0	0	20	0	2	10	39
West Bengal	1	5	0	9	2	0	33	50
Tamil Nadu	2	9	0	18	0	1	22	52
Kerala	1	1	0	29	0	1	25	57
Maharashtra	1	2	0	22	0	2	31	58
Total	24	33	5	238	6	11	233	

dynamics, ethnozoological values and diversity trends of important species/groups and/or the taxon as a whole.

Temporally, the second half of the study timeline (2010–20) accounted for a significant increase in publication records, contributing to 75% of the total literature (Figures 2 and 3). The dominating themes accounted for <64% of the data, in a noteworthy alternating pattern. Further studies may be needed to reach a consensus regarding the determining factors for the same. Unsurprisingly, research efforts along the timeline remain distributionally biased across the aforementioned leading Indian states, spreading the remainder thinly across other states (Figures 6–8). The lack of substantial taxonomic and ecological inventories from lesser-worked regions render further taxon-centric research difficult, leading to a continued domino effect of this indicative group being largely ignored from systematic conservation strategies. This spatial discrepancy can be accredited to facility hotspots in the five arachnologically leading Indian states. Contributions from leading Araneae-centric facilities such as the Arachnology Division of Sacred Heart College, Kochi, Kerala; Deva Matha College, Kottayam, Kerala; Spider Research Lab, Amravati, Maharashtra; Zoological Survey of India, Kolkata, West Bengal; Ramakrishna Mission Vivekananda University, Narendrapur, West Bengal and Christ College, Bengaluru, Karnataka, among others, have conclusively furthered arachnology in India, through both scientific and media communications. However, the potential of the field remains to be explored through better facilitation and research (both logistically and financially) by other prominent institutions associated with wildlife and allied research.

Taxonomic work on spiders can be traced back to the 19th century, with noteworthy Indian contributions by Tikader since the 1960s. Although much of his work has been subject to misidentifications and criticisms, the baseline information derived from limited technology continues to serve as essential taxonomic keys. A significant fraction of past records continue to be updated with the advent of better technology, although misidentifications remain prevalent even in contemporary research. In contrast, the factors driving the dominance of checklists remain factually unclear

and may be attributed to the ease of qualitative listings from small spatial settings. Further studies on the subject could provide better clarity. A paradigm shift is critical to tackling the qualitative nature of most inventories, which fail to convey information beyond the presence–absence of a species. Acknowledging that bio-inventories constitute one of the primary and urgent necessities for understanding local and regional biota, the incomplete lists and inter-inventory comparability owing to non-standardized sampling protocols and data-handling procedures, renders much of the data misleading and unusable[117–119]. Within the context of globally changing diversity trends, although anthropogenic influences have led to a decrease in diversity, regional and local scales often exhibit the opposite pattern. Sax and Gaines[120] reported that the total increase in species diversity is often a result of exotic species outweighing local native ones. A lesser recognized facet of this phenomenon is the increment of local species diversity at the cost of a lessened community heterogeneity[121,122]. Therefore, interpreting the extent of ecologically robust information conveyed by quantitative inventories may constitute an urgent objective for future research perspectives. Furthermore, the missing links in connecting local species occurrences to the larger and contiguous regional pool essentially translate to an information pitfall, wherein the critical properties of multi-species associations within ecoregions remain unknown, hindering further conservation applications of potential data.

Conclusion and future perspectives

An extensive review of the available arachnological literature in India has highlighted the biased dominance of qualitative inventories and taxonomic reports from the country. Although relatively understudied in comparison to other arthropod fauna such as lepidoptera and coleoptera, this field of study has gained attention in the last few decades. This is reflected in the upsurge in scientific communications reporting species occurrences from various parts of India, including several novel discoveries. Prioritized efforts to better understand taxonomic accuracies are also emphasized through the recurrence of the literature pertaining to taxonomic revisions. However, despite an accelerating pace of inventorying, the potential of contemporary arachnological research in the country remains to be diversified into more quantitative assessments of diversity patterns and processes across environmental gradients. Contemporary research is concentrated in certain regions, such as the Western Ghats and West Bengal, while the others remain under a mild–severe information dearth. This highlights the acute need to initiate more systematic research to bridge the existing gaps in under-worked regions, especially climate-vulnerable zones and biodiversity hotspots. This is especially needed to better understand the patterns and drivers of spider diversity, along with their inherent community properties. Additionally, the current status of knowledge also stresses the diversification of research initiatives to (currently) marginal thematic subjects (e.g. natural history, behavioural dynamics and inter- and intra-specific interactions), in order to achieve a more comprehensive understanding of the Araneae fauna in India.

Overall, the trend and focus of arachnological research in India reflect limited, yet growing research initiatives and associated support, making inventorization and taxonomic reports the most achievable objectives for many academic groups. Rapid surveys translating to qualitative checklists along with reports of new species occurrences seem to form the primary choice for the country's arachnological community. Although this fast-paced thrust strengthens the national faunal database, the lack of data comparability and subsequent ecological interpretations hinder the prioritization of this taxon within management frameworks. Currently, 14 spider species are afforded legal protection under the IUCN Red List[123], eight of which are threatened with endangerment. There is a further possibility of enlisting species of the genus *Poecilotheria* (Araneae: Theraphosidae) under the Wildlife Protection Act (1972) (M.S. pers. commun.). However, owing to the lack of both comprehensive knowledge and monitoring data for particular species, the overall conservation status of Indian spiders is difficult to characterize. To accurately establish population trends (a fundamental element for assessing long-term dynamics), strong baseline knowledge of the present conservation status of this species is imperative, corroborated with regular evaluation over time. This preliminary objective can only be achieved by circumventing the lack of homogeneity in species-specific data across national databases.

Immediate responses to overcoming the existing gaps would be to identify indicative species, either at the level of state administration or biogeographic regions, to establish a reliable database of species distribution patterns and population trends, supplemented by functional traits as predictors of risks. Robust monitoring protocols to comprehend and assess potential threats to populations need to be established and improved upon. Suggestive protection of key identified habitats has also been established as an effective approach to spider conservation[4]. Overall, improving on the fragmented understanding of the status of Indian spiders along with devoted legislation and funding programmes can further conservation efforts in an otherwise neglected, albeit ecologically critical taxon.

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