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Mapping Ecosystem Service Research Gaps of Sacred Groves in the Indian Himalayan Region: A Bibliometric Review of Biocultural Evidence

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ABSTRACT: Sacred groves are patches of community-conserved forest maintained through religious, cultural, and traditional norms, which makes them among the oldest conservation institutions in the Indian Himalayan Region (IHR). Spanning the Western Himalayas (Himachal Pradesh, Uttarakhand, Jammu & Kashmir), Eastern/Northeastern Himalayas (Sikkim, Meghalaya, Nagaland, Manipur, Mizoram, Arunachal Pradesh), and transitional Himalayan foothills (Assam, Tripura, West Bengal), these landscapes give twelve analytical units in total (Jammu & Kashmir and Ladakh are treated as one unit) and constitute a critical but under-documented component of montane biodiversity conservation. Known regionally as 'Dev vans', 'Deodars', 'Orans', 'Law Kyntang', and 'Gamkhap', they represent the confluence of ecological function and biocultural heritage. This study presents a bibliometric analysis of 452 publications (1986–2026) on sacred grove research in India, with a focused, non-aggregating synthesis of the evidence on ecosystem services (ES) of sacred groves in the Indian Himalayan Region. A research evidence heatmap is introduced to show where documentation of nine ES categories is thin across twelve IHR units. It is a research-mapping aid and not a valuation or ranking of groves. Bibliometric analyses were conducted using bibliometrix (R) and VOSviewer, including Multiple Correspondence Analysis for the thematic map. Publication trends are described from observed counts only; no growth model or forecast is made. Ecosystem services were classified using CICES v5.1 (Provisioning, Regulation & Maintenance, Cultural, *etc.*). Documentation depth was scored on a four-level scale (No Study/Anecdotal/Limited/Robust) for each state–ES combination and visualised as a heatmap. The indexed corpus is dominated by biophysical and conservation-ecology themes, while governance-oriented social sciences remain peripheral. Documented ES evidence is concentrated in Uttarakhand and Sikkim (and in Meghalaya for some services), whereas Ladakh/Jammu & Kashmir, Mizoram, Arunachal Pradesh and Tripura have almost no documented evidence for any of the nine categories. This gradient is consistent with differences in accessibility and research capacity and may partly reflect indexing and language coverage. Pollination, soil formation and nutrient cycling, microclimate regulation and genetic resources are the least documented categories. Monetary valuation covers only a narrow subset of the values of sacred groves, and no aggregate economic value is estimated. The heatmap indicates a geographic concentration of documented evidence and thematic gaps in cultural, spiritual and knowledge-related services. These gaps are better explained by accessibility,

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research capacity and the resistance of taboo-protected sacred values to monetisation than by any lack of importance of the groves. Closing them calls for supporting community-led documentation of cultural and spiritual ecosystem services and traditional ecological knowledge, for example through Biodiversity Management Committees and People's Biodiversity Registers, rather than prioritising monetary valuation or measurement equipment.

Keywords: Biocultural heritage; Biodiversity conservation; Community-conserved areas; Ecosystem services; Indian Himalayan Region; Sacred groves; Traditional ecological knowledge; Cultural ecosystem services; Biodiversity Management Committees

1. Introduction

The Indian Himalayan Region (hereby IHR), encompassing twelve states and union territories across approximately 530,000 km^2, is embedded within both the Himalaya and Indo-Burma global biodiversity hotspots [1]. Its sacred groves constitute one of the world's most ancient and extensive systems of community-based conservation, yet they remain among the least systematically documented and least formally recognised in policy. This paradox of high ecological value and low policy recognition is the central problematic of this study.

Sacred groves, patches of forest protected by local communities on religious grounds, have long been recognised in India, and systematic scientific interest in them dates from the 1970s, when Gadgil and Vartak [2] described the sacred groves of the Western Ghats as relics of earlier forest cover maintained by a customary conservation institution. Gadgil and Guha [3] set such customary resource regimes in the wider ecological history of India, in which colonial and post-colonial state forestry progressively displaced locally governed forests and the institutions that sustained them. Research has since expanded from floristic inventories [4] to biodiversity management, community-based governance and policy [5–9]. The comparative volume edited by Coggins and Chen [10] extends this work to village sacred forests across South, East and Southeast Asia and addresses their political, governance and legal dimensions, and its Afterword [11] links their ecosystem services to the UN Sustainable Development Goals. This literature treats sacred groves as living institutions of spiritual ecology and not only as ecological stocks, which is the perspective adopted here.

Sacred groves across the IHR are extraordinarily diverse in governance, ecology, and cultural identity. In Uttarakhand, 'Dev vans' (forest of the deity) and alpine 'Bugyals' are governed through village deity traditions integrated with panchayati raj institutions (the three-tier system of elected village, intermediate and district councils established by the 73rd Constitutional Amendment of 1992, which gives local self-government bodies a statutory role in managing village commons). In Himachal Pradesh, 'Shamilat' and 'Deodar' groves are maintained through customary usufruct rights negotiated within revenue village boundaries. In Meghalaya, the 'Law Kyntang' of the Khasi Hills represent arguably the most ecologically intact and institutionally robust sacred grove system in South Asia, governed by clan-based customary law that effectively excludes all extractive activity [12,13]. In contrast, the 'Gamkhap' and 'Mauhak' of Mizoram and Manipur operate within shifting cultivation landscapes where grove boundaries are more permeable and governance more contested [14]. These differences have profound implications for ES assessment: the same category of service (e.g., watershed regulation) may be robust and measurable in Uttarakhand's spring-dependent communities but anecdotal and unquantified in Ladakh's more arid sacred groves.

Figure 1 and Table 1 reproduce the pre-existing national compilation of reported sacred grove numbers by state, published by the C.P.R. Environmental Education Centre (CPREEC) for the Government of India; The data are counts of groves recorded in that compilation. They do not measure grove density and largely

reflect where documentation has been carried out. Maharashtra and the southern states show the highest counts, whereas much of northern, central and north-eastern India is light grey, indicating lower numbers or, more probably, incomplete documentation. The map covers the whole country and therefore says little about the IHR, which is the scope of this study: Table 1 lists only some IHR states, and groves in several unlisted states are discussed later in this paper. The map highlights the need for community-based mapping and documentation of groves.

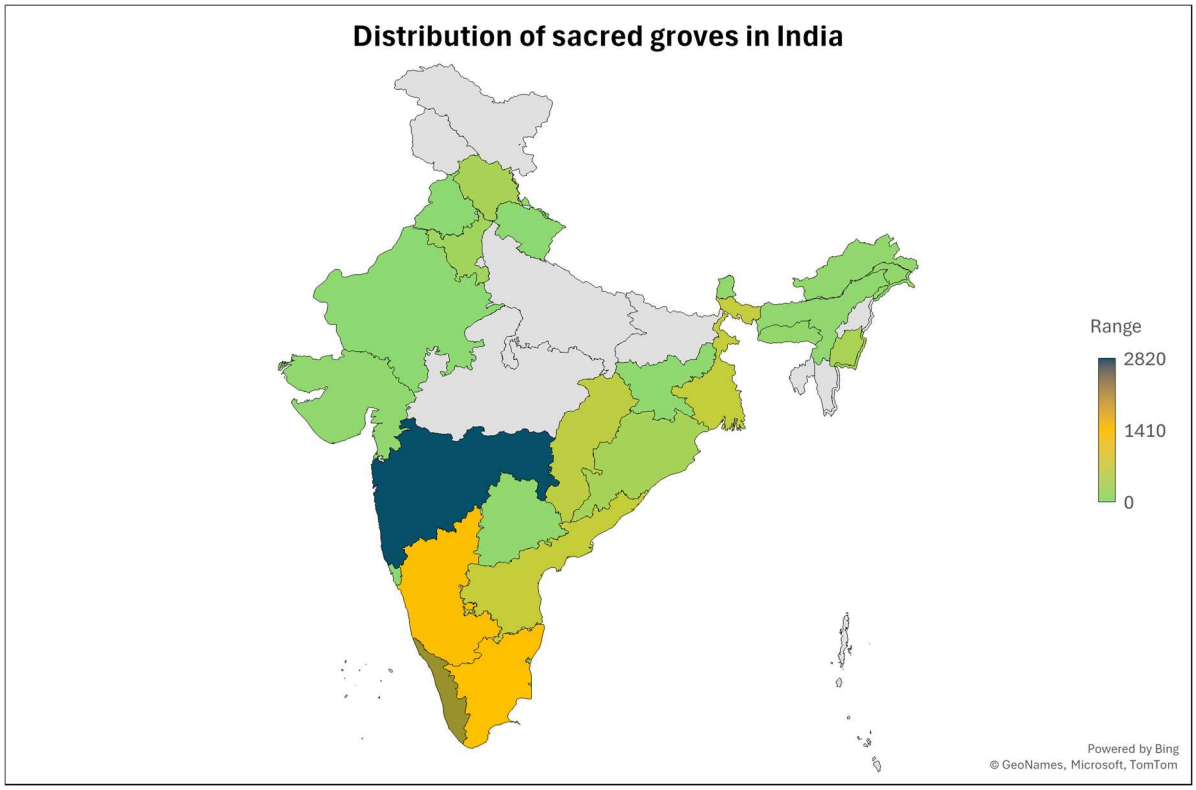


Figure 1. Distribution map of reported sacred groves in India, showing the number of groves recorded per state (data: C.P.R. Environmental Education Centre, Government of India, 2026; see Table 1). Counts reflect documentation effort and not grove density, and the map shows the national context rather than the IHR.

Throughout this review, biocultural heritage denotes the inseparable, co-produced bundle formed by biological diversity, ecosystem processes, and the cultural knowledge, practices, and institutions (deity worship, customary taboo, and clan-based governance) that generate and sustain them. Under this framing, the cultural rules governing a sacred grove are not incidental context for its ecology but an active, measurable input into ecosystem service production: the taboo that excludes logging, the ritual calendar that restricts entry during breeding seasons, and the customary tenure that assigns stewardship to a lineage or village deity each function as a governance mechanism whose ecological output can, in principle, be quantified alongside more conventional biophysical drivers. The central task of this review is therefore not only to catalogue what ecosystem services sacred groves provide, but to examine how well the literature has captured the causal link between biocultural heritage as a governance system and ecosystem services as its measurable output, a link that, as shown below, remains empirically thin.

Three interconnected policy failures make this review urgent. First, sacred groves are largely absent from India's National Mission for Green India, the Compensatory Afforestation Fund Management and Planning Authority (CAMPA), and the Biodiversity Finance (BIOFIN) initiative, all programmes that channel resources toward ecosystem conservation but lack specific sacred grove provisions. Second, the Forest Rights Act (2006), while theoretically recognizing community forest rights, has been inconsistently implemented in sacred grove contexts, with many groves remaining in legal limbo between revenue land,

reserved forest, and customary territory. Third, the National Biodiversity Authority's Biodiversity Management Committees (BMCs), intended to document biodiversity including in sacred groves, have achieved low compliance rates in Himalayan states, leaving most IHR sacred groves without any formal biodiversity documentation let alone economic valuation.

Table 1. Reported Sacred groves across the Indian region (Source: C.P.R. Environmental Education Centre of the Government of India, 2026). This is the pre-existing national compilation that the present study responds to; it is context and not an input to any score. Of the IHR units, Jammu & Kashmir, Ladakh, Meghalaya, Nagaland, Mizoram and Tripura do not appear in it.

State	Number of Groves
Maharashtra	2820
Kerala	2000
Karnataka	1424
Tamil Nadu	1400
West Bengal	670
Andhra Pradesh	691
Chhattisgarh	600
Manipur	365
Himachal Pradesh	329
Orissa	322
Haryana	248
Puducherry	108
Arunachal Pradesh	65
Telangana	65
Gujarat	42
Assam	40
Sikkim	56
Jharkhand	21
Uttarakhand	18
Rajasthan	9
Punjab	9

A further premise concerns how the gaps reported here should be interpreted. The scarcity of quantitative and monetary studies of sacred grove services is not only an information deficit. Extraction is prohibited by taboo in most groves, and spiritual and cultural values are held as obligations and relationships rather than as tradable goods. Monetary valuation captures mainly values linked to immediate use (non-timber products, avoided costs, carbon) and can place a grove alongside other investments, such as a road, in a comparison that in many cases favours conversion. Reluctance to monetise sacred groves, and the difficulty of doing so, may therefore be among the reasons for the gap, in addition to accessibility and research capacity. We accordingly use 'evidence' in a plural sense that includes biophysical measurement, ethnographic and participatory documentation of cultural and spiritual services, and traditional ecological knowledge, with economic estimates only where communities consider them appropriate [15,16]. The heatmap shows where documentation is thin; it does not propose that monetary valuation is the goal.

Against this backdrop, the present study makes three specific contributions: (1) a descriptive bibliometric analysis of the 1986–2026 sacred grove literature on India, using the full suite of bibliometric visualisations; (2) a structured, non-aggregating synthesis of the evidence on ecosystem services of IHR sacred groves using the CICES v5.1 framework; and (3) a research evidence heatmap that shows where documentation is thin across twelve IHR units and nine ES categories. CICES v5.1 (the Common International Classification of Ecosystem Services) [17] is a hierarchical classification of the final ecosystem services that people obtain from ecosystems, grouped into three sections: Provisioning,

Regulation & Maintenance, and Cultural. It deliberately excludes supporting services, which are treated as underlying ecological functions, to avoid double counting. The terms used throughout, including spiritual and cultural services, traditional ecological knowledge, customary governance, watershed regulation, carbon, pollination, and genetic resources, are examined in Section 4.

2. Materials and Methods

2.1. Data Acquisition

In this study, we used a systematic bibliometric analysis to evaluate research trends, thematic orientations, and knowledge gaps on sacred groves in India. Data for this study were retrieved from Scopus, Google Scholar, and OpenAlex, accessed on 10 February 2026. Only peer-reviewed journal articles, book chapters, and academic reports published between 1986 and February 2026 were considered. These three platforms were deliberately chosen because they represent some of the most comprehensive and authentic repositories of scholarly literature worldwide. Scopus is one of the largest curated abstract and citation databases, holding roughly 98 million records from about 28,000 active journals, in addition to conference proceedings and books [18]. Google Scholar, in contrast, provides a freely accessible search engine that covers a wide range of scholarly outputs including journal articles, theses, books, conference papers, and patents. Its inclusivity ensures that region-specific studies and grey literature, which may not appear in subscription-based databases, are incorporated into the review. OpenAlex, an open-source scholarly index, offers structured metadata on millions of research outputs, including citation networks, institutional affiliations, and author collaborations. Its transparent and machine-readable datasets make it particularly valuable for bibliometric mapping and open science integration.

The search strategy employed Boolean logic operators (‘AND’, ‘OR’) with the following strings: “India AND Sacred groves” and “Sacred groves AND Ecosystem services”. The search was applied across titles, abstracts, and keywords of peer-reviewed literature. The initial retrieval yielded 688 documents, which were downloaded as CSV files containing citation details, bibliographic information, abstracts, keywords, and other metadata.

Records from the three sources were merged into one file and deduplicated on DOI and normalised title, with manual checking of remaining near-duplicates. Because author keywords, citation counts, and country attribution are not directly comparable among Scopus, Google Scholar, and OpenAlex, and because Google Scholar does not provide structured exports suited to bibliometrix, indicators based on these fields should be read as indicative.

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework [19], documents were screened and excluded based on specific criteria. These included duplicate entries (88), irrelevant titles, keywords, or abstracts lacking connection to sacred groves/forests (118), and language or geographic filters (30; non-English or non-Indian context). The numbers reconcile at each stage: 688 records were identified; 88 duplicates were removed, leaving 600 records screened; 148 records (118 irrelevant and 30 outside the language or geographic scope) were excluded; and 452 records were included. This screening process ensured that the final dataset of 452 publications accurately reflected the scope and purpose of the review, thereby enhancing the credibility, focus, and reproducibility of the study (Figure 2).

Restricting the corpus to English-language records in indexed sources is a material limitation for this study. Regional scholarship on sacred groves, particularly from the north-eastern states, also appears in regional-language, non-indexed, and grey literature, as well as in community documentation such as People’s Biodiversity Registers, which none of the three sources capture well. The evidence ‘voids’ reported below therefore refer to the indexed English-language literature and may partly be an artefact of indexing and language coverage and not a true absence of research or of knowledge.

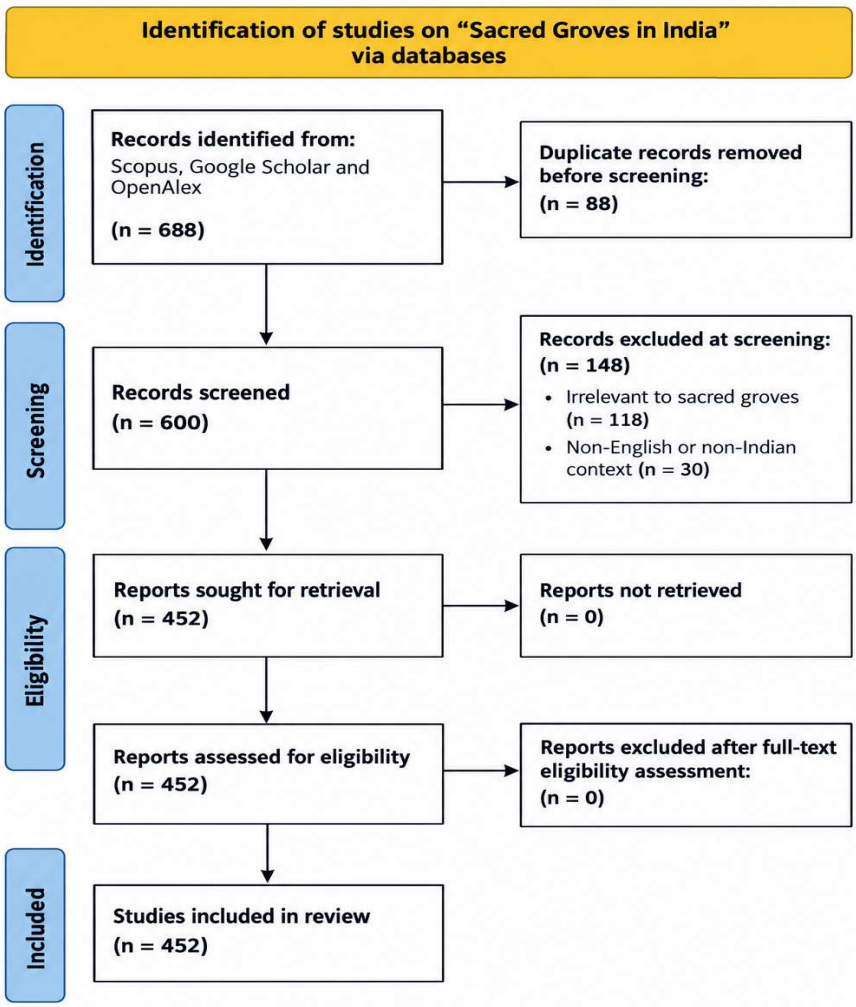


Figure 2. PRISMA 2020-style workflow diagram for the identification of studies on sacred groves in India (redrawn so that the numbers reconcile: 688 − 88 duplicates = 600 screened; 148 excluded; 452 included).

The final curated dataset comprised 452 documents, including peer-reviewed journal articles and book chapters, all of which were thematically and geographically aligned with the study's objectives. This dataset formed the basis for subsequent bibliometric evaluations, including publication trend analysis, citation mapping, authorship productivity, journal distribution, and keyword co-occurrence, to identify dominant research themes, institutional contributors, and emerging knowledge frontiers in sacred groves in India (Table 1).

The grove counts in Table 1 are not a proxy for research effort or evidence quality. Uttarakhand (18 groves) and Sikkim (56 groves) are reported with few groves yet have the best-documented ES evidence in the heatmap, whereas Meghalaya, Nagaland, Mizoram, Tripura, Ladakh and Jammu & Kashmir are absent from the table although groves occur there. Thus, the compilation reflects documentation effort more than the number of groves, and the reported evidence patterns reflect research effort and accessibility, not grove abundance.

2.2. Data Analysis

To conduct a comprehensive bibliographic review of sacred grove research in India, we employed the R programming language in conjunction with the bibliometrix package [20], a specialized tool designed for quantitative research in scientometrics and bibliometrics. This enabled the systematic extraction, cleaning, and analysis of metadata retrieved from Scopus, Google Scholar, and OpenAlex. Scopus provided rigor and authenticity through its coverage of high-impact journals, Google Scholar ensured inclusivity by capturing

grey literature and region-specific studies, and OpenAlex offered structured, open-access metadata that strengthened bibliometric mapping and collaboration analysis. Together, these sources ensured that the dataset was both comprehensive and authentic, thereby enhancing the reliability of the review.

Within the R environment, key bibliometric indicators such as annual scientific production, source impact, author productivity, and citation analysis were computed. To complement this statistical analysis, VOSviewer [21] was used to construct and visualize bibliometric networks. It was used to generate knowledge maps and perform network analyses, including co-authorship clustering, keyword co-occurrence, and bibliographic coupling, which provided deeper insights into the intellectual structure and thematic evolution of sacred grove research in India.

Author names exported by bibliometrix as 'Surname Initials' contain parsing artefacts (for example given names read as surnames, such as 'Alison A O' for A. Ormsby, and the same person appearing under two forms, such as 'Ormsby A'/'Alison A O' and 'Bhagwat S'/'Shonil B'), and Zenodo, a repository, appears among the sources.

Additionally, Microsoft Excel 2021 was utilized to tabulate, graph, and present publication trends, research output distribution by country, and year-wise growth in a clear and interpretable format. This integration of R-based bibliometric analysis, VOSviewer's visualization capabilities, and Excel's tabulation ensured a robust and multidimensional understanding of the research landscape. By combining statistical rigor with visual interpretation, the methodology captured not only the quantitative growth of sacred grove research but also the collaborative networks and thematic trajectories shaping this field in the Indian context. The ES synthesis focused on the IHR, defined here as twelve analytical units: Jammu & Kashmir and Ladakh (treated as one unit, as the evidence predates their separation in 2019), Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya, and the Himalayan hill areas of Assam and West Bengal (Darjeeling) (Figure 3). The same twelve units are used in the abstract, the heatmap, and the tables.

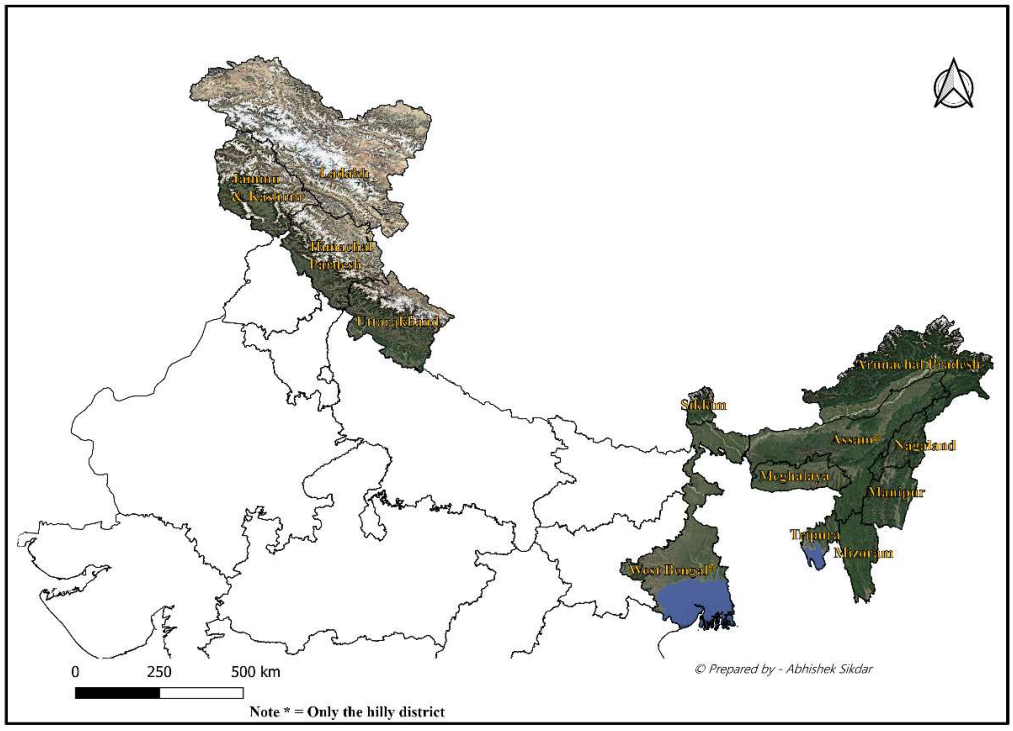


Figure 3. The Indian Himalayan Region (IHR) and the twelve states and union territories analysed in this study. Jammu & Kashmir and Ladakh are combined into one unit; Assam and West Bengal are represented only by their Himalayan hill areas. Map prepared by A. Sikdar; an asterisk marks states represented only by their hill districts.

2.3. ES Evidence Synthesis and Evidence Scoring

The retrieved data were supplemented by targeted searches for studies documenting at least one CICES v5.1 ecosystem service in IHR sacred groves. Inclusion required an empirical basis (biophysical measurement, ethnographic or participatory documentation, or economic estimation); monetary estimates were not a requirement. Ecosystem services were classified under CICES v5.1, which has three sections (Provisioning, Regulation & Maintenance, Cultural) and does not include supporting services. Nine categories were scored: NTFPs/medicinal plants and genetic resources (Provisioning); carbon sequestration, watershed regulation, microclimate regulation, soil formation and nutrient cycling, and pollination (Regulation & Maintenance); and spiritual/cultural values and ecotourism/recreation (Cultural). Education and traditional ecological knowledge are discussed in Section 4.4.3 and appear in the heatmap as an additional column that has not yet been scored. For each of the 12 IHR units and each category, an evidence score was assigned from primary studies, grey literature and forest department reports (Table 2). The details are provided in Table 2.

Table 2. Evidence quality scoring rubric for the IHR research evidence heatmap.

Score	Label	Criteria
0	No Study	No quantitative or qualitative ES study identified for this state–service combination.
1	Anecdotal/Grey Lit.	ES mentioned in grey literature, forest reports, or ethnographic accounts; no systematic measurement or documentation method applied.
2	Limited Quantitative	At least one peer-reviewed study documenting the service with a stated method (biophysical, ethnographic/participatory, or economic); single site or small sample
3	Robust Quantitative	Multiple peer-reviewed studies with rigorous, documented methods suited to the service (e.g., biophysical measurement, ethnographic or participatory documentation, or economic valuation where culturally appropriate); cross-site comparability possible. Monetary valuation is not required for a high score.

Monetary estimates are mentioned only where the original studies provide them, in the units and price year of the original authors; they are not converted, pooled or extrapolated between sites, and no aggregate or benefit-transfer value is computed (see Section 4.6).

3. Results: Bibliometric Analysis of Sacred Grove Research (1986–2026)

3.1. Corpus Overview

The 452-document corpus (1986–2026) is distributed across 280 unique sources and 1008 authors. Key descriptors: mean co-authorship 2.79 authors/document; average document age 11.1 years; average citations per document 15.66; annual growth rate 3.53%; international co-authorship 5.53%; author keywords 1151 unique terms (Table 3).

Table 3. Main bibliometric indicators showing sacred groves research corpus (1986–2026).

Bibliometric Indicator	Value	Contextual Note
Publication Timespan	1986–2026	40-year scholarly record
Total Documents	452	Articles, chapters, reviews, conference papers
Unique Sources	280	Journals, conference series, books
Total Authors	1008	Unique contributing scholars
Single-Authored Documents	139 (30.7%)	High solo publication rate
Annual Growth Rate	3.53%	Descriptive only; as the final two years are incomplete
International Co-Authorship	5.531%	Predominantly national scholarship
Co-Authors per Document	2.79	Moderate collaboration density
Author Keywords (DE)	1151	Rich and diverse thematic vocabulary

Average Document Age	11.1 years	Mid-career literature base
Average Citations per Document	15.66	Moderate citation impact

3.2. Annual Publication Trend

Annual output (Figure 4) is described from observed counts only. Observed output was between one and five documents per year up to 1999, between two and fifteen per year in 2000–2009, between sixteen and twenty-five per year in 2010–2019, and between eighteen and thirty-two per year in 2020–2025, with the highest annual count (32) in 2021; 2020 (18 documents) is therefore not a peak. The corpus was retrieved on 10 February 2026, so 2025 and early 2026 are structurally incomplete because of indexing lag. Output in 2020–2022 is also not read as a measure of research activity in those years: field studies were restricted during the COVID-19 pandemic, whereas publication in these years combines delayed reporting of earlier fieldwork with increased online and repository indexing, so an apparent peak around 2020 is not a substantive trend. We do not fit growth models or project future output. A logistic fit to a cumulative series with an incomplete final period places a peak in the recent past by construction, its coefficient of determination on a monotone series is not evidence of fit, and its saturation, carrying-capacity and decline estimates would be model artefacts. No reliable indicator exists either of which socio-ecological topics will attract research in the future. No claim about field maturity or saturation is therefore made.

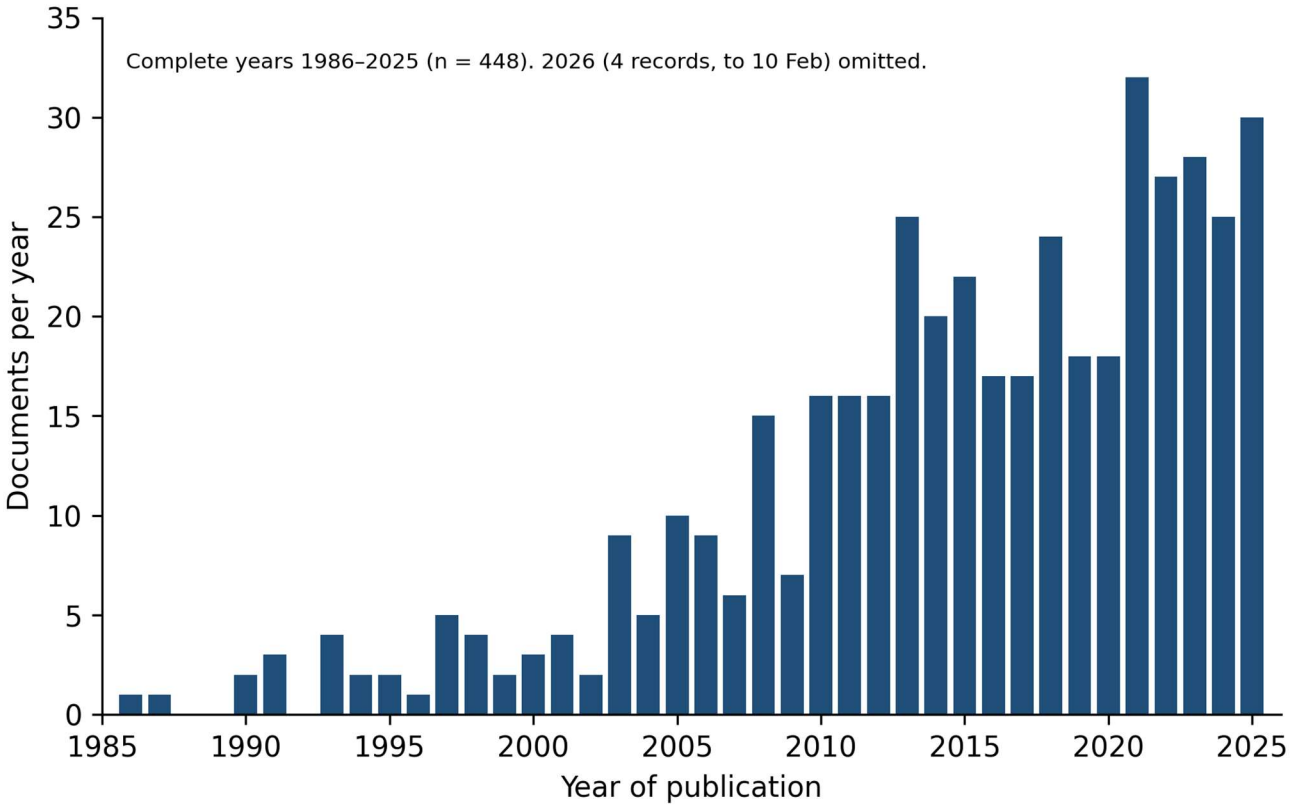


Figure 4. Annual scientific production of the sacred grove literature, observed counts for complete years (1986–2025). No model fit or forecast is shown.

3.3. Lotka's Law Showing Author Productivity Distribution

Lotka's Law (Figure 5) confirms the expected power-function authorship structure: approximately 85% of the 1008 authors have contributed exactly one publication; the observed curve (solid line) closely tracks the theoretical Lotka distribution (dashed). The modest deviation at the 3–5 document range indicates a slightly more concentrated authorship core than predicted by theory, reflecting the field's dependence on a

small group of persistent IHR researchers. Critically, the long tail of single-publication authors, primarily early-career Indian ecologists and regional forest researchers, represents an enormous untapped potential for field diversification if institutional research support is directed toward training in ES assessment, including participatory and ethnographic methods.

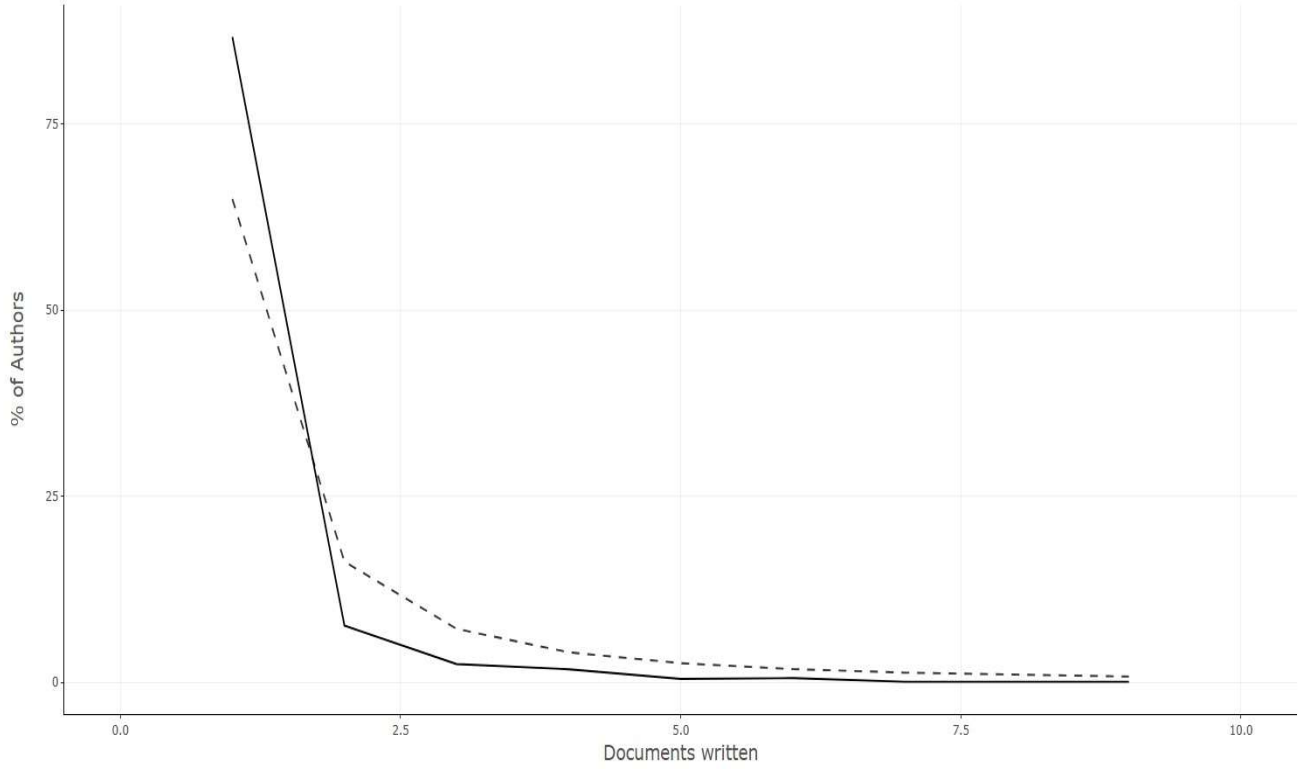


Figure 5. Lotka's Law showcasing Author Productivity Distribution. Solid line = observed proportion of authors by document count; dashed = theoretical Lotka curve. Close alignment at 1–3 documents confirms the law holds for this corpus. The steeper-than-theoretical decline at 3–5 documents reflects the niche concentration of sacred grove scholarship in a small IHR research core.

3.4. Most Relevant Sources and Source Dynamics

Biodiversity and Conservation lead with 15 cumulative publications (Figure 6), reflecting the field's dominant conservation biology framing. The prominence of Indian practitioner outlets Indian Forester (10), Tropical Ecology (9), Current Science (7), Indian Journal of Traditional Knowledge (6) reflects the dual orientation of IHR sacred grove research toward international conservation audiences and domestic forest management communities. Zenodo, a general-purpose open repository rather than a journal, also appears (7 records, primarily 2022–2025), indicating deposition of grey literature and preprints; it is excluded from the source ranking in Figure 6.

The Sources' Production over Time chart (Figure 7) reveals temporal dynamics: Biodiversity and Conservation's early dominance (established 1992) contrasts with Indian Forester's sharp post-2018 acceleration and the abrupt post-2022 appearance of Zenodo deposits (a repository, not a journal). This structural shift in the publication landscape has equity implications open-access outlets make IHR sacred grove knowledge accessible to community institutions and state forest departments that lack journal subscriptions.

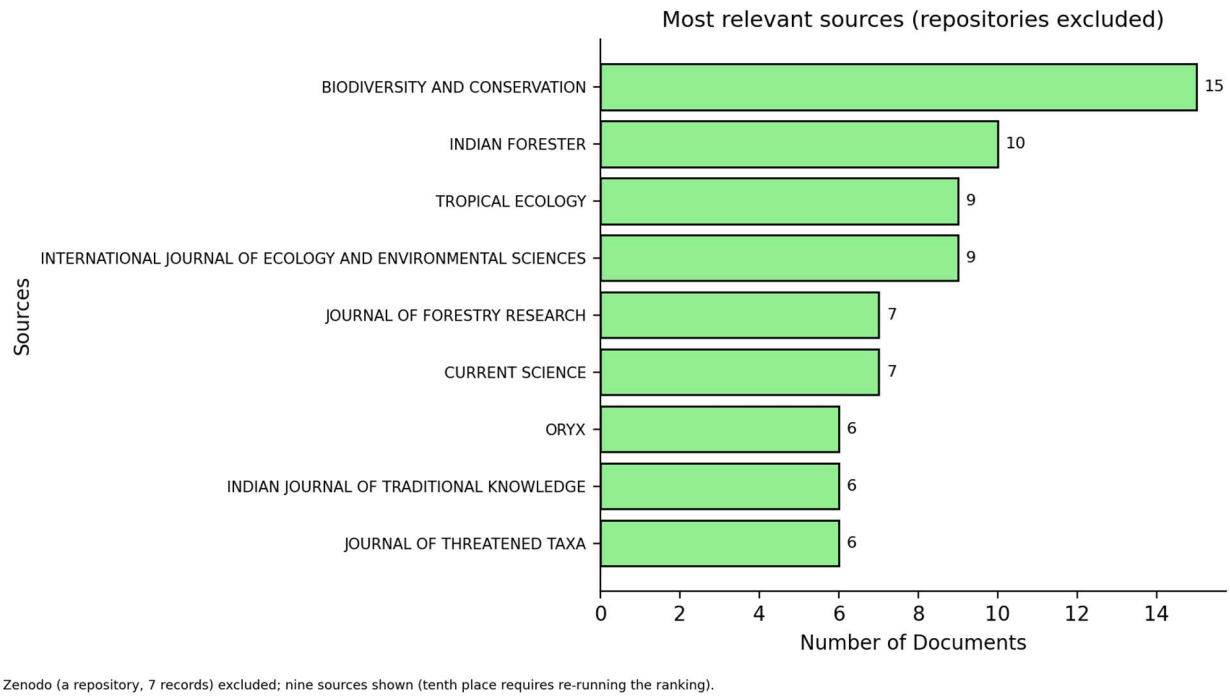


Figure 6. Most Relevant Sources showing Top 10 Journals by Cumulative Publication Count (1986–2026). Biodiversity and Conservation dominate (15 pubs), reflecting the field's conservation biology alignment. The growing presence of Indian practitioner outlets (Indian Forester, Current Science, Indian Journal of Traditional Knowledge) signals increasing domestic engagement. Zenodo is a repository and not a journal and is excluded from this ranking; nine sources are shown.

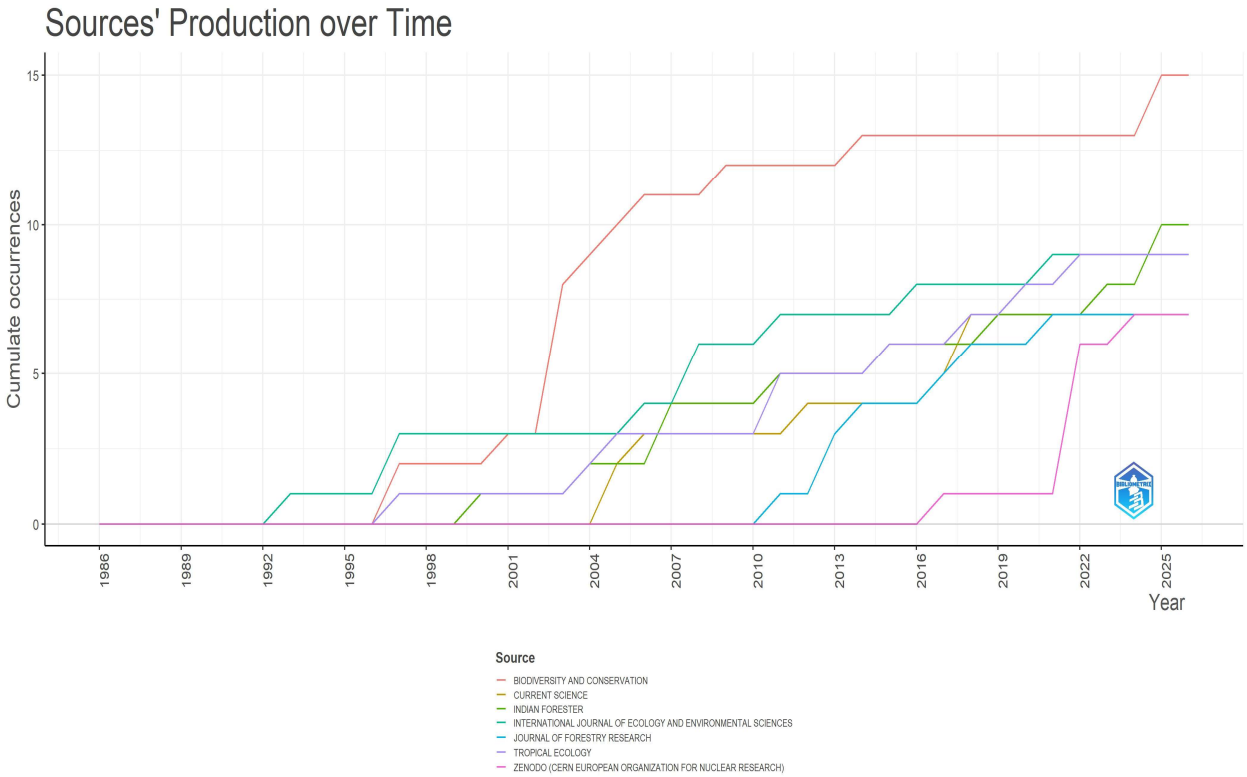


Figure 7. Sources' Production over Time showing Cumulative Occurrences by Journal (1986–2026). Step-function trajectories mark individual publication events; steeper slopes indicate productivity surges. Biodiversity and Conservation (red) shows sustained multi-decade leadership. Indian Forester (dark green) shows the most marked recent acceleration; Zenodo (magenta) is a repository and not a journal. The parallel growth of Journal of Forestry Research and International Journal of Ecology and Environmental Sciences from 2010 onward reflects a broadening mid-tier publishing base for IHR sacred grove science.

3.5. Most Global Cited Documents

Graeme A (2007) leads with 300 total citations, more than 50% above the second-ranked work representing the global benchmark for comparative sacred grove science (Figure 8). IHR-specific works (Khan M 2008 [22]: 152 citations; Mishra B 2004 [23]: 162 citations; Bhogendra M 2003: 188 citations) demonstrate strong within-field impact. Notably, no valuation-focused study appears in the top 10, indicating that economic assessment of sacred grove services has been a peripheral concern relative to biodiversity ecology and governance, which may reflect limited capacity as well as principled reservations about monetising sacred values (Section 5.2). Author labels in Figure 8 are as exported by bibliometrix and include given names parsed as surnames (e.g., 'Graeme A', 'Bhogendra M'); figure seven can be matched to Ormsby and Bhagwat [8], Mishra et al. [23], Khan et al. [22], Bhagwat et al. [24,25], Khan et al. [26] and Eck [27]; the labels 'Graeme A (2007)', 'Bhogendra M (2003)' and 'Vicky T (2020)' could not be matched without the source records.

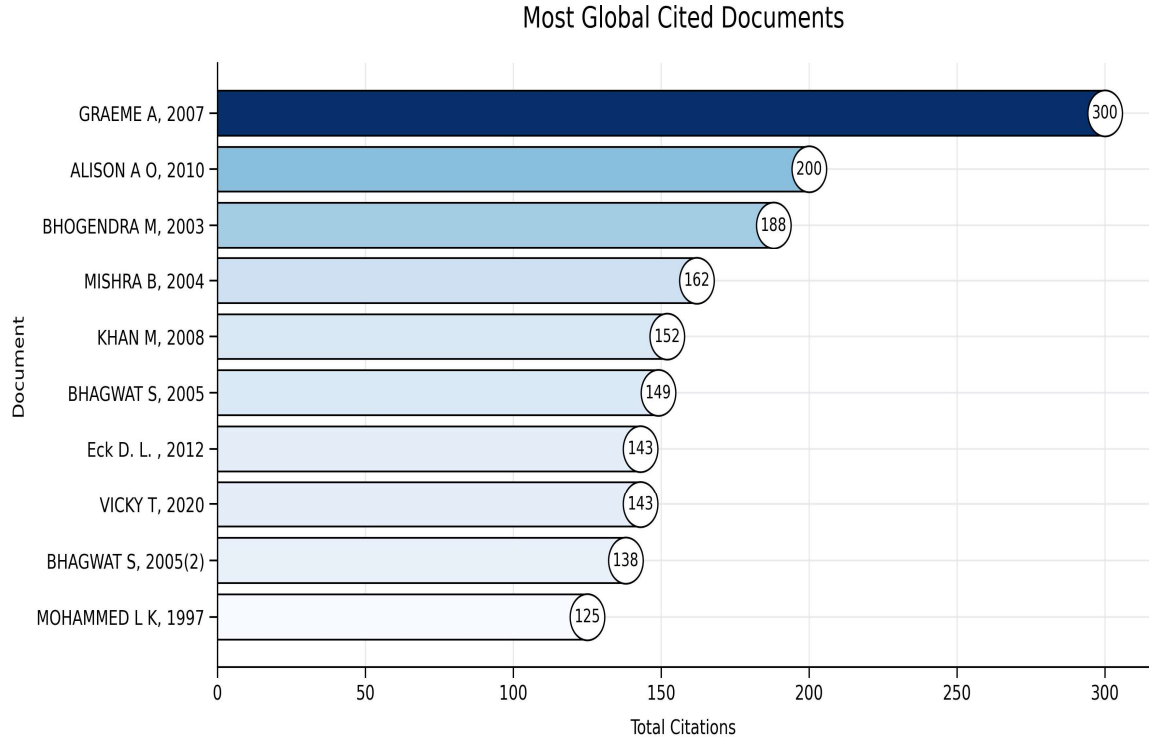


Figure 8. Most Global Cited Documents showcasing Top 10 by Total Citations. Dark-to-light blue gradient bar chart with citation counts in circular badges. Graeme A (2007, 300 citations) dominates as the field's global synthesis reference. The absence of any ES valuation study from the top 10 is consistent with the interpretation that quantitative ecosystem services assessment has not yet produced the landmark, field-shaping publications that biodiversity ecology and sacred grove governance have.

3.6. Most Relevant Authors and Production Over Time

Tripathi R leads article count with 9 publications (Figure 9), followed by Chandrakanth M (8, socioeconomics of Karnataka) and Khan M (7, Northeastern India). Some author labels in Figure 9 are name variants of the same person ('Alison A O' and 'Ormsby A'; 'Shonil B' and 'Bhagwat S') and are counted separately, so the mid-tier ranking is not interpreted until the names have been merged and the figure regenerated. The concentration of IHR-affiliated authors (Tripathi, Khan, Joshi, Pandey, Upadhaya) confirms the Indian Himalayan subcontinent as the productive epicenter. Critically, no author's primary focus is ES valuation methodology, and the dominant research profiles are biodiversity ecology, socioeconomics, and governance.

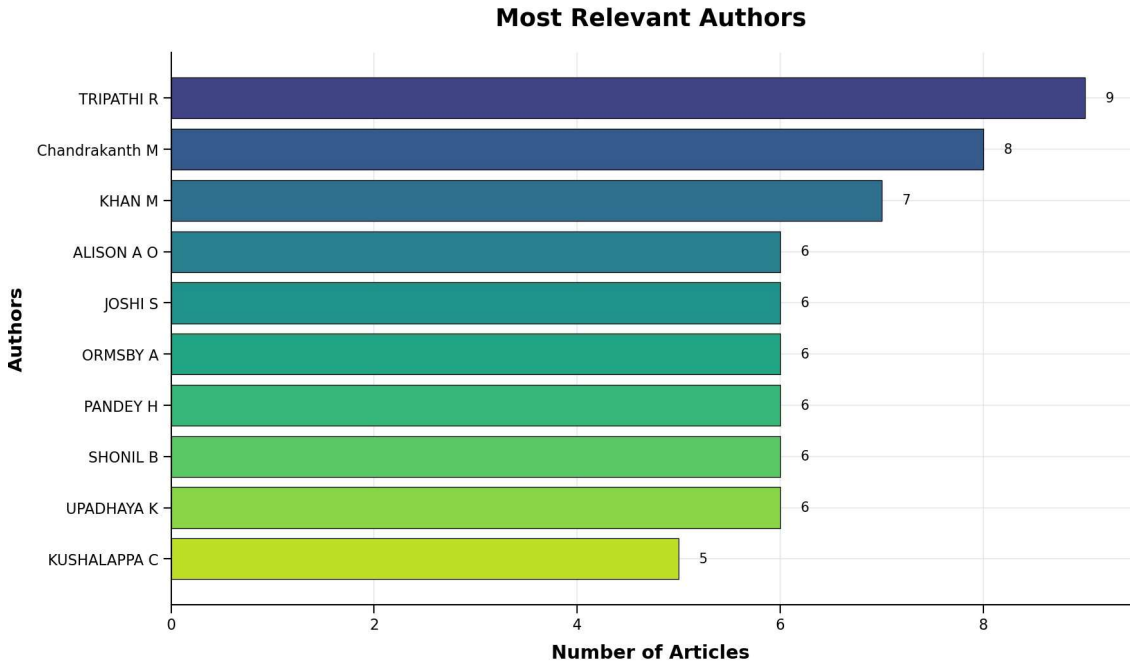


Figure 9. Most Relevant Authors showcasing Top 10 by Article Count (1986–2026). Gradient bar chart from dark navy (highest) to yellow-green (lowest). Tripathi R (9 articles, Sikkim Himalaya ecology) leads decisively. The absence of any ES valuation specialist in the top 10 reinforces the finding from the Most Global Cited Documents analysis: ecosystem services economic assessment is structurally underrepresented among the field's most productive scholars.

The Authors' Production over Time bubble chart (Figure 10) reveals career spans and citation intensity. Tripathi R's 1997–2024 span is the longest in the corpus. Chandrakanth M's large 2023 bubble (8 articles) represents an exceptional single-year concentration. The high citations-per-year (dark blue) of Kushalappa C's 2005 entry and Shonil B's 2010 entry indicate landmark single publications with disproportionate field influence.

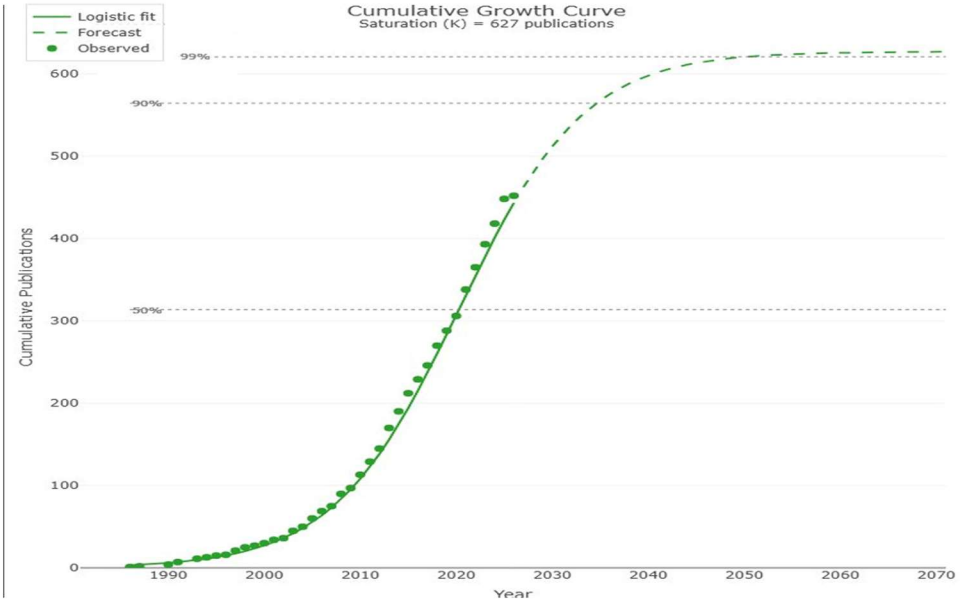


Figure 10. Authors' Production Over Time (1986–2026).

3.7. Keyword Co-Occurrence Network and Density Analysis

Three primary disciplinary clusters structure the sacred grove literature (Figure 11) a biophysical core (red) anchored by geography, ecology, and biology; a conservation-applied cluster (blue) centered on

biodiversity, India, and sacred groves; and a socio-political cluster (green) anchored by political science and archaeology. Inter-cluster connections are asymmetric: biophysical conservation links are strong, but conservation and socio-political bridges are sparse, reflecting the governance–ecology divide that limits progress on IHR sacred grove policy.

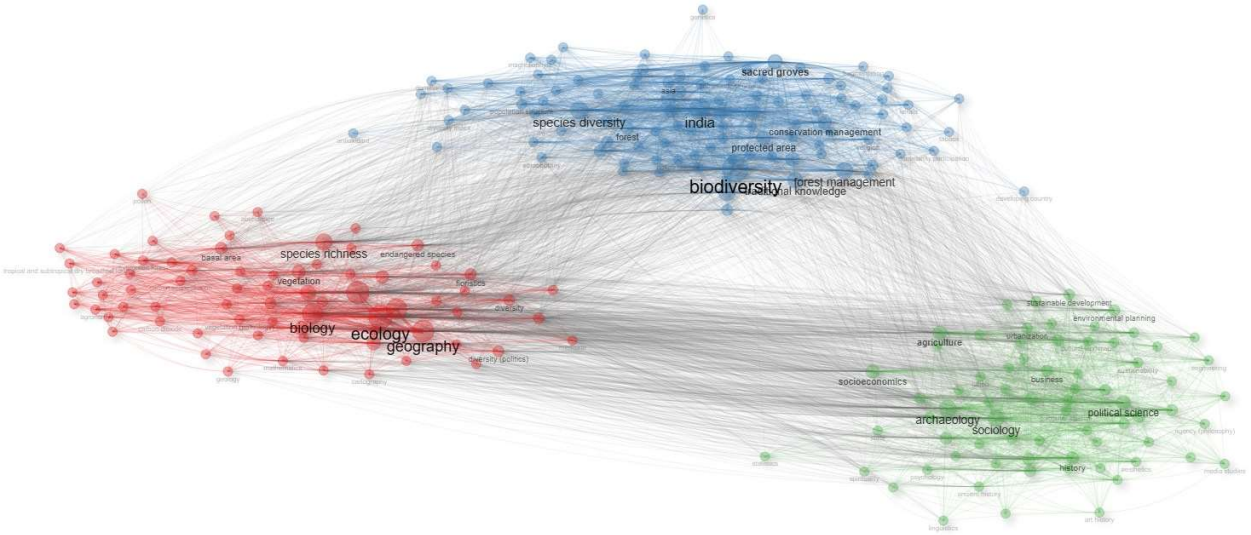


Figure 11. Keyword Co-Occurrence Network showcasing Three-Cluster Structure.

The density heat-map overlay (Figure 12) confirms two primary red hot-spots: the geography–biology–agroforestry nexus (maximum intensity) and the biodiversity conservation–India cluster (secondary intensity). The political science–sociology zone registers as orange-red, indicating moderate scholarly investment that has not yet achieved the internal coherence of the biophysical core.

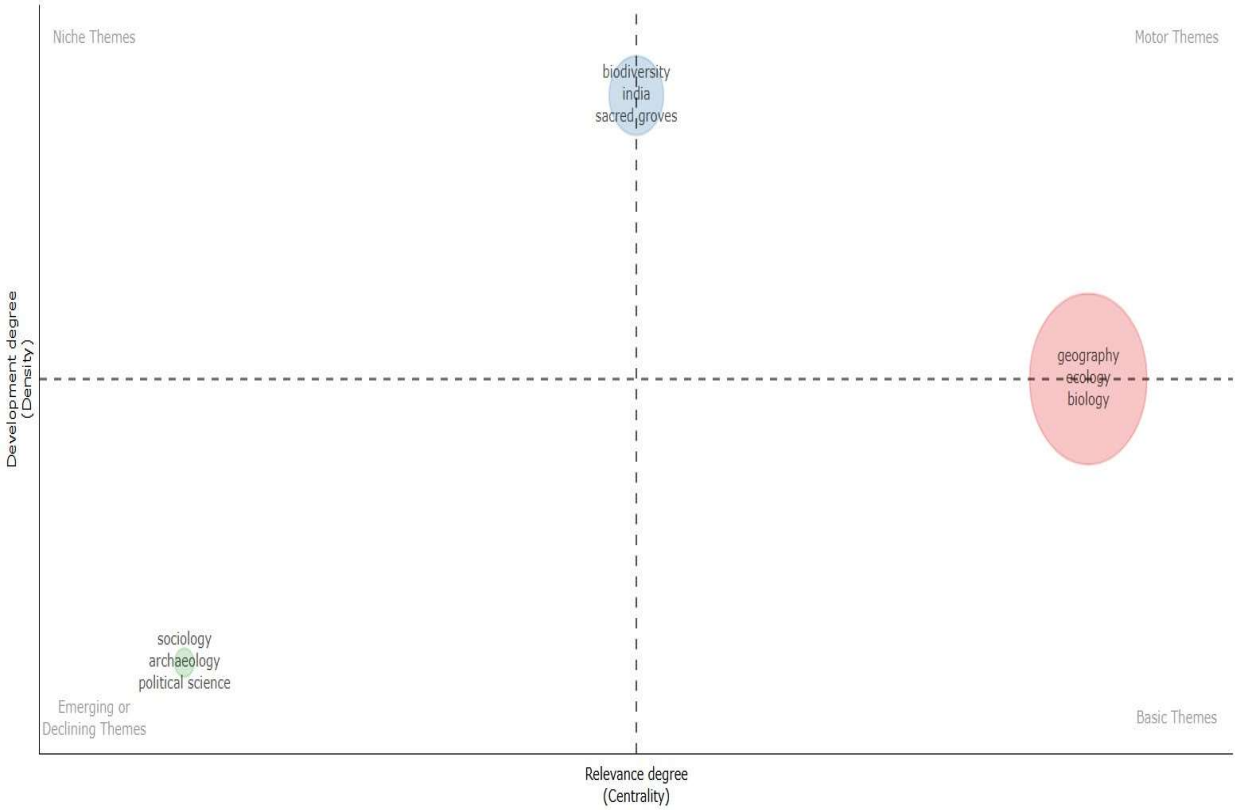


Figure 12. Keyword Co-Occurrence Density Heat-Map.

3.8. Thematic Map: Centrality–Density Quadrant Analysis

The thematic map (Figure 13) plots three clusters in centrality–density space. Geography–Ecology–Biology occupies the Motor Themes quadrant (high centrality, high density), the field's intellectual engine. Biodiversity–India–Sacred Groves occupies the Niche Themes quadrant (low centrality, high density), internally coherent but not yet field-central, representing the highest growth opportunity. Sociology–Archaeology–Political Science occupies the Declining/Emerging quadrant (low centrality, low density), marginal and weakly developed despite containing the governance tools most needed for ES policy integration.

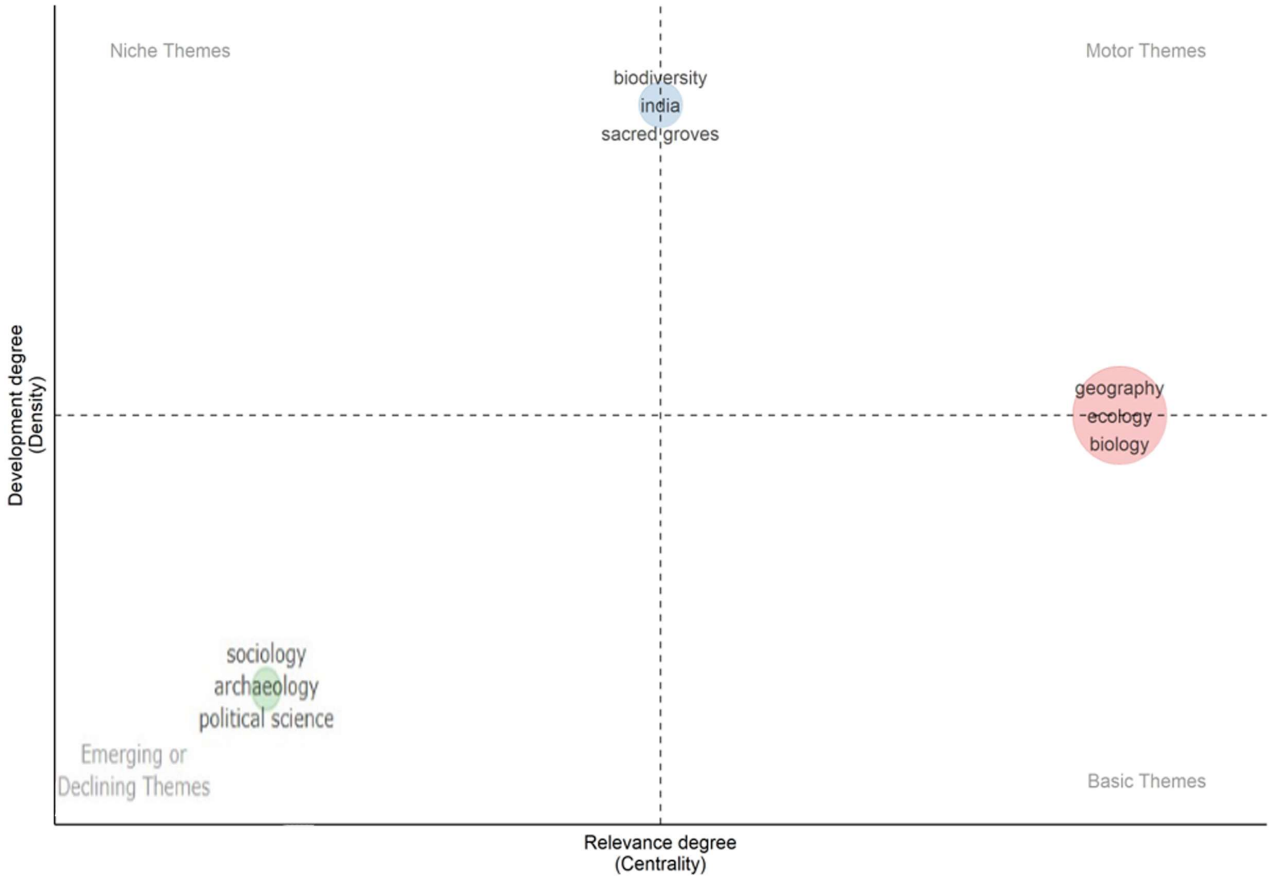


Figure 13. Thematic Map showcasing Centrality–Density Quadrant Analysis.

3.9. Trend Topics Analysis

The Trend Topics chart (Figure 14) maps the chronological emergence of key terms (2003–2024). Agency (philosophy), sustainability, climate change, and colonialism are the most recent emerging themes (2018–2024), signaling a normative and decolonial turn in the literature. Core ecological terms (geography, ecology, biology, agroforestry) show large bubbles with wide temporal spans, confirming sustained field-wide salience. Early botanical specialist terms (magnoliophyta, canopy, dry season, tree diversity) show narrow 2003–2008 bars, indicating a fading specialist sub-current that has not been sustained by subsequent scholarship.

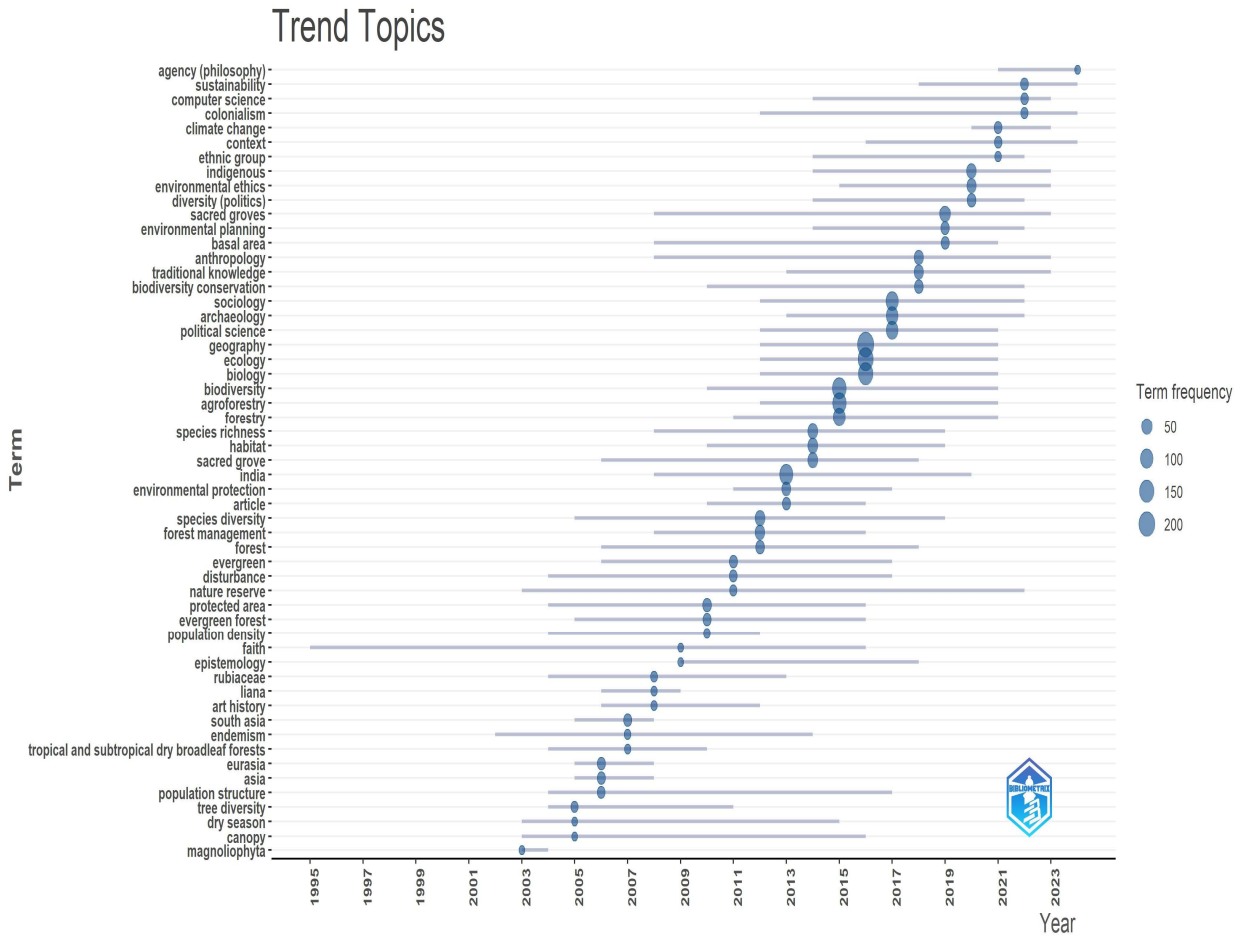


Figure 14. Trend Topics (2003–2024).

3.10. Word Cloud and Words' Frequency over Time

The Word Cloud (Figure 15) renders keyword frequency as font size, immediately communicating the field's center of gravity: geography, ecology, biology, biodiversity, and agroforestry dominate. Sacred groves, India, and India appear in the core cluster. The relative smallness of 'ecosystem services', 'valuation', and 'traditional knowledge' in the word cloud graphically confirms the bibliometric under-representation of ES-focused research.

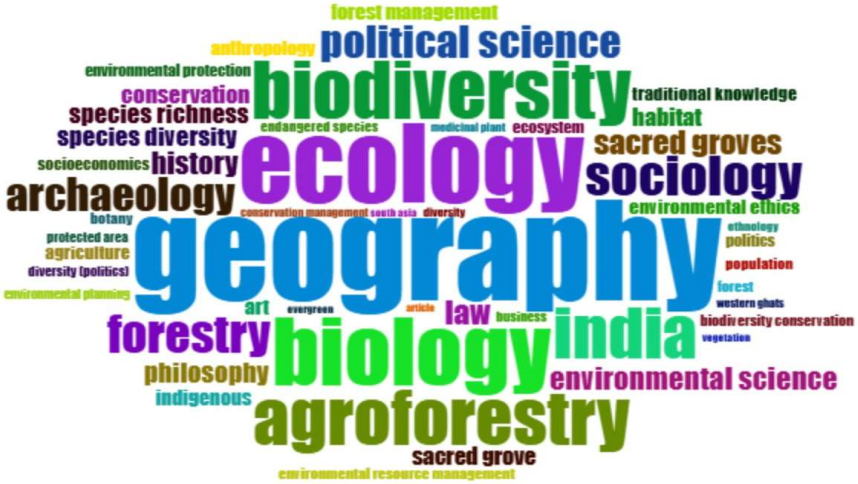


Figure 15. Word Cloud showing Author Keyword Frequency (1986–2026).

The Words' Frequency over Time chart (Figure 16) tracks ten key terms from 1986 to 2026. Geography (light blue, ~220 cumulative) and Ecology (dark teal, ~175) maintain dominant positions. The acceleration of all terms from 2010 onward reflects the overall publication surge. Sociology and Political Science show the flattest trajectories and the lowest absolute accumulation, confirming their structural marginality.

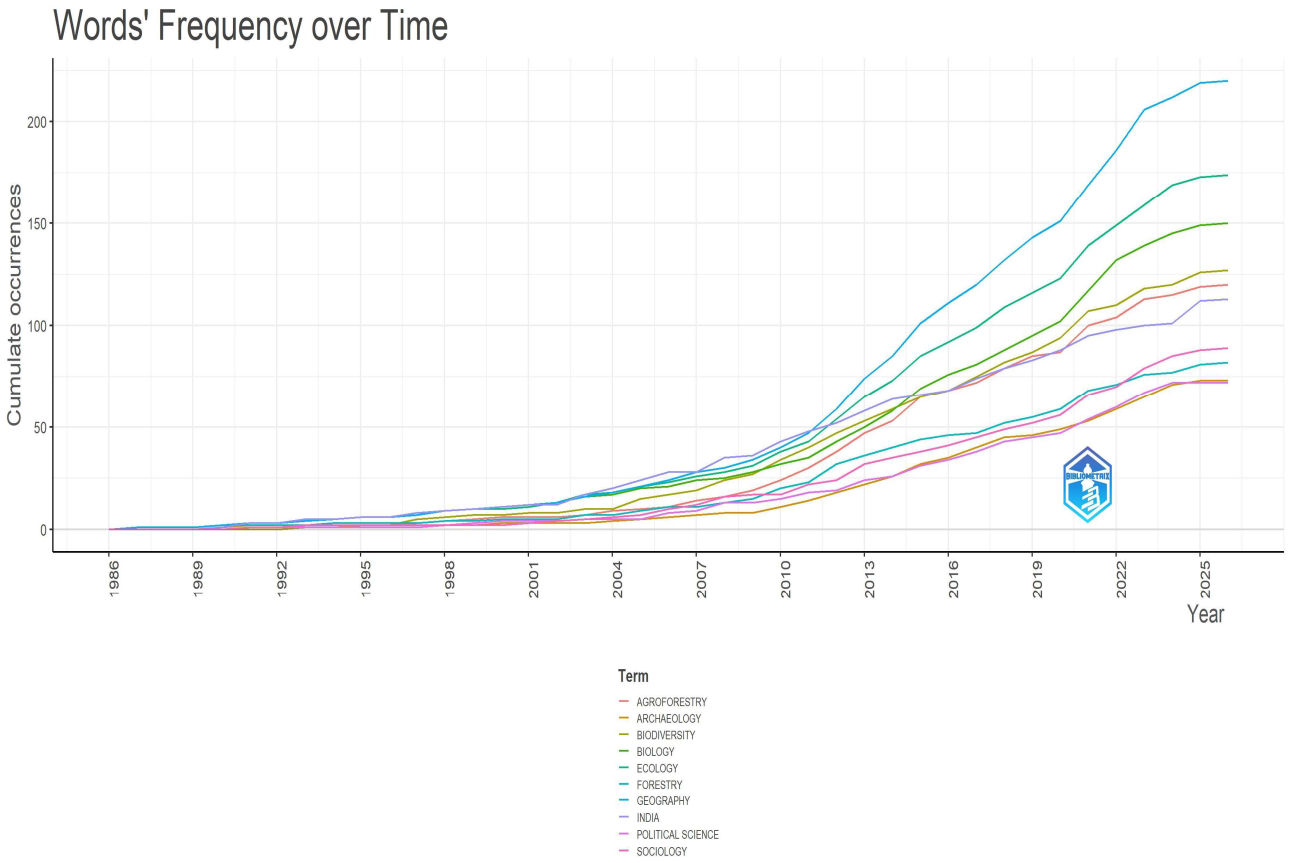


Figure 16. Words' Frequency over Time showing Cumulative Occurrences (1986–2026).

3.11. Country-Wise Citation Distribution and Geographic Concentration of Sacred Grove Scholarship

The choropleth world map (Figure 17) and the accompanying country-wise total citations bar chart (Figure 18) together reveal a striking geographic concentration in the global sacred grove literature. India dominates unambiguously, accounting for 2548 total citations, representing 55.7% of all citations in the corpus and is rendered in the deepest navy on the map, visually separating it from all other contributing nations. The United States ranks second with 758 citations (16.6%), followed by the United Kingdom at 584 citations (12.8%), together accounting for a further 29.4% of global citation share. The Russian Federation contributes 331 citations (7.2%), while South Korea (120, 2.6%), Ethiopia (94, 2.1%), the Netherlands (55, 1.2%), Brazil (43, 0.9%), Sweden (24, 0.5%), and Germany (17, 0.4%) each represent minor but geographically significant contributions. On the world map, the light-blue shading of Russia, the United States, the United Kingdom, and scattered representation from Brazil, Ethiopia, and South Korea confirms that sacred grove research, while nominally global, is effectively produced and cited within a small constellation of nations, with the vast majority of the remaining world in ungrouped grey, indicating zero citation contribution.

The citation dominance of India is both expected and analytically significant. It confirms that the sacred grove literature is not merely studying India as an object of inquiry from an external scholarly gaze, but is overwhelmingly produced, cited, and consumed within the Indian academic community itself a pattern

consistent with the Lotka's Law findings (85% single-publication authors concentrated in Indian institutions) and the bibliometric evidence of low international co-authorship (5.53%). The secondary citation presence of the USA and UK reflects the role of internationally trained Indian diaspora scholars and globally oriented conservation biology journals (principally Biodiversity and Conservation and Oryx, both UK-edited) in providing international platforms for IHR sacred grove research.

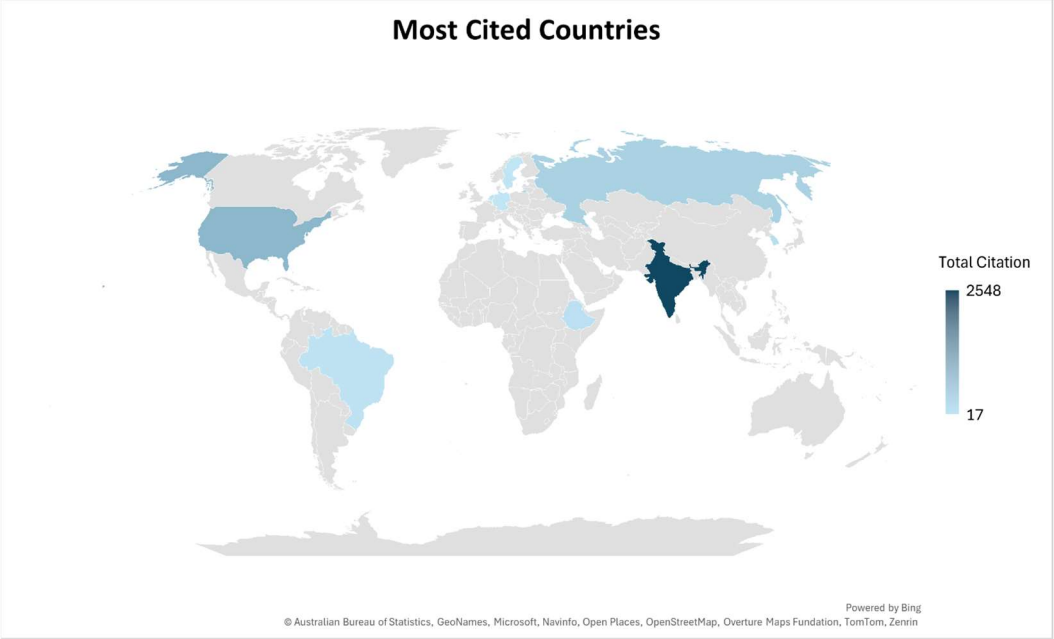


Figure 17. The citation distribution shows a strong concentration among a small number of countries. India leads by a substantial margin, accounting for 2548 citations, which represents 55.7% of the total citation output among the analyzed countries. The United States ranks second with 758 citations (16.6%), followed by the United Kingdom with 584 citations (12.8%). Together, these three countries contribute more than 85% of the total citations, indicating a highly skewed citation landscape.

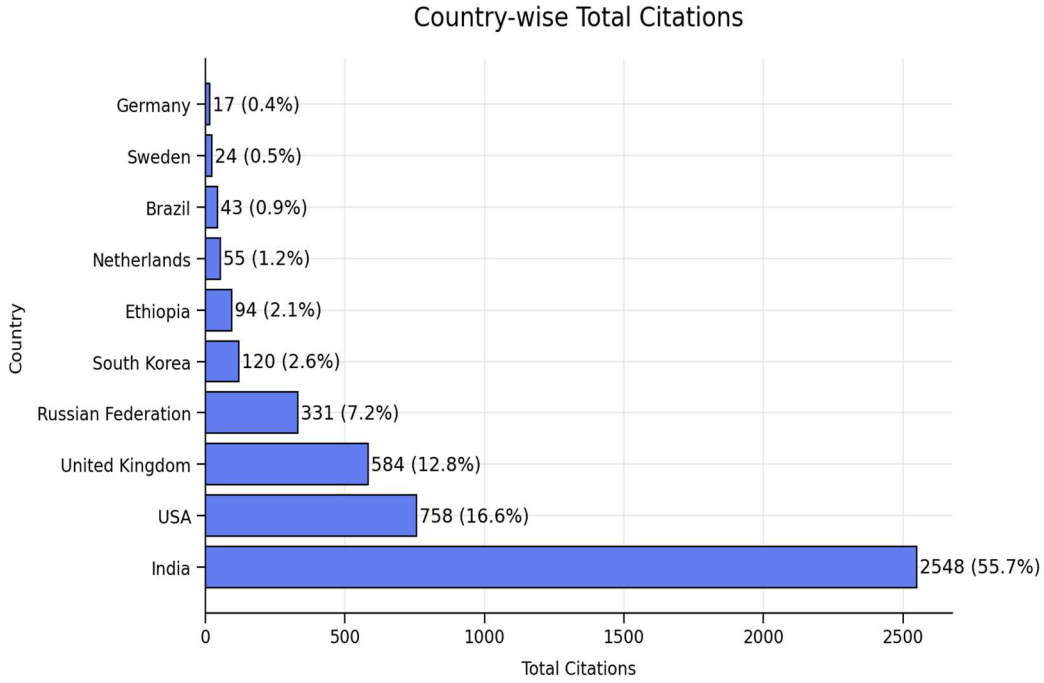


Figure 18. Country-wise total citation counts for the sacred grove literature (ranked bar chart). India (2548 citations, 55.7%) leads by a wide margin, followed by the United States (758, 16.6%) and the United Kingdom (584, 12.8%); together these three countries account for over 85% of total citations, confirming the highly skewed citation landscape visualized geographically in Figure 17.

The near-absence of citation contribution from Southeast Asia, Africa, and Latin America regions with their own rich sacred grove traditions underscores the limited cross-cultural scholarly dialogue identified in the collaboration network analysis and represents a significant opportunity for comparative ecosystem services valuation research that could elevate the field's global policy relevance beyond its current South Asian epicenter.

4. Biocultural Heritage and Ecosystem Services in IHR Sacred Groves: An Evidence Synthesis

4.1. Conceptual Framework: Sacred Groves as Socio-Ecological Production Landscapes

IHR sacred groves are best understood not as simple conservation reserves but as Socio-Ecological Production Landscapes (SEPLs), in the tradition of Japan's 'Satoyama': mosaic landscapes where human use, cultural norms, and biodiversity co-exist in dynamic equilibrium. This SEPL framing is critical for ES valuation because it positions community governance not as a constraint on ecosystem service delivery but as its primary enabling mechanism. A sacred grove from which all extractive use is excluded by religious taboo provides different (and often greater) ES than one in which selective harvesting is permitted under customary protocols; neither should be valued using the same market-based methodologies appropriate for commercial forests.

Following CICES v5.1 [17], ecosystem services are organised in three sections: Provisioning, Regulation & Maintenance, and Cultural. Supporting services are not a CICES section; therefore, soil formation, nutrient cycling, and pollination are treated under Regulation & Maintenance. For each category, we synthesise the available evidence from IHR-based studies, whether biophysical, ethnographic or economic, and identify methodological and geographic gaps, culminating in the Research Evidence Heatmap given in preciding Figure 19. Monetary estimates are mentioned only as reported by the original authors and are not aggregated (Section 4.6).

India's National Action Plan on Climate Change (NAPCC) includes the National Mission for Sustaining the Himalayan Ecosystem (NMSHE), which explicitly recognizes sacred groves as traditional conservation institutions [28]. However, the NMSHE's implementation guidelines [29] provide no specific methodology or funding mechanism for documenting the ecosystem services and cultural values of sacred groves, a policy gap to which this review points.

The Biocultural Heritage–Ecosystem Service Pathway

The pathway from biocultural heritage to measurable ecosystem service flow follows a consistent structural logic across the IHR's diverse grove traditions, whatever the local idiom Dev van, Law Kyntang, Oran, or Gamkhap [30]. A grove's sacred status is codified into an institutional rule (a taboo on felling, a restriction on grazing, a ritual calendar limiting human entry); that rule is enforced through customary authority (village deity councils, clan elders, panchayati raj bodies) rather than statutory law; the enforced rule produces a distinctive disturbance regime (near-zero extraction, canopy continuity, undisturbed leaf litter and soil); and that disturbance regime, in turn, generates the biophysical conditions underlying each ES category reviewed in Sections 4.2–4.5, from spring-flow stability to microclimate buffering. When this pathway breaks down as governance weakens under land-use pressure, migration, or religious change, ES provision degrades even where the grove's vegetation remains nominally intact, because biocultural heritage functions as the governance engine of the service, not merely its backdrop. Valuation studies that measure ES stocks without also recording the strength and type of biocultural governance therefore risk attributing to "forest cover" an effect that is, mechanistically, produced by the surviving institution. This distinction motivates the recommendation in Section 5.4 that governance be documented alongside ES evidence. The pathway is consistent with institutional analyses of common-pool resource governance [31,32] and with the role of traditional ecological knowledge in adaptive management [33].

4.2. Provisioning Services

4.2.1. Non-Timber Forest Products (NTFPs) and Medicinal Plants

IHR sacred groves function as living pharmacopoeias. The Western Himalayan region (Uttarakhand, Himachal Pradesh) and Meghalaya have the best-documented evidence on medicinal plants and NTFPs, mainly ethnobotanical inventories: Studies have documented 40–120 medicinal species per grove in Garhwal [34], and Pandy et al. [35] have reported 60–180 medicinal species per sacred grove (Law Kyntang) in Meghalaya's Khasi Hills, Where monetary estimates exist they come from a few site-specific market-price or income studies of species with established trade networks; species used only for subsistence or ritual healing are excluded by design, so such figures capture only a small part of the value of the groves to local communities and are not reported here.

The Northeast Indian states (Nagaland, Manipur, Mizoram) have significant sacred grove medicinal plant richness documented in ethnobotanical surveys [36,37], but no quantitative market-price or income-accounting studies exist. This is the most significant NTFP evidence gap: Nagaland's 'Khom' and 'Naga Sacred Groves' contain high endemism but remain poorly documented beyond ethnobotanical inventories. Whether monetary accounting is the appropriate way to fill this gap is for custodian communities to decide; documentation of use and knowledge, with consent, comes first.

4.2.2. Water Provisioning

The hydrological provisioning function of IHR sacred groves is most rigorously documented in Uttarakhand, where spring-head protection by Dev vans is well-established in both traditional knowledge systems and quantitative hydrology. Khan M's studies in Uttarakhand [22] demonstrate that sacred grove watersheds maintain perennial spring flow during the critical pre-monsoon dry season (April–May), when adjacent deforested catchments show 60–80% reduced flow.

In Himachal Pradesh's terraced agricultural landscapes, sacred grove-protected catchments supply irrigation water, but the evidence consists mainly of local accounts and a few replacement-cost studies that are not reported here. Ladakh and Jammu & Kashmir remain evidence voids, particularly significant given that water provisioning in arid Himalayan ecosystems is arguably the single most valuable ES for local communities facing accelerating glacier retreat.

4.2.3. Genetic Resources

IHR sacred groves harbor documented populations of wild relatives of major food crops: Oryza sativa wild relatives in Meghalaya, Zea mays wild relatives and traditional landraces in Uttarakhand, and multiple Cucurbitaceae and Fabaceae wild relatives across the Northeastern states. Quantitative evidence on genetic resources is very limited: apart from two contingent valuation studies from Uttarakhand, documentation consists mainly of species lists and ethnobotanical records, and the genetic diversity of crop wild relatives and landraces in groves is largely unsurveyed. These groves may act as *in situ* refugia, and questions of access and benefit sharing under the Nagoya Protocol arise, but the option value of such resources cannot meaningfully be summarised by a willingness-to-pay figure.

4.3. Regulation and Maintenance Services

4.3.1. Carbon Sequestration and Storage

Tripathi R and colleagues [37] (Sikkim Himalayan sacred groves) have produced the most rigorous carbon stock data in the IHR corpus, reporting above-ground biomass of 280–450 Mg ha^{-1} using standardized allometric equations, values comparable to or exceeding primary montane forests in formally protected areas (Table 4). Carbon stocks are reported in biophysical units only; no monetary conversion is made.

To our knowledge, IHR sacred groves are not covered by India's Carbon Credit Trading Scheme (CCTS, notified 2023) [38] or the proposed National Carbon Market, partly for methodological reasons (no standardized sacred grove-specific allometric equations), partly legal (tenure ambiguity) and partly institutional (no designated agency) Whether carbon-market participation is desirable for sacred groves is itself contested: crediting would bring external monitoring and commodify landscapes whose protection rests on taboo, and secure tenure, community consent and benefit sharing (for example through Community Forest Rights) are governance prerequisites that precede measurement.

Table 4. Carbon stock evidence by IHR sub-region (biophysical values as reported by the original authors; monetary conversion removed.

Sub-Region/Study	AGB (Mg/ha)	Annual Seq. (tC/ha/yr)	Evidence Quality
Sikkim Himalaya (Tripathi et al. [37])	280–450	3.5–6.0	3 Robust
Meghalaya Khasi Hills (Pandey et al. [35])	220–380	2.8–4.8	2 Limited Quant.
Uttarakhand Dev vans	150–320	2.0–4.2	2 Limited Quant.
Himachal Pradesh Shamilat	120–260	1.8–3.5	1 Anecdotal
NE India (Manipur/Nagaland)	180–400 (est.)	2.2–5.0	1 Anecdotal
Ladakh/J&K	Not measured	Not measured	0 No Study

4.3.2. Watershed Regulation and Hydrological Services

Beyond direct water supply, sacred groves provide critical watershed regulation: flood attenuation, groundwater recharge, erosion prevention, and sediment retention. Evidence on erosion and landslide damage prevention is largely restricted to avoided-cost analyses from Uttarakhand. The 2013 Kedarnath disaster, in which flash floods devastated areas where sacred grove and forest cover had been reduced, provides a catastrophic natural experiment in the consequences of hydrological service degradation, but no systematic post-disaster valuation study has been conducted for sacred grove hydrological services in the affected catchments.

4.3.3. Microclimate Regulation

Temperature differentials of 2–5 °C between sacred grove interiors and adjacent deforested areas have been documented in Uttarakhand, Meghalaya, and Sikkim [39]. The agricultural productivity benefit from microclimate buffering, particularly relevant for high-altitude crops vulnerable to late frost and heat stress, has been suggested but quantified only in isolated cases. No microclimate regulation studies exist for Himachal Pradesh, Ladakh, or any Northeastern state other than Meghalaya and Sikkim.

4.4. Cultural Services

4.4.1. Spiritual and Religious Values

Cultural services are the foundational justification for sacred grove conservation across the IHR. Contingent valuation (CV) studies of willingness to pay (WTP) for spiritual and religious preservation exist for only three states: Uttarakhand, Himachal Pradesh, and Meghalaya, and we interpret them with caution. In the Khasi Hills, where Law Kyntang groves are connected to the clan's spiritual identity and desecration is a serious customary offence, reported WTP is highest. In such contexts, however, extraction is prohibited by taboo, so a WTP figure is at best an expression of the community's refusal to extract and not a price for a service that could be traded. Aggregating it across households into a per-grove value would mix incommensurable values and invite comparison with alternative land uses that ignores the non-substitutable character of sacred sites. International literature treats spiritual, relational, and identity values as a distinct

category of cultural ecosystem services and relational values, best documented through qualitative, participatory, and place-based methods [40,41].

CV estimates are also subject to hypothetical bias, since stated WTP can exceed actual payment, but the more fundamental issue is conceptual: triangulation with revealed-preference methods would not resolve the incommensurability of sacred values. A more appropriate research priority is the participatory documentation of cultural and spiritual values by custodian communities themselves, for example through Biodiversity Management Committees and People's Biodiversity Registers (Section 5.4).

4.4.2. Ecotourism and Recreation

Controlled ecotourism generates documented revenue in Uttarakhand's accessible sacred grove networks and in Meghalaya's community-managed Law Kyntang tours. Travel-cost studies of recreation value are scarce. Meghalaya's model, where the Khasi Hills Autonomous District Council manages guided Law Kyntang visits with strict visitor caps, revenue sharing with grove-custodian clans, and a prohibition on photography in sacred areas, illustrates a locally governed institutional framework for sacred grove ecotourism in the IHR.

4.4.3. Education, Research, and Traditional Knowledge

IHR sacred groves function as open-air universities for ecological knowledge transmission, ethnobotanical documentation, and formal environmental education. Traditional Ecological Knowledge (TEK) embodied in sacred groves species-specific harvesting protocols, seasonal taboos, and early warning indicators of ecological stress represents irreplaceable intellectual heritage. The Nagoya Protocol on Access and Benefit Sharing (ABS) provides a legal framework for recognizing and compensating TEK holders whose knowledge is used in pharmaceutical or agricultural research, but implementation in IHR sacred grove contexts remains at an embryonic stage. No state programme currently documents grove-specific traditional knowledge, and Biodiversity Management Committees and People's Biodiversity Registers are the existing statutory channel for doing so (Section 5.3). No IHR state has established an operational ABS protocol specifically for sacred grove TEK.

4.5. Soil, Nutrient Cycling, Pollination and Seed Dispersal (Regulation and Maintenance)

CICES v5.1 does not recognise supporting services as a separate section; the underlying processes appear within Regulation & Maintenance (for example, maintenance of soil fertility and structure, pollination and seed dispersal). IHR sacred groves contribute soil formation and organic matter accumulation, nutrient cycling, pollination through native bee habitat, and seed dispersal by resident frugivorous birds and mammals. Scattered replacement-cost and productivity estimates exist for some of these services, but we do not report them: they rest on assumptions (such as fertiliser equivalents) that say little about the value of the groves, and the services are methodologically resistant to monetisation. Pollination is among the most policy-relevant of these services given India's National Bee Board mandate, yet no study has explicitly valued or quantified pollination provision by IHR sacred groves.

4.6. Why No Aggregate Economic Value Is Estimated

The present study does not aggregate monetary estimates into a Total Economic Value (TEV) range per hectare, for four reasons. First, the estimates came from heterogeneous sites, methods, units (per household, per grove and per hectare) and price years, and could not be traced to sources; pooling them would be a benefit-transfer exercise whose validity and transfer error would have to be demonstrated, which the available evidence does not allow. Second, the services that can be measured with market prices, avoided cost or replacement cost cover only a narrow set of immediate-use values, while the values for which sacred groves

are most distinctive (spiritual, cultural and relational values and traditional knowledge) are the ones that monetary figures represent worst. Third, where extraction is forbidden by taboo, WTP expresses non-extraction and not a price. Fourth, a per-hectare monetary total invites direct comparison with competing land uses such as roads or agriculture, which in many cases would favour conversion and so devalue groves whose protection rests on non-monetary grounds. How evidence is mobilised in impact assessment and appraisal procedures [42] determines whether non-monetary values are visible in decisions, which is a reason to present plural evidence in these procedures and not a single monetary total.

The present study instead recommends pluralistic valuation [40,41], in which biophysical indicators, descriptors of governance and cultural continuity, and community-defined values are presented side by side, and monetary estimates, where communities find them acceptable, are reported site by site with units, price year and method and are never summed.

4.7. Research Evidence Heatmap: Mapping Where Documentation of IHR Sacred Grove Ecosystem Services Is Thin

A further contribution of this study is the Research Evidence Heatmap (Figure 19), which maps the geographic and categorical distribution of documented ES evidence across 12 IHR units and 9 ES categories. To our knowledge, no comparable state-by-service overview exists for the sacred grove literature, although we did not conduct a documented search for such instruments. The heatmap records how much documented evidence exists, not how important a service is, and it is a research-mapping aid and not a priority ranking of groves for monetisation. Scores are provisional until independent double coding has been completed and the supporting studies listed (Section 2.3).



Provisional first-pass scores (0 = No Study, 1 = Anecdotal / grey literature, 2 = Limited quantitative, 3 = Robust quantitative); to be re-scored by two independent coders.
*Labelled 'Spiritual / Cultural WTP' in the first-pass version; records evidence located for spiritual and cultural values, mostly WTP-based. †Added column; not yet scored.

Figure 19. Research Evidence Quality Heatmap Ecosystem Services Valuation in IHR Sacred Groves by State and Service Category. Scores are provisional first-pass scores pending independent double coding; Soil formation, nutrient cycling and pollination are treated under CICES Regulation & Maintenance. Rows represent the 12 Indian Himalayan states/union territories; columns represent nine CICES v5.1 ecosystem service categories. Cell color and annotation indicate evidence quality: deep red

= No Study (Score 0); amber = Anecdotal/Grey Literature (Score 1); yellow = Limited Quantitative evidence (Score 2); forest green = Robust Quantitative evidence (Score 3). Dashed horizontal line separates the Western Himalayan states (above) from Sikkim and the Northeastern IHR states (below). Dotted line marks the boundary between Sikkim–Meghalaya (relatively better studied) and the remaining Northeastern states.

4.7.1. Geographic Asymmetry: The Western–Northeastern Gradient

The heatmap exposes a striking Western–Northeastern gradient in ES evidence quality. Uttarakhand and Sikkim states, where the academic institutions (HNB Garhwal University, Sikkim University, G.B. Pant National Institute of Himalayan Environment) have maintained long-term sacred grove research programs exhibit the densest evidence coverage. This reflects not greater ecological significance but greater institutional research capacity and accessibility. The gradient is largely expected, given the remoteness, difficult terrain, permit requirements, and security constraints in parts of the north-east and its limited research infrastructure; it quantifies a known access problem and is less a discovery than a description of which services are most affected. Part of it may also be an artefact of indexing and language coverage (Section 2.1). The Northeastern states Nagaland, Manipur, Mizoram, and Arunachal Pradesh are reported to harbour some of the most intact sacred grove systems (in terms of governance integrity, biodiversity richness, and cultural continuity) yet remain near-total evidence voids in the indexed literature.

The consequences of this gradient for policy are severe. When India's Ministry of Environment, Forests and Climate Change (MoEFCC) makes decisions about sacred grove recognition, funding allocation, or integration into state forest policy, the evidence base systematically over-represents the Western Himalayan experience. Uttarakhand's Dev van model with its panchayat-integrated governance and relatively open access for subsistence use is institutionally very different from Nagaland's clan-based 'Khom' groves with strict taboo-based exclusion. Policy derived from the Uttarakhand evidence base may be wholly inappropriate for Nagaland contexts.

4.7.2. Service Category Gaps: Pollination, Soils, Microclimate and Genetic Resources

Across the IHR units, four service categories stand out as the least documented, with the largest numbers of No Study cells: pollination, soil formation and nutrient cycling, microclimate regulation and genetic resources. Carbon stocks have robust evidence only in Sikkim and are thin elsewhere. These services require specialist biophysical methods (systematic pollinator surveys, soil and nutrient measurements, wild relative population genetics, allometric surveys) that are typically beyond the capacity of ecologists whose primary training is in floristic inventory or governance ethnography. The heatmap does not capture non-monetary documentation held in community records, and it therefore probably understates evidence on cultural and spiritual services.

Whether to extend carbon measurement is a policy choice and should not be assumed. Carbon crediting is only one use of such data, and its prerequisites (secure tenure, community consent and benefit sharing) are governance questions that precede measurement. We therefore do not recommend equipment-led carbon programmes as a first priority.

4.7.3. From Heatmap to Research Investment Prioritization

The heatmap can inform, but not determine, research priorities. Cells with Score 0–1 mark where documentation is thinnest, and which of them matter most should be judged with custodian communities and policy stakeholders. The priority matrix in Table 5 is indicative and gives precedence to community-led documentation.

Table 5. Evidence gap priority matrix for IHR sacred grove ES research (indicative; to be refined with custodian communities).

Priority	State	ES Category	Current Score	Rationale for Priority
1-Critical	All IHR units	Cultural and spiritual services; traditional ecological knowledge	Not scored	Not captured by the current heatmap; Biodiversity Management Committees and People's Biodiversity Registers are the statutory channel for community-led documentation
1-Critical	Ladakh/J&K	All services (0)	0	Complete evidence void in glacially fed, arid sacred landscapes; highest climate vulnerability
1-Critical	Nagaland	Cultural and spiritual services; TEK	0–1	Clan-governed groves with strict taboo-based exclusion; evidence limited to anecdotal and ethnobotanical accounts; community-led documentation with consent
1-Critical	All IHR states	Pollination services	0–1	No quantitative pollination study in any state; biophysical survey needed, with community participation
1-Critical	All IHR states	Genetic resources	0–1	Crop wild relative and landrace populations largely undocumented; access and benefit-sharing questions to be settled with custodians
2-High	Mizoram	Watershed regulation	0–1	Dense forest cover + community water dependence; high methodological tractability
2-High	Arunachal Pradesh	NTFP and medicinal plant documentation	0–1	Rich sacred grove biodiversity reported; no quantitative study exists; documentation of use and knowledge, with consent, precedes any economic accounting
2-High	Manipur	Cultural and spiritual services	0–1	Meitei sacred groves (Umanglai forests) have strong customary governance; community-led participatory documentation preferred over contingent valuation
3-Moderate	Himachal Pradesh	Carbon sequestration	1	Transition from anecdotal to robust; standardized allometry study needed
3-Moderate	Meghalaya	Genetic resources	1	Khasi knowledge of crop wild relatives documented; community-led documentation of wild relatives and associated knowledge needed

5. Discussion

5.1. IHR as a Sacred Grove Research Epicenter and Its Limitations

The bibliometric evidence confirms the IHR as the productive epicenter of global sacred grove scholarship. IHR-affiliated authors dominate productivity rankings (Tripathi R, Pandey H, Upadhaya K, Khan M, Joshi S); IHR-specific terms (sacred groves, India, western ghats) anchor the Niche Theme cluster; and Indian practitioner journals (Indian Forester, Current Science, Tropical Ecology) have established themselves as the primary conduit for national-scale sacred grove research.

Yet the evidence quality heatmap exposes the limitations of this epicenter status. Geographic concentration of research in Uttarakhand and Sikkim driven by institutional history, topographic accessibility, and historical research program momentum has created a systematically biased evidence base. This geographic bias has been invisible in aggregate bibliometric analyses but is starkly visible in the state-by-service heatmap. Part of the apparent north-eastern void may be an artefact of indexing and language: regional-language, non-indexed and community documentation (for example People's Biodiversity Registers) is not captured by our sources, so the 'void' should be read as a void in the indexed English-language literature (Section 2.1). The policy risk is that conservation interventions designed from the Western Himalayan evidence base will be misapplied to structurally and ecologically different Northeastern sacred grove systems.

The Lotka's Law analysis reveals a complementary dimension of this problem: the long tail of single-publication authors (85% of 1008) may partly reflect researchers who made one-off contributions (the affiliations of single-publication authors were not analysed here). Filling the heatmap's evidence voids in the north-eastern states is best approached first through community institutions: supporting Biodiversity Management Committees to map cultural and spiritual ecosystem services and record traditional ecological knowledge, with universities in a supporting role, rather than distributing measurement equipment to universities or requiring monetary valuation in biodiversity inventories.

5.2. The Ecosystem Services Valuation Gap in Global and Indian Contexts

The most globally cited document in the corpus (Graeme A 2007: 300 citations) is a biodiversity ecology synthesis. No valuation study appears in the top 10 most-cited works. The Trend Topics chart shows no emergence of 'ecosystem services valuation' as a prominent term. The thematic map places Sociology and Political Science as the disciplines most engaged with governance and with deliberative and pluralistic valuation in the Declining/Emerging quadrant. Across all these analytical dimensions, the same conclusion emerges: monetary ES assessment is peripheral in the sacred grove literature, which need not be a deficiency (see below).

This contrasts with the global trajectory of ES valuation science, where the Millennium Ecosystem Assessment [43], TEEB [44] and the IPBES Global Assessment [45] progressively normalised economic valuation as a policy translation tool. The same body of work has also recognised its limits: the IPBES Values Assessment [40] and Pascual et al. [41] show that market-based valuation captures only part of the diverse values of nature and frequently overlooks relational and intrinsic values, with consequences for decisions. The low engagement of the sacred grove literature with monetary valuation is therefore not only a capacity problem (specialist CV and replacement-cost skills are rare in an ecology-dominated field); it is also principled. Monetizing sacred groves risks commodifying cultural heritage; a taboo on extraction means WTP expresses non-extraction; and monetary values capture mainly immediate-use values, putting groves into direct competition with infrastructure and agriculture on terms that favour conversion. We therefore treat the principled objection as substantive and as part of the explanation of the gap. Pluralistic approaches are the constructive response: biophysical indicators, governance and cultural-continuity descriptors and community-defined values are presented together, with monetary estimates only where communities choose them. Because the arenas where sacred groves are most contested (infrastructure approvals, forest land diversion, state forest policy) are those in which economic arguments often carry decisive weight (cf. Nita et al. [42] on assessment procedures), legal recognition and safeguards (Community Forest Rights, OECMs, Biodiversity Management Committees) are better protections than price tags.

5.3. Governance, Policy Integration, and the IHR Sacred Grove Opportunity

India's policy architecture contains several underused opportunities. Biodiversity Management Committees (BMCs) under the Biological Diversity Act (2002) are legally mandated to document biodiversity, including in sacred groves, and to prepare People's Biodiversity Registers (PBRs), but PBR formats do not currently include fields for ecosystem services. A practical step is to give BMCs resources and guidance to record the cultural and spiritual services, custodian institutions, and traditional ecological knowledge of sacred groves in the PBR, with communities controlling what is recorded and disclosed, consistent with access and benefit-sharing provisions. The four-level rubric used here could serve as a simple monitoring aid, not as a valuation requirement.

The Forest Rights Act (2006)'s Community Forest Rights (CFR) provisions allow communities to legally claim management authority over community forests, including sacred groves. CFR titles have been

issued over a substantial area, but sacred grove claims appear to be a small share CFR recognition would secure customary tenure and governance authority, a precondition for any community-controlled benefit arrangement. State governments in Meghalaya, Nagaland, and Manipur, where customary governance of sacred groves is strongest, should be targeted for pilot CFR registration programs specifically designed for sacred grove conservation.

At the international level, the Kunming-Montreal Global Biodiversity Framework's Target 3 (30 × 30) explicitly recognizes Other Effective Area-based Conservation Measures (OECMs) as contributors to the 30% target. Sacred groves, governed by community institutions and demonstrably conserving biodiversity and ES, are strong candidates for OECM recognition [46,47], provided that recognition rests on the free, prior and informed consent of custodians and does not impose external management. India's OECM recognition framework, being developed by MoEFCC, should explicitly include IHR sacred groves as a priority OECM category.

This governance blind spot is not incidental it is the same disciplinary imbalance identified in the bibliometric analysis (Section 3.7–3.8), where the socio-political cluster (political science, sociology, archaeology) remains structurally peripheral to the biophysical Motor Theme. Because biocultural heritage is fundamentally a governance phenomenon encoded in customary law, ritual authority, and community institutions rather than in vegetation structure alone a literature that under-recruits governance and social science expertise is, by construction, poorly positioned to document the mechanism connecting cultural practice to ecosystem service outcome (Section 4.1.1). Correcting this imbalance is as much a research-workforce and funding-allocation problem as a methodological one: valuation teams need ethnographers and legal scholars embedded alongside foresters and ecologists if the biocultural heritage–ecosystem service link is to be evidenced rather than assumed.

5.4. Future Research Priorities

The heatmap and the discussion above point to a research agenda that begins with communities and not with instruments. First, community-led mapping of cultural and spiritual ecosystem services and documentation of traditional ecological knowledge, supported through BMCs and PBRs, should be the priority in the north-eastern states and in Ladakh/Jammu & Kashmir, where indexed evidence is thinnest. Documentation protocols should be co-designed with custodian communities, respect their decisions about what is recorded and shared, and follow access and benefit-sharing safeguards.

Second, biophysical gaps that communities and managers consider relevant can be filled with standard, low-cost methods: systematic pollinator surveys in grove-adjacent landscapes in at least three IHR states; surveys of crop wild relatives and landraces in Meghalayan, Naga and Manipuri groves; and, where communities agree, carbon-stock inventories using national allometric equations, treated as one option and not as a prerequisite for protection. In Uttarakhand, post-2013 Kedarnath flow data can be used for avoided-damage analysis in physical terms (flow regulation, sediment), with monetary conversion optional. Third, capacity building in north-eastern institutions should favour participatory, ethnographic and ecological methods taught alongside community partners; training in economic valuation can be offered where custodians request it. Fourth, OECM registration pilots designed with MoEF&CC, state forest departments, and custodian communities in at least three states should document biodiversity, governance, and ES evidence following the IUCN-WCPA [46] technical guidance, with free, prior, and informed consent.

Finally, pluralistic and decolonial valuation frameworks, in which community-defined indicators of sacred grove well-being co-developed through participatory processes are presented alongside biophysical and, where accepted, economic estimates, address concerns that monetary valuation erodes cultural sovereignty in sacred landscape governance.

6. Conclusions

This study has mapped the state of research on the relationship between biocultural heritage and ecosystem services through two contributions: a bibliometric analysis of 452 publications spanning 1986–2026, which shows how thinly the indexed literature has studied the cultural and governance mechanisms underpinning that relationship, and a Research Evidence Heatmap that shows where documentation of nine ES categories is thin across twelve Indian Himalayan units.

The bibliometric analysis shows a field dominated by a biophysical Motor Theme (Geography–Ecology–Biology) that marginalises the governance-oriented social sciences. No valuation study appears among the ten most-cited documents, ES valuation vocabulary does not feature among the prominent trend topics, and sociology and political science are the lowest-accumulating terms. These signals describe the orientation of the indexed literature; they are not a deficiency in themselves, because monetary valuation is neither universally appropriate nor necessarily desirable for sacred groves. We make no claim about field maturity: growth projections were removed because the final years of the corpus are incomplete and publication counts around 2020–2021 were affected by the pandemic.

The heatmap gives this finding geographic and categorical specificity. Evidence is concentrated in Uttarakhand and Sikkim (and Meghalaya for some services), whereas Ladakh/Jammu & Kashmir, Mizoram, Arunachal Pradesh and Tripura are near-total voids in the indexed literature. The gradient is consistent with differences in accessibility and research capacity and may partly be an artefact of language and indexing. Pollination, soil formation and nutrient cycling, microclimate regulation and genetic resources are the least documented categories. The heatmap thus shows where and for which services documentation is thin, without implying that the missing evidence should be monetary.

The policy opportunity is real. India's Biodiversity Management Committees and People's Biodiversity Registers, the Community Forest Rights provisions of the Forest Rights Act and the OECM recognition framework provide legal and institutional pathways for sacred groves to be documented and protected on their own terms. Realising this requires supporting custodian communities in mapping cultural and spiritual services and traditional knowledge, plural forms of evidence that do not reduce sacred values to prices that compare unfavourably with infrastructure or agriculture, and a shift of research support from instrument-led programmes towards the north-eastern sacred grove systems that hold much of the IHR's biocultural heritage.

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Author Contributions

Conceptualization, Methodology, Validation, Writing Original Draft Preparation, Supervision, Resources, Formal Analysis, Writing Review & Editing: H.P.; Software, Data Curation, Primary data analysis: P.U. and A.S. All authors have read and agreed to the published version of the manuscript.

Ethics Statement

Not applicable. This study is a bibliometric and literature-based ecosystem services valuation synthesis; it did not involve primary data collection from human or animal subjects.

Informed Consent Statement

Not applicable, as this study did not involve human subjects.

Data Availability Statement

Data is available with corresponding author on reasonable request.

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