Research Progress of Rubber Forest Ecological Restoration Based on CiteSpace

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Abstract. Currently, more and more attention is being paid to ecological restoration, and research on ecological restoration of rubber forests is also developing. In this paper, using CiteSpace 6.3.R1 software and bibliometric analysis, the literature in the field of ecological restoration of rubber forests is visualized and analyzed to support the development of ecological restoration of rubber forests and provide guidance for further research. The results show that the most important research priorities and trends in the field of ecological restoration of rubber forests are currently:(1) Community structure and biodiversity of rubber forests and their influencing factors. Particular attention is paid to the diversity of understorey plants and microbial diversity in the soil. (2) Effects of the conversion of tropical rainforests into rubber forests. Particular attention will be paid to the impact on soil physicochemical properties, ecosystem functions, carbon stocks, biomass, etc. (3) Sustainable management of rubber forests: Special attention will be given to agroforestry rubber forests and the role of semi-natural management practices in the restoration of rubber forests. Future research should continue to promote breeding programs, further explore agroforestry rubber systems and improve management programs for rubber plantations, evaluate and implement ecological restoration projects, and integrate research on climate change and ecological restoration of rubber forests.

Keywords: rubber (*Hevea brasiliensis*), agroforestry rubber forest, ecological restoration, CiteSpace, visualisation analysis.

1. Introduction

The preservation of biodiversity, the enhancement of food and water security, the provision of goods and services, economic prosperity, and the mitigation, recovery, and adaptation to climate change are all reasons why ecological restoration is gaining more and more attention[1]. 2021–2030 has been designated as the decade of ecological restoration by the UN (Fischer J et al., 2021). There are several novel restoration tests as a result of the current socio-ecological changes occurring throughout the world. Restoration objectives need to be held to a higher standard as social and environmental situations continue to change. This calls for tight cooperation between ecologists, social scientists, and other pertinent groups and encompasses not just ecological success criteria but also a mix of human benefits, landscape multifunctionality, and ecological resilience [2].

The present rubber plantation areas are steadily growing outside of the traditional plantation areas and rubber's natural range due to the growing demand for rubber and the decreasing output of rubber in the core suitable locations [3]. Asia currently produces 89% of the world's rubber, with major producers including Thailand, Vietnam, Indonesia, India, China, and Malaysia. In the last ten years, rubber plantations have grown by roughly 2 million hectares, and these plantations are having long-term negative effects on the environment and society[4]. Monoculture rubber forests drastically lower biodiversity, alter soil physicochemical characteristics (such as increased soil erosion, nutrient depletion, and decreased soil water content), lower the value of ecosystem services, and worsen the environment when compared to tropical rainforests[5,6]. Furthermore, the majority of rubber plantations today are monocultures of high-yielding varieties that are typically managed intensively[7]. Inappropriate management, such as overuse of fertilizers and herbicides, excessive soil and water management, and other practices that result in plantation degradation, such as low latex yields and poor rubber tree growth, has also significantly impeded the plantations' ability to develop sustainably[8]. More and more scientists are highlighting the shortcomings of traditional farming practices.

With the growing threats to global soil health, human well-being, and sustainable development, there is an urgent need for remedies to mitigate their harmful effects [9]. In recent years, researchers have primarily focused on the effects of the transition from tropical rainforest to rubber forest on soil physicochemical properties, biodiversity, and ecosystem service functions, as well as rubber forest management programs and policies related to rubber forest restoration. So far, research on the ecological regeneration of rubber forests has been ongoing. This paper presents a visual analysis of the pertinent literature on ecological restoration of rubber forests using CiteSpace 6.3.R1 visual analysis software and bibliometric analysis. It also combs and summarizes the research findings of the field's development thus far, with the goal of revealing the study's development history and trend as well as exploring the frontier and hotspots in the field to provide useful references for the ecological restoration of rubber forests and future research.

2. Data collection and Analysis Methods

2.1. Data sources

Data were selected from the Web of Science core database. The search formula was TS=(rubber AND (recovery OR rejuvenation OR repair OR restore OR restoration OR resilience OR recovery OR remediation OR rehabilitation)) . The literature type was "Article", the search was conducted on September 15, 2024, and 7,295 documents were retrieved, 111 documents were included in the analysis, spanning the period 2010-2024.

2.2. Methods of analysis

In this work, authors, publishing institutions, literature co-citations and keywords in this field of ecological restoration of rubber forests were visualized and analyzed using the visualization and analysis software CiteSpace 6.3.R1.CiteSpace, as a Java-based scientific network construction and visualization tool, enables rapid observation of knowledge and research in a given field using Kuhn's model of scientific development, Price's theory of frontiers of science, social network analysis, and structural hole theory, etc. [10-11].

3. Results

3.1. Analysis of the research team

Citespace was used to analyze the publishing team in the subject of ecological restoration of rubber forests, yielding the author collaboration graph (Fig. 1). With 632 links and 286 nodes, the graph's network density is 0.0155. Price's law states that one must produce at least mp articles in order to be considered a core author in this subject, where $mp=0.749\sqrt{(npmax)}$, where npmax is the number of papers published by the author with the most publications during the statistical time period [12]. Table 1 indicates that Liu Wenjie is the author with the most number of publications in this discipline, with four publications (npmax=4). Then mp≈1.498, meaning that in order to be considered a core author in this subject, one must have at least two publications. With 55 publications, or 17.4% of the total, there are 25 core writers in the subject, as seen in Table 1. According to Price's theorem, 50% of the total number of publications in the subject must be from core writers in order for them to constitute a stable group [11]. It indicates that the team of issuing papers in the field of ecological restoration of rubber forests has not formed a stable joint group of core authors.

According to Figure 1, the most prominent issuing teams in this field Cheylan V-Hammecker C-Suvanang N team, Choosai C-Chevallier T-Brauman A-Alonso P team. Team Cheylan V focused on the effects of land use conversion (from monoculture to intercropping) on soil nutrients, water, microbes, and rubber tree growth [13-14]. Team Choosai C concentrated on the effects of legumes on logging, the effects of soil organisms on soil health, and the effects of logging on rubber forests[15-17].

Table 1. Core authors in the field of ecological restoration of rubber forests

serial number Code	author Author	volume of publications Literaturenumber
1	Liu, Wenjie	4
2	Brauman, Alain	4
3	Chen, Chunfeng	3
4	Robain, Henri	2
5	Yang, Xiaodong	2
6	Herrmann, Laetitia	2
7	Pena-venegas, Clara P.	2
8	Qiao, Dan	2
9	Zhang, Desheng	2
10	Das, Ashesh Kumar	2
11	Singh, Ashutosh Kumar	2
12	Ostle, Nicholas J	2
13	Cao, Min	2
14	Brahma, Biplab	2
15	Masson, Aurelien	2
16	Luo, Chunling	2
17	Zhu, Xiai	2
18	Zhang, Dayi	2
19	Wiriyakitnateekul, Wanpen	2
20	Nath, Arun Jyoti	2
21	Zhang, Gan	2
22	Xu, Tao	2
23	Suvannang, Nopmanee	2
24	Robin, Agnes	2
25	Lesueur, Didier	2

Fig. 1 Mapping of author collaborations in the field of rubber forests ecological restoration

3.2. Analysis of issuing institutions

Fig. 2 displays the issuing institutions' collaboration graph, which consists of 54 nodes, 83 links, with a network density of 0.058. According to Table 2, the Chinese Academy of Sciences is the organization that has published the most studies on rubber ecological restoration. More papers from China and France are found at Xishuangbanna Tropical Botanical Garden, CIRAD, Universite de Montpellier, Institut Agro, and other institutions, suggesting that Chinese and French institutions are very engaged in this field of study. There is still more work to be done in the ecological restoration of rubber forests, and in order to achieve technological advancements and experience sharing, institutions must work together more closely. China has consistently worked to restore the environment and develop rubber forests sustainably. With the goal of creating an environmentally friendly rubber sector, "Guidance for Sustainable Natural Rubber" is the first set of social and environmental sustainability guidelines for the natural rubber sector in history [18].

Table 2. Institutions with more publications in the field of rubber forest ecological restoration research

serial number Code	organization Research institution	volume of publications Literaturenumber
1	Chinese Academy of Sciences	22
2	Xishuangbanna Tropical Botanical Garden	15
3	CIRAD	11
4	University of Chinese Academy of Sciences	9
5	Universite de Montpellier	9
6	Institut Agro	9
7	INRAE	6
8	Institut de Recherche pour le Developpement (IRD)	6
9	Montpellier SupAgro	6
10	Hainan University	5
11	Assam University	5

Fig. 2 Mapping of cooperative network of institutions in the field of rubber forests ecological restoration

3.3. Analysis of Research Hot Spots and Trends

3.3.1. Analysis of cited literature

A co-citation relationship shows that two or more pieces of literature are cited in the same article or articles, helping to identify common themes of literary interest [30]. As shown in Table 5, the most frequently cited literature in the field of research on ecological restoration of rubber forests is an article published by Chen CF entitled “Can intercropping with the cash crop help improve the soil physico-chemical properties of rubber plantations?” The author selected a single rubber plantation in Xishuangbanna, China, and two rubber agroforestry systems, H. brasiliensis-T. cacao and H. brasiliensis-F. macrophylla, and confirmed that the soil physico-chemical properties of rubber agroforestry systems can be improved by determining their soil physico-chemical properties, confirming the feasibility of rubber agroforestry systems [5]. It is evident from Table 5 that the majority of the literature with a large number of citations focuses on the detrimental effects of monoculture rubber forests, such as decreased soil nutrients and water saturation.

Table 3. Literatures with more cited and main ideas in the field of rubber forests ecological restoration

Literatures	Year	Author	Main idea	Count
Can intercropping with the cash crop help improve the soil physico-chemical properties of rubber plantations?	2019	Chen CF	In comparison to rubber monoculture, rubber-based agroforestry systems optimize soil structure, enhance soil nutrients, lower break-even points, and dramatically improve the physical and hydrological characteristics of soil.	6
Effects of rubber-based agroforestry systems on soil aggregation and associated soil organic carbon: Implications for land use	2017	Chen CF	Compared to monoculture rubber forests, rubber agroforestry produces soil aggregates with a higher capacity to sequester carbon and nitrogen.	5
The conversion of tropical forests to rubber plantations accelerates soil acidification and changes the distribution of soil metal ions in topsoil layers layers	2019	Liu CA	By drastically decreasing soil exchangeable Ca, exchangeable Mg, effective Zn, effective Mn, and Fe and increasing soil exchangeable Al effective Cu, the conversion of tropical natural forests to rubber forests sped up soil acidification processes and restricted plant development.	5
Increasing Demand for Natural Rubber Necessitates a Robust Sustainability Initiative to Mitigate Impacts on Tropical Biodiversity	2015	Warren-Thomas E	The biodiversity of birds, bats, and invertebrates may suffer if forests or agricultural land are converted to rubber monoculture.	4
Carbon costs and benefits of Indonesian rainforest conversion to plantations	2018	Guillaume T	The conversion of tropical rainforests to rubber forests reduces carbon stocks	4
Where the rubber meets the garden	2009	Qiu J	In addition to decreasing the value of ecosystem services, large-scale rubber plantations have seriously harmed the environment and climate.	3
Soil Carbon Stocks Decrease following Conversion of Secondary Forests to Rubber (Hevea brasiliensis) Plantations	2013	de Blécourt M	Conversion of forests to monoculture rubber forests reduces soil carbon stocks	3

3.3.2. Co-occurrence keyword analysis

The cutting-edge hotspots of the research topic during the study period might be reflected in keyword analysis [19]. The terms biodiversity, diversity, rain forest, hevea brasiliensis, land use, forest, rubber plantation, xishuangbanna, impact, ecological restoration, etc. are more frequently used in the field of ecological restoration of rubber forests, as Table 4 illustrates. These keywords primarily highlight the detrimental effects of rubber forests, which is in line with the findings from the review of the referenced literature. With a Q value of 0.5453 and a S value of 0.8291, the clustering map of the co-occurring keywords in the field of ecological restoration of rubber forests is displayed in Fig. 3. A Q value greater than 0.3 indicates a significant clustering structure, a S value greater than 0.5 indicates a reasonable result, and a value greater than 0.7 indicates a convincing result [20]. It suggests that the findings are quite reliable and that the cluster is significant. Table 5 displays the specific keyword clustering data, which indicates that the primary research areas in this area are (1) the effects of land-use changes, such as the conversion of tropical rainforests to rubber forests, on biodiversity, organic carbon, and other factors. (2) Elements influencing the growth of rubber. (3) Agroforestry rubber forests' ecological service functions.

High-frequency keywords (Fig. 4) and keyword prominence over time (Table 6) show that research in this area has been growing over time, with new research hotspots forming as well as a progressive expansion of the study scope and deepening of the content. Table 4 indicates that the study of rubber agroforestry systems, land use change, and the understory flora and community structure of rubber forests may be the main areas of current and future research interest. According to the timeline, the field can be loosely separated into three stages by combining the terms that appeared in China at various times: Between 2010 and 2015, scientists started studying the ecological restoration of rubber forests after realizing the effects of land-use changes, such as the conversion of tropical rainforests into rubber forests and the abandonment of agriculture; Between 2015 and 2020, research on the ecological restoration of rubber forests is expanding quickly due to growing concerns about the ecological security brought on by land concentration. Additionally, more research is being done on the effects of organic carbon, biomass, ecosystem services, and agroforestry ecosystems beneath rubber forests; Between 2020 and 2024, the field is constantly growing and carrying on with earlier studies, but many new terms have also emerged, such as carbon sequestration and land acidification. Future study topics may become more pertinent due to the frequency of natural catastrophes and climate change worldwide. The physicochemical characteristics of rubber forest soils, biodiversity, and ecosystem services have always been in the forefront of research on ecological restoration of rubber forests, according to the examination of the aforementioned historical periods. The advancement of time has encouraged the ongoing growth of theories, and research methods and methodologies have also improved. The majority of studies and monitoring programs, for instance, use additive methods of measuring physical, chemical, and biological parameters to assess soil inventories. However, the development of functional methods in recent years has made it possible to directly assess soil functions, such as carbon transformations, nutrient cycling, and structural maintenance, without measuring the biological structures or physicochemical properties of the soil, but by directly measuring the outcomes of their interactions [21].

Table 4. Keywords with a high number of occurrences in the field of rubber forests ecological restoration

byword Keywords	ordinal number Count	center value Central value
biodiversity	22	0.5
diversity	16	0.23
rain forest	14	0.17
hevea brasiliensis	12	0.43
land use	11	0.14
forest	10	0.14
rubber plantation	9	0.34
xishuangbanna	7	0.02
impact	4	0.01
ecological restoration	4	0.01
recovery	4	0.38
plantations	4	0.04
ecosystem services	4	0.01
community	4	0.02
carbon	4	0.01
agroforestry systems	4	0.06
Land use change	4	0.02
organic matter	4	0.01

Table 5. Clustering of high-frequency keywords in the field of rubber forests ecological restoration

Clustering of foreign keywords in the field Clueter name abroad	Foreign keywords in this field Keywords abroad
0 forest restoration	diversity (16), rainforest (14), impact (4), plantations (4), carbon (4), organic matter (4)
1 ecological restoration	biodiversity (22), land use (11), xishuangbanna (7), ecological restoration (4), community (4), land use change (4), conversion (3)
2 photosynthesis	growth (3), responses (3)
3 soc:ecosystem c stock	hevea brasiliensis (12), forest (10)
4 caribbean	recovery (4), tropical forests (3)
5 rubber plantation	rubber plantation (9), ecosystem services (4), agroforestry systems (4)

Note: The numbers in () represent the frequency of keyword appearances.

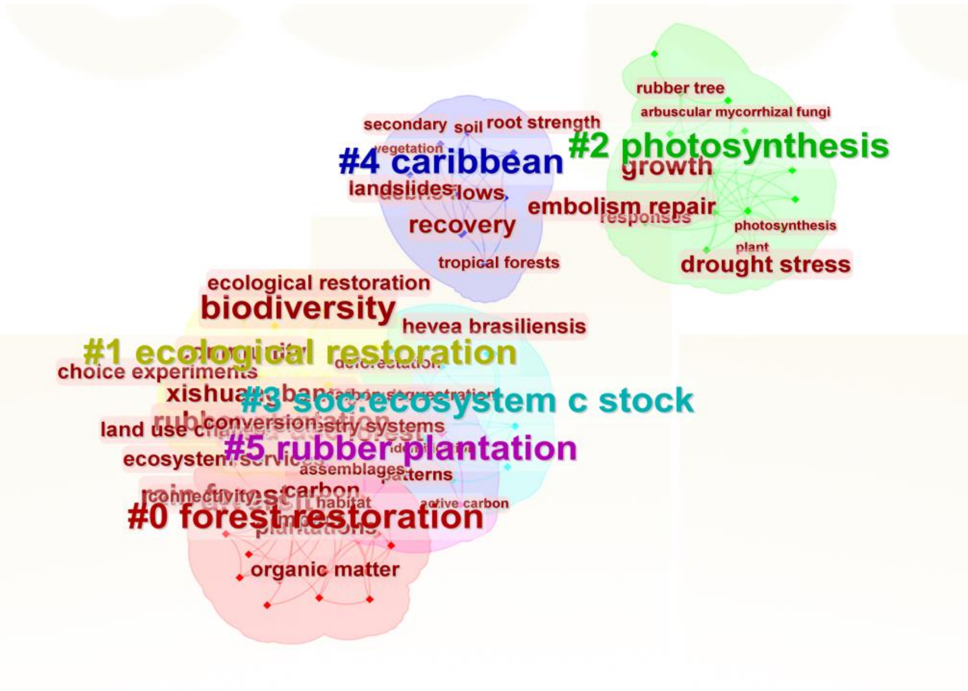

Fig. 3 Mapping of keyword clustering network in the field of rubber forests ecological restoration

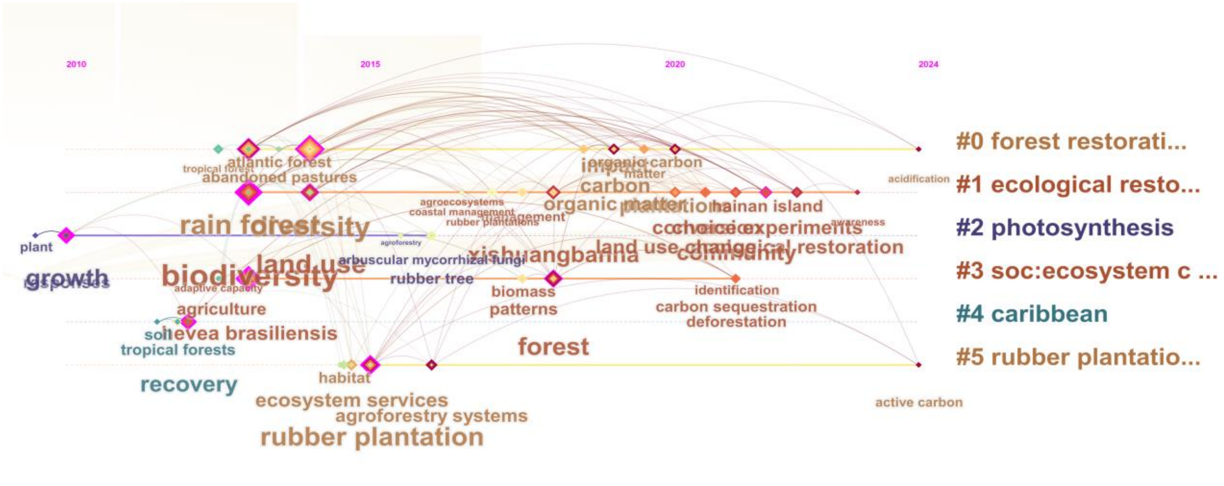

Fig. 4 Time mapping of keyword clustering in the field of rubber forests ecological restoration

Table 6. keyword prominence over time

Keywords	Year	Strength	Begin	End	2010 - 2024
tropical	2013	1.31	2013	2013	
habitat	2015	1.31	2015	2015	
arbuscular mycorrhizal	2016	1.31	2016	2016	
rubber tree	2016	1.31	2016	2016	
tropical forests	2012	1.27	2016	2016	
growth	2010	1.27	2016	2016	
rubber plantations	2017	1.33	2017	2017	
diversity	2014	3.38	2018	2020	
soil organic carbon	2018	1.25	2018	2018	
biomass	2018	1.25	2018	2018	
patterns	2018	1.25	2018	2018	
management	2018	1.25	2018	2018	
rain forest	2013	1.34	2019	2020	
quality	2019	1.21	2019	2019	
nitrogen	2019	1.21	2019	2019	
connectivity	2019	1.21	2019	2019	
Land use change	2020	1.78	2020	2021	
hevea brasiliensis	2013	1.75	2021	2022	
community	2021	1.74	2021	2022	
conversion	2021	1.68	2021	2021	
ecological restoration	2022	2.04	2022	2024	
recovery	2012	1.63	2022	2022	
land use	2014	1.4	2022	2024	
agroforestry systems	2016	1.59	2023	2024	
orest	2024	1.55	2023	2024	

4. Discussion

Through a variety of lenses, we conducted a thorough examination of the research hotspots and trends in the field of ecological restoration of rubber forests both domestically and internationally. We discovered from the co-cited literature that the majority of the highly cited material focused on the detrimental effects of a single rubber forest (e.g., reduction of soil nutrients, water content, etc.). The impacts of the conversion of tropical rainforest to rubber forest, the factors influencing rubber development, and the ecological service functions of agroforestry rubber forests are the primary research directions in this topic, according to the co-occurring keywords. The study of rubber agroforestry systems, land use change, and the understory vegetation and community structure of rubber forests are potential future research hotspots, as indicated by the high-frequency keywords and keyword prominence in various time periods. The stage of study development essentially progresses from concentrating on ecological restoration and land use change to systematically analyzing organic carbon, biomass, and ecosystem service changes in rubber forests during the restoration process to discussing carbon sequestration and land acidification. Based on the analysis mentioned earlier, the following are the current key topics in the field of ecological restoration of rubber forests:

(1) Community structure and biodiversity of rubber forests and the variables impacting them. Particular focus is made to the effects of altitude and precipitation on understory plant diversity and soil microbiological diversity.

(2) The effects of turning tropical rainforests into rubber forests. The effects on soil physico-chemical characteristics, ecosystem services, carbon stocks, biomass, etc., are given special consideration.

(3) Sustainable management of rubber forests: the relevance of near-natural management approaches for rubber forest rehabilitation, with special focus to agroforestry rubber forests.

There is currently agreement that the conversion of tropical rainforests to rubber forests will have numerous detrimental effects, and researchers and associated organizations worldwide are dedicated to finding ways to lessen the issue through modeling studies, policy development, and research on the physicochemical characteristics of rubber forest soils, ecohydrological processes, biodiversity, etc. Three categories of workable answers are now being put up by researchers:

(1) Enhancement of management practices in rubber plantations: Through their research, numerous scholars have offered recommendations on various topics, and management practices in rubber plantations are essential to the restoration of rubber forests. In addition to reducing anthropogenic disturbances and implementing near-natural management techniques, Wu et al. recommended that the development of the rubber business concentrate on the diversity of plants and soil microbes in the rubber understory [22-26]. Liu Wenjie et al. recommended apron management and conservation to improve soil water content and textural conditions and increase soil carbon sequestration [27-28,29]. In order to regulate the process of soil acidification, Liu CA et al. recommended suitable measures (the use of lime and biochar) to decrease exchangeable Al and raise exchangeable Ca, exchangeable Mg, and effective Zn levels [30].To guarantee long-term soil health and productivity in rubber plantation systems, Liu C. A. et al. recommended keeping soil pH above 5.2 and boosting phosphorus fertilizer and micronutrient inputs [30].According to Garousi F et al., rubber plantation soils' ability to produce inorganic nitrogen can be successfully increased by applying organic, phosphorus, and potassium fertilizers appropriately [7].

(2) Creation of complex systems for rubber agroforestry: Rubber agroforestry ecosystems offer a variety of ecosystem services that are beneficial to biodiversity, the environment, and farmers' profits [31-33]. In order to increase vegetation complexity, Zheng G et al. recommended intercropping tea, coffee, or cocoa with rubber to create multilayered systems [34]. Consequently, the complexity of the vegetation is increased [34]. Rubber agroforestry ecosystems should be given priority in order to restore land quality, according to Zou X et al.'s comparison of a single rubber forest with rubber-Camellia sinensis agroforestry and rubber-Dracaena cochinchinensis agroforestry systems [35]. In contrast to rubber monocropping, coffee intercropping increases soil carbon and nitrogen content, which can result in sustainable land management, according to research by Li X A et al. [36]. In rubber plantations, some native tree species with therapeutic or commercial value are frequently planted as intercrops [35].

(3) Promotion by the government and related departments: Investigations conducted by the government and related departments as well as relevant policies will promote the implementation of rubber forest restoration. Liu W G et al. have a greater potential to promote the conversion of a single rubber plantation to a planted rainforest by simulating the establishment of a payment system (payment for ecosystem services) [37]. By recommending that residents' ecological concerns be strengthened and their ecological awareness be targeted in order to successfully diminish their cognitive biases, Ji Y et al. raised their desire to participate in rubber forest ecological restoration [38]. In addition to improving the precision and application of public environmental regulations, rubber forest restoration should pay greater attention to the demands of the general population [39].

The way these initiatives are being implemented still has a lot of shortcomings. Despite the numerous advantages of rubber agroforestry, monoculture systems are still widely used for natural rubber production; in Thailand, intercropping only accounts for 10% of the total planted area, and in southern China's Xishuangbanna, a household survey revealed that only 14% of the rubber plantation area was intercropped [40]. China has started to try its hand at ecological compensation/payment schemes. To encourage 'greener' rubber plantation practices, the Chinese government of Xishuangbanna has established a Leadership Group for Environmentally Friendly Rubber (LGEFR) and a Bio-industry Crops Office [41]. These organizations are dedicated to creating market-based eco-compensation/payment schemes and have set up 8,500 hectares of demonstration plots [41]. However, public awareness is still slow compared to other agricultural crops [41].

We still have a lot of work and research to do in the future regarding the restoration of rubber forests (Figure 4).

(1) Continuation of the breeding programme: Breeding programs should be continuously promoted since rubber forests are susceptible to weather extremes including strong winds that can destroy rubber tree trunks and branches, causing latex leakage and regular tree growth [3]. Rubber forests with low levels of disease and insect resistance have been produced, nonetheless, as a result of the selection of rubber seedlings based on rising production [42]. One of the most crucial technological elements supporting the production and long-term growth of the natural rubber sector is the use of high-quality rubber planting materials [43]. However, hampered by the biological characteristics and genetic complexity of rubber, its breeding program is usually based on a 25-30 year cycle, which includes hybridization, evaluation and selection of field progeny, and propagation of selected superior materials [44-45]. As science and technology have advanced, the use of genomic techniques like marker-assisted selection (MAS), genomic selection (GS), and gene editing technologies (like the CRISPR/Cas9 system) has significantly decreased the time and expense of creating new species [44–46]. Additionally, several new techniques have been put forth to assess how well new species tolerate various stressors, such as drought factor index (DFI), chlorophyll a fluorescence (CF), etc., for a straightforward and accurate way to measure plant resistance to abiotic factors [47]. To lower the risk of plantation decline, we should keep improving breeding programs and figuring out where various clones are appropriate for planting [3].

(2) Comprehensive investigation of agroforestry rubber systems and enhanced management initiatives for rubber plantations: In order to create sustainable rubber agroforestry systems, decision makers must take into account the various obstacles that intercrops in rubber intercropping systems frequently encounter, including species competition, metal toxicity, and environmental considerations [48]. In addition to being determined by agronomic study, the choice of appropriate intercrops must also be tailored to the local market and farmers' requirements [49]. However, the shift to agroforestry rubber plantation systems necessitates adequate finance, technology, experience, and expertise [50], and further policy support is required to promote the future development of rubber agroforestry systems. Through model simulations and field trials, numerous researchers have already examined the spatial arrangement of rubber plantations, weed control, irrigation, and fertilization strategies [30,51-52]. Nevertheless, no proposal has yet been made that incorporates the aforementioned elements, and further research is still required.

(3) Evaluation and execution of ecological restoration initiatives: Ecological benefits and economic and social indicators, such as the extent of the impact on the health of the surrounding population and the economic output value, are the primary focus of the evaluation criteria for ecological restoration projects [53]. At the moment, ecological restoration project evaluation standards and models are still being investigated. In order to determine the proper criteria, we should actively measure a variety of factors at the national and regional levels. Numerous stakeholders, including the government, rubber growers, urban dwellers, etc., must be involved in the implementation of ecological restoration projects in rubber forests, and their views must be fully taken into account [54]. Non-market social benefits should be given particular attention when planning or carrying out ecological restoration initiatives for rubber plantations, and measuring techniques should be continuously enhanced [39].

(4) Combining ecological restoration and climate change: Changes in vegetation and the connection and interplay between vegetation and climate have emerged as significant topics in the field of global change studies [55]. Although ecological restoration is a strategy for climate change

adaptation and mitigation, the outcomes themselves are susceptible to climate change, and effective ecological restoration must consider climate change [56]. Future ecological restoration of rubber forests must be ready for long-term restoration and promptly adapt to changes in the environment. In order to reduce losses in rubber plantations, climatic change and the frequency of disasters should be tracked over time.

For the ecological restoration of rubber forests, we still face many difficulties, and the future requires the joint efforts of the government, researchers and rubber farmers.

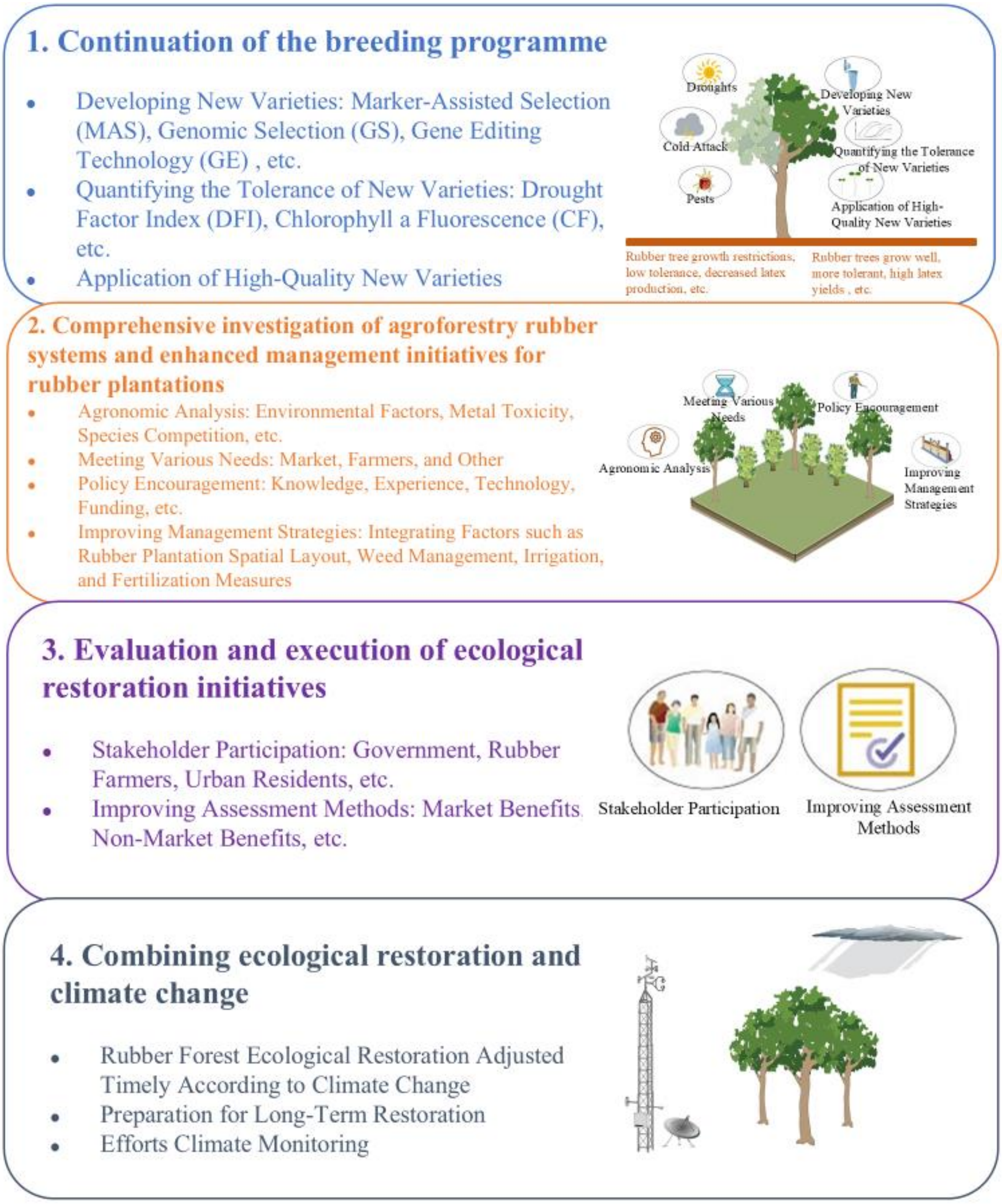

Fig. 4 Integration of new technologies, multi-party co-operation and integration of disciplines to promote research in the field of rubber forests ecological restoration

5. Conclusion

In order to provide useful references for the ecological restoration of rubber forests and future research, this paper uses CiteSpace 6.3.R1 software and bibliometric analysis to visualize and analyze the literature in the field. Its goals are to explore the frontier and hotspots in the field and reveal the development history and trend of the research. The findings indicate that:

(1) The author with the highest number of publications is Liu Wenjie, who has 4 publications and does not form a core group of coauthors. The top issuing teams Cheylan V-Hammecker C-Suvanang N team, Choosai C-Chevallier T-Brauman A-Alonso P team.

(2) The organization with the most publications in the field of rubber ecological restoration is the Chinese Academy of Sciences.The organizations with more publications are from China and France.

(3) Currently, the main research hotspots and trends in the field of ecological restoration of rubber forests include: community structure and biodiversity of rubber forests and the factors affecting them. Particular attention is paid to the diversity of understory plants and soil microbial diversity; the impact of the transformation of tropical rainforest into rubber forest. Particular attention is paid to the impacts of soil physicochemical properties, ecosystem service functions, carbon stocks, biomass, etc.; sustainable management of rubber forests: particular attention is paid to agroforestry rubber forests, and the role of near-natural management modes in the recovery of rubber forests.

(4) Three key programs have been presented by contemporary researchers: the construction of rubber agroforestry composite systems, the enhancement of management practices in rubber plantations, and the necessity of government and related department promotion.

Future studies should continue to develop breeding programs, investigate agroforestry rubber systems more thoroughly, enhance management practices for rubber plantations, assess and carry out ecological restoration projects, and combine study on climate change and ecological restoration in rubber forests.

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