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植物保育科學文獻之引文網絡分析

A Citation Network Analysis of Scientific Literature on Plant
Conservation

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摘要

植物保育對於維護生物多樣性、確保生態系功能及維持生態系服務至關重要。然而，植物物種與生態群落正面臨棲地退化、氣候變遷、土地利用集約化、生物多樣性喪失及其他環境變化所造成的相互關聯壓力。儘管針對上述問題的科學研究已大幅增加，相關文獻仍分散於生態學、保育、管理及監測等不同研究領域，因而增加了辨識該領域主要研究主題、概念關聯及研究優先方向的難度。

本研究採用文獻計量分析與關鍵詞共現圖譜分析，探討自 Web of Science 核心合輯（Web of Science Core Collection）所選取的植物保育相關文獻，並使用 VOSviewer 1.6.20

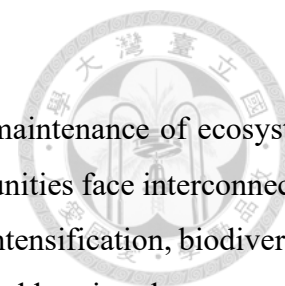
版建構及視覺化關鍵詞共現網絡。最終網絡包含 82 個關鍵詞、1,963 條連結，總連結強度為 6,426。分析結果形成四個主題群集，分別為生物多樣性保育、管理與生態系服務；物種多樣性與生態系功能；氣候變遷、環境動態與植被反應；以及生物多樣性監測、族群趨勢與生態指標。

研究結果顯示，生物多樣性、保育、多樣性、物種豐富度、管理、氣候變遷、生態系服務、生態群落及生態動態等概念，在所選文獻中占有重要位置。關鍵詞網絡亦顯示，保育管理、生態系功能、環境變遷與生物多樣性監測之間存在密切關聯。對這些模式進行質性詮釋後發現，相關文獻將長期植物保育視為一項相互關聯的生態與管理挑戰，需要結合生物多樣性保護、生態系復育、對環境變遷的調適性回應、持續監測，以及以實證為基礎的保育規劃。

本研究透過系統性整理所選文獻的概念架構，辨識出未來可能需要加強整合的研究領域。研究結果所呈現的是學術關注程度與關鍵詞之間的關聯模式，而非保育成效或因果關係的直接證據。

關鍵詞：植物保育、生物多樣性、文獻計量分析、關鍵詞共現分析、VOSviewer、生態系功能、氣候變遷、生物多樣性監測

Abstract



Plant conservation is essential to biodiversity preservation and the maintenance of ecosystem functions and services. However, plant species and ecological communities face interconnected pressures arising from habitat degradation, climate change, land-use intensification, biodiversity loss, and other environmental changes. Although scientific research addressing these concerns has expanded considerably, the literature remains distributed across multiple ecological, conservation, management, and monitoring domains. This fragmentation makes it difficult to identify the principal themes, conceptual relationships, and research priorities characterizing the field.

This study applies bibliometric analysis and keyword co-occurrence mapping to a selected body of plant-conservation literature retrieved from the Web of Science Core Collection. VOSviewer version 1.6.20 was used to construct and visualize the keyword co-occurrence network. The final network consisted of 82 keywords connected by 1,963 links, with a total link strength of 6,426. The analysis generated four thematic clusters: Biodiversity Conservation, Management, and Ecosystem Services; Species Diversity and Ecosystem Functioning; Climate Change, Environmental Dynamics, and Vegetation

Responses; and Biodiversity Monitoring, Population Trends, and Ecological Indicators.

The results show that biodiversity, conservation, diversity, species richness, management, climate change, ecosystem services, communities, and ecological dynamics occupy prominent positions within the selected literature. The network also demonstrates substantial connections among conservation management, ecosystem functioning, environmental change, and biodiversity monitoring. Qualitative interpretation of these patterns suggests that long-term plant conservation is treated in the literature as an interconnected ecological and management challenge requiring biodiversity protection, ecosystem restoration, adaptive responses to environmental change, sustained monitoring, and evidence-informed conservation planning.

This study contributes a structured account of the conceptual organization of the selected literature and identifies research areas that may require greater integration. The findings represent patterns of scholarly attention and keyword association rather than direct evidence of conservation effectiveness or causal relationships.

Keywords: plant conservation; biodiversity; bibliometric analysis; keyword cooccurrence analysis; VOSviewer; ecosystem functioning; climate change; biodiversity monitoring



Table of Contents



Acknowledgements.....	i
摘要	ii
Abstract.....	iii
Table of Contents	v
List of Tables	ix
List of Figures.....	ix
Chapter 1: Introduction.....	1
1.1 Background of study	1
1.2 Problem Statement	4
1.3 Research Gap and Contribution of the Study.....	6
1.4 Motivation of the study.....	8
1.5 Research Objectives	11
1.5.1 General Objective	11
1.5.2 Specific Objectives	11
1.6 Research Questions	12
1.6.1 General Research Question.....	12
1.6.2 Specific Research Questions.....	13
Chapter 2: Literature Review.....	15
2.1 Overview of Plant Conservation Research	15
2.2 Major Challenges in Long-Term Plant Conservation	19
2.2.1 Habitat Loss, Fragmentation, and Landscape Connectivity	20
2.2.3 Climate Change, Ecosystem Resilience, and Adaptive Conservation	22
2.2.4 Biological Invasions and Ecological Interactions	24
2.2.5 Institutional, Financial, and Capacity Constraints	26

2.3 Key Enablers of Effective Plant Conservation	28
2.3.1 Integrated Conservation Planning and Protected Area Networks	29
2.3.2 Ecological Restoration and Ecosystem Recovery	30
2.3.3 Community Participation, Indigenous Knowledge, and Collaborative Governance	32
2.3.4 Technological Innovation and Data-Driven Conservation	35
2.4 Bibliometric and Keyword Co-occurrence Analysis in Conservation Research	37
2.4.1 Evolution of Bibliometric Analysis	37
2.4.2 Science Mapping and Knowledge Visualization	39
2.4.3 Keyword Co-occurrence Analysis as a Science Mapping Technique	41
2.4.4 Applications of Bibliometric and Keyword Co-occurrence Analysis in Conservation Research...	44
2.5 Future Directions and Research Priorities	46
2.5.1 Adaptive Management and Long-term Monitoring	46
2.5.2 Climate Change Adaptation	47
2.6 Conceptual Framework of the Study	47
Chapter 3: Methodology	50
3.1 Research Design	50
3.1.1 Data Collection and Literature Selection	51
3.1.2 Data Source	52
3.1.3 PRISMA Literature Selection Procedure	53
3.2 Data Analysis Procedure	55
3.2.1 Data Preparation and Keyword Standardization	56
3.2.2 Keyword Co-occurrence Analysis	58
3.2.3 Network Construction	60
3.2.4 VOSviewer Clustering Algorithm and Cluster Interpretation	61
3.2.5 Network Visualization	65
3.2.6 Overlay Visualization	66



3.2.7 Density Visualization	66
3.2.8 Thematic Interpretation.....	67
3.2.9 Analytical Outputs	67
Chapter 4: Results.....	69
4.1 Bibliometric Overview of the Literature.....	69
4.2 Keyword Co-occurrence Network and Cluster Identification	71
4.2.1 Visual Presentation of the Research Topic	74
4.3 VOSviewer Analysis Results	76
4.3.1 Keyword Visualization Analysis	76
4.4 Citation Network Analysis	77
4.5 Co-Authorship Analysis.....	77
4.6 Density Visualization Analysis	77
4.6.1 Interconnections Between Clusters.....	89
4.6.2 Overall Interpretation.....	90
Chapter 5: Discussion.....	107
5.1 Overview of the Study	107
5.2 Synthesis of Major Findings	107
5.3 Interpretation within the Theoretical Framework	110
5.3.1 Cluster 1: Biodiversity Conservation and Ecosystem Services	110
5.3.2 Cluster 2: Species Diversity and Ecosystem Functioning	110
5.3.3 Cluster 3: Climate Change and Environmental Dynamics	111
5.3.4 Cluster 4: Governance, Monitoring, and Conservation Management	111
Integrated Interpretation of the Clusters	112
5.4 Challenges in Long-Term Plant Conservation	112
5.5 Implications for Research and Practice.....	115
5.6 Enablers of Long-Term Plant Conservation.....	116



5.7 Implications for Biodiversity Conservation and Ecosystem Preservation.....	118
5.8 Implications for Research and Practice.....	121
5.8.1 Implications for Conservation Research.....	121
5.8.2 Implications for Conservation Practice.....	123
5.8.3 Broader Sustainability Implications.....	124
5.9 Chapter Summary	124
Chapter 6: Conclusion and Recommendations.....	127
6.1 Conclusions.....	127
6.2 Recommendations.....	128
6.2.1 Strengthening Interdisciplinary Collaboration.....	128
6.2.2 Expanding Long-Term Monitoring Programs.....	128
6.2.3 Enhancing Climate-Adaptive Conservation Strategies.....	129
6.2.4 Promoting Ecosystem Restoration Initiatives.....	129
6.2.5 Strengthening Policy and Governance Frameworks.....	129
6.2.6 Increasing Stakeholder Participation	129
6.2.7 Expanding the Use of Technological Innovation.....	129
6.3 Study Limitations.....	129
6.4 Future Research Directions.....	130
References.....	132

List of Tables

Table 1. Bibliometric Dataset Characteristics.....	69
Table 2. Clusters and Relative Keywords Resulting from the Co-occurrence Analysis of Keywords.....	74
Table 3. Shows the clusters in correspondence with their themes and their representative keywords.....	78

List of Figures

Figure 1. Data selection criteria and procedure	55
Figure 2. Preliminary keyword co-occurrence network before final keyword standardization and threshold selection.	70
Figure 3. Keyword Co-occurrence Network in Long-Term Plant Conservation Literature (VOSviewer Visualization).	73
Figure 4. Box plot of normalized citation impact across four thematic clusters identified in VOSviewer.	80
Figure 5. Violin plot of publication years across four thematic clusters. The Red and Green clusters show bimodal distributions, the orange cluster reflects recent emergence, and the Blue cluster demonstrates concentrated, novel activity in computational	81
Figure 6. Bar chart of top 10 keyword occurrences in long-term plant conservation literature. The term 'biodiversity' dominates, reflecting the field's core focus, while other terms show progressively lower frequencies, illustrating niche diversification.	82
Figure 7. Density Visualization Map of Keyword Co-occurrence in Long-Term Plant Conservation Research.	83
Figure 8. Network Visualization Map of Keyword Co-occurrence (Four Thematic Clusters).	86
Figure 9. Density Visualization Map of Keyword Co-occurrence	91
Figure 10. Network Visualization Map of Keyword Co-occurrence (Four Thematic Clusters).	95
Figure 11. Density Visualization Map of Keyword Co-occurrence.	99
Figure 12. Network Visualization Map of Keyword Co-occurrence (Four Clusters)	102

Chapter 1: Introduction

1.1 Background of study

Plant diversity constitutes the biological foundation upon which the structure, functioning, resilience, and sustainability of terrestrial ecosystems depend. As primary producers, plants drive fundamental ecological processes by capturing solar energy through photosynthesis, regulating global biogeochemical cycles, maintaining soil fertility, supporting trophic interactions, regulating hydrological systems, and contributing substantially to carbon sequestration and climate regulation (Díaz et al., 2019; Corlett, 2020; IPBES, 2019). Beyond their ecological significance, plants provide indispensable provisioning, regulating, supporting, and cultural ecosystem services that sustain human societies through food production, medicine, timber, fibre, fuel, and countless other biological resources essential for economic development and human well-being (MEA, 2005; Díaz et al., 2019; Sharrock et al., 2014).

Consequently, the conservation of plant diversity extends beyond the protection of individual species to encompass the preservation of ecosystem integrity, ecological resilience, and the long-term provision of ecosystem services upon which both biodiversity and human livelihoods fundamentally depend (CBD, 2022; IPBES, 2019; Corlett, 2020). Recognizing this ecological significance, international conservation initiatives, including the Convention on Biological Diversity (CBD), the Global Strategy for Plant Conservation (GSPC), and more recently the Kunming–Montreal Global Biodiversity Framework, have consistently identified plant conservation as a strategic priority for achieving global biodiversity conservation, ecosystem restoration, and sustainable development objectives (CBD, 2022; Sharrock et al., 2014; Antonelli et al., 2020).

Despite the widespread recognition of plant conservation as a global environmental priority, the status of plant biodiversity continues to deteriorate across virtually all biogeographical regions. Contemporary assessments indicate that human-induced environmental change has accelerated species extinction rates to levels unprecedented in recent evolutionary history, with vascular plants among the taxonomic groups experiencing substantial declines in abundance, distribution, and genetic diversity (IPBES, 2019; Díaz et al., 2019). It is estimated that approximately 40% of the world's known plant species are threatened with extinction, while many additional species remain insufficiently studied or formally assessed, particularly within biodiversity-rich tropical

ecosystems (Nic Lughadha et al., 2020; Antonelli et al., 2020). The continuing erosion of plant diversity not only threatens individual species but also compromises ecosystem stability, ecological resilience, and the capacity of natural systems to deliver essential ecosystem services that sustain both biodiversity and human societies (Cardinale et al., 2012; Díaz et al., 2019; Corlett, 2020).

The drivers of plant biodiversity loss are multifaceted, highly interconnected, and operate across multiple spatial and temporal scales. Habitat destruction and fragmentation resulting from agricultural expansion, infrastructure development, urbanization, mining, and deforestation remain the dominant causes of species decline worldwide (Fahrig, 2003; Haddad et al., 2015; IPBES, 2019). Simultaneously, climate change is altering species distributions, disrupting phenological processes, modifying ecological interactions, and increasing the frequency and intensity of extreme climatic events, thereby reducing the adaptive capacity of many plant populations (Parmesan & Yohe, 2003; Corlett, 2020; Gao et al., 2020). Additional pressures arising from invasive alien species, pollution, unsustainable resource exploitation, altered fire regimes, and emerging plant pathogens further compound conservation challenges by disrupting ecological processes and reducing ecosystem resilience (Pyšek et al., 2020; Seebens et al., 2021; IPBES, 2019). Rather than acting independently, these drivers frequently interact synergistically, amplifying biodiversity loss and increasing uncertainty regarding the long-term effectiveness of conventional conservation interventions (Brook et al., 2008; Mantyka-Pringle et al., 2015).

Recognizing the complexity of these threats, the international conservation community has progressively shifted from species-centred conservation towards more integrated approaches that simultaneously address ecological, environmental, social, economic, and governance dimensions of biodiversity preservation. Contemporary conservation planning increasingly incorporates ecosystem-based management, ecological restoration, adaptive management, landscape connectivity, ex situ conservation, climate adaptation, community participation, Indigenous and local ecological knowledge, and technology-assisted biodiversity monitoring as complementary rather than independent conservation strategies (Heywood, 2017; Dhyani et al., 2020; Breman et al., 2021; Fricke & Olden, 2023). While these developments have substantially expanded the scientific foundation of plant conservation, they have also resulted in an increasingly diverse and multidisciplinary body of knowledge, making it progressively more difficult to obtain a

comprehensive understanding of the dominant research themes, conceptual relationships, and evolving priorities that characterize long-term plant conservation research.

The rapid expansion of conservation science has generated an unprecedented volume of scientific knowledge addressing virtually every aspect of plant conservation. Over the past three decades, research has proliferated across numerous disciplines including conservation biology, ecology, forestry, environmental science, geography, restoration ecology, sustainability science, environmental policy, and biodiversity informatics each contributing distinct theoretical perspectives, methodological approaches, and practical conservation strategies (Heywood, 2017; Corlett, 2020; Breman et al., 2021). Consequently, long-term plant conservation is no longer represented by a single conservation paradigm but rather by a diverse assemblage of interconnected research domains encompassing protected area management, ecological restoration, ecosystem based conservation, climate adaptation, landscape ecology, ex situ conservation, conservation genetics, ecological monitoring, community-based conservation, environmental governance, and technology-assisted conservation planning (Dhyani et al., 2020; Sharrock et al., 2014; Fricke & Olden, 2023; Lahoz-Monfort & Magrath, 2021). While this diversity reflects the maturity and interdisciplinary nature of conservation science, it simultaneously presents a significant challenge for researchers and practitioners attempting to synthesize existing knowledge into a coherent understanding of long-term plant conservation.

Despite the abundance of scientific literature, there remains no universally accepted conceptual model or standardized framework that comprehensively integrates the principal conservation approaches, recurring challenges, enabling factors, and emerging research priorities that collectively define long-term plant conservation. Existing studies frequently focus on individual conservation issues such as habitat fragmentation, climate change adaptation, ecological restoration, invasive species management, conservation policy, or biodiversity monitoring without systematically examining how these themes interact within the broader intellectual landscape of conservation research (IPBES, 2019; Antonelli et al., 2020; Nic Lughadha et al., 2020). Consequently, although substantial knowledge has been generated, the literature remains highly fragmented across disciplinary boundaries, geographical contexts, methodological traditions, and conservation objectives, making it increasingly difficult to determine whether common

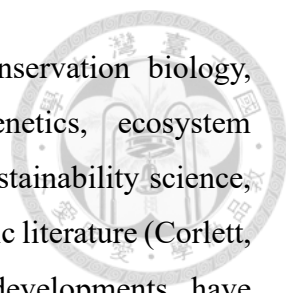
research patterns, dominant conservation paradigms, or integrated long-term conservation strategies have emerged.

This fragmentation presents an important research challenge. Traditional narrative literature reviews provide valuable qualitative syntheses but are inherently limited when attempting to evaluate thousands of publications spanning multiple disciplines, decades of scientific development, and diverse conservation contexts. Narrative reviews are often influenced by subjective article selection and are generally unable to objectively visualize thematic relationships, conceptual structures, or the evolution of research topics across an entire scientific field (Zupic & Čater, 2015; Donthu et al., 2021). As conservation literature continues to expand exponentially, there is an increasing need for systematic, transparent, and reproducible analytical approaches capable of synthesizing large bodies of scientific knowledge while simultaneously identifying dominant research themes, conceptual relationships, emerging research frontiers, and persistent knowledge gaps (van Eck & Waltman, 2010; Chen, 2017; Donthu et al., 2021).

Within this context, bibliometric analysis and keyword co-occurrence analysis provide an appropriate methodological framework for investigating the intellectual organization of long-term plant conservation research. Unlike conventional literature reviews that primarily summarize research findings, bibliometric approaches quantitatively examine publication characteristics, keyword relationships, and thematic structures to reveal how scientific knowledge is organized and how research priorities evolve over time (Donthu et al., 2021; Zupic & Čater, 2015). In particular, keyword co-occurrence analysis identifies concepts that frequently appear together within scientific publications, enabling the construction of thematic clusters that objectively represent the principal domains of research activity within a field (van Eck & Waltman, 2010). When complemented by qualitative thematic interpretation, these bibliometric outputs provide a robust foundation for identifying recurring conservation challenges, enabling factors, conceptual relationships, and knowledge gaps that may not be readily apparent through conventional narrative synthesis alone.

1.2 Problem Statement

The scientific understanding of long-term plant conservation has expanded substantially over the past several decades, reflecting increasing global concern regarding biodiversity loss, ecosystem degradation, and the long-term sustainability of natural ecosystems. This



expansion has been accompanied by significant advances in conservation biology, restoration ecology, biodiversity monitoring, conservation genetics, ecosystem management, environmental governance, climate adaptation, and sustainability science, resulting in an extensive and highly multidisciplinary body of scientific literature (Corlett, 2020; Heywood, 2017; Breman et al., 2021). While these developments have considerably strengthened the scientific foundation of plant conservation, they have also introduced substantial complexity into the field by generating numerous conservation concepts, analytical approaches, management frameworks, and policy perspectives that are often investigated independently across different research disciplines (Díaz et al., 2019; Dhyani et al., 2020; IPBES, 2019).

Consequently, contemporary plant conservation research is characterized by an increasingly fragmented knowledge landscape. Studies frequently examine specific aspects of conservation, such as habitat restoration, protected area management, ecological connectivity, climate resilience, conservation genetics, ecosystem services, community participation, or biodiversity monitoring, without systematically examining how these research themes relate to one another within the broader intellectual structure of the discipline (Antonelli et al., 2020; Nic Lughadha et al., 2020). Although each of these research areas contributes valuable scientific knowledge, the absence of an integrated synthesis makes it difficult to determine which conservation approaches have emerged as dominant research themes, how different conservation concepts are interconnected, which challenges consistently recur across the literature, and what enabling factors are most frequently associated with successful long-term conservation outcomes.

This fragmentation presents both a scientific and practical challenge. From a scientific perspective, researchers are confronted with an increasingly large and complex body of literature that is difficult to synthesize using conventional narrative review methods alone. Narrative reviews rely primarily on manual interpretation and selective literature synthesis, making it challenging to objectively identify thematic relationships, conceptual structures, emerging research fronts, and the evolution of scientific knowledge across hundreds or thousands of publications (Zupic & Čater, 2015; Donthu et al., 2021). From a practical perspective, conservation practitioners and policymakers require evidence-based understanding of the principal conservation themes, recurring implementation challenges, and enabling conditions that have consistently emerged from decades of

scientific investigation in order to support informed decision-making and the development of effective long-term conservation strategies (CBD, 2022; IPBES, 2019).

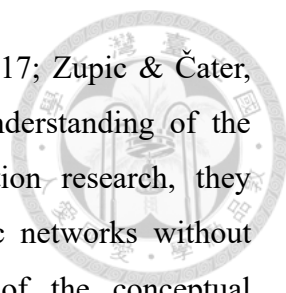
Despite the increasing application of bibliometric methods across environmental and sustainability research, relatively few studies have comprehensively employed bibliometric analysis in combination with keyword co-occurrence analysis to investigate the intellectual structure of long-term plant conservation research. Existing bibliometric investigations have frequently focused on specific conservation topics, individual taxa, protected areas, ecosystem services, or climate-related issues, rather than providing a comprehensive synthesis of the broader plant conservation literature (Donthu et al., 2021; Chen, 2017). Consequently, there remains limited understanding of how the diverse body of scientific literature is organized into thematic research domains, how these domains relate to one another, and how they collectively contribute to addressing long-term plant conservation.

The research problem addressed by this study therefore lies not in the absence of conservation research, but in the absence of a systematic synthesis capable of revealing the thematic organization, conceptual relationships, conservation challenges, enabling factors, and knowledge gaps embedded within the existing scientific literature.

Addressing this gap requires an analytical approach that extends beyond conventional qualitative review by objectively examining the intellectual structure of the literature through bibliometric analysis and keyword co-occurrence mapping, followed by thematic interpretation of the identified research clusters. By doing so, this study seeks to provide a comprehensive understanding of the evolution of long-term plant conservation research while generating evidence that can support future scientific inquiry, conservation planning, and biodiversity policy development.

1.3 Research Gap and Contribution of the Study

Although bibliometric analysis has become an increasingly established methodology within environmental and conservation research, the existing literature reveals several important limitations that continue to restrict its contribution to the comprehensive understanding of long-term plant conservation. Most published bibliometric studies primarily emphasize descriptive indicators such as publication productivity, citation performance, author collaboration, institutional networks, and the visualization of



keyword relationships (Donthu et al., 2021; Aria & Cuccurullo, 2017; Zupic & Čater, 2015). While these investigations have substantially improved understanding of the structural characteristics and developmental trends of conservation research, they frequently conclude with descriptive presentations of bibliometric networks without extending their analyses toward comprehensive interpretation of the conceptual significance represented by the identified thematic clusters.

Furthermore, existing conservation bibliometric studies generally focus on broad research domains such as biodiversity conservation, environmental sustainability, ecosystem services, restoration ecology, or climate change, with comparatively limited attention devoted specifically to the conceptual development of **long-term plant conservation** as an integrated research field (Antonelli et al., 2020; Corlett, 2023; Nic Lughadha et al., 2020). Although previous investigations have successfully identified research hotspots, influential publications, collaborative networks, and frequently occurring keywords, relatively few studies have systematically examined how the thematic relationships revealed through keyword co-occurrence analysis can be interpreted to explain the principal conservation challenges, enabling factors, and emerging priorities that collectively influence long-term biodiversity preservation. Consequently, an important gap remains between quantitative science mapping and the broader theoretical understanding required to support evidence-based conservation planning and policy development.

Recent methodological literature increasingly advocates integrating bibliometric analysis with qualitative evidence synthesis to generate richer and more meaningful scientific interpretations (Chen, 2017; Donthu et al., 2021; Cobo et al., 2011). Rather than viewing bibliometric visualization as the final analytical outcome, researchers emphasize that thematic clusters generated through keyword co-occurrence analysis should provide the empirical foundation for subsequent interpretation, allowing broader scientific conclusions to be developed through careful examination of the literature represented within each cluster (Zupic & Čater, 2015; van Eck & Waltman, 2018). Such an integrated analytical approach enables researchers to move beyond identifying conceptual relationships toward explaining how research themes collectively contribute to scientific understanding, knowledge development, and future research directions. This methodological perspective is particularly appropriate for conservation science, where

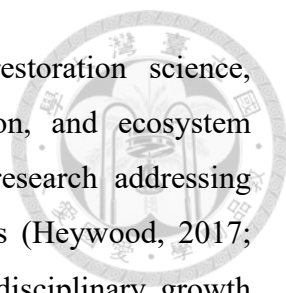
ecological, technological, institutional, governance, and socio-economic factors interact in highly complex and multidisciplinary ways.

Accordingly, the present study addresses these limitations by combining **bibliometric analysis** and **keyword co-occurrence analysis** with **systematic qualitative thematic interpretation** to examine the scientific literature on long-term plant conservation indexed in the **Web of Science Core Collection**. Bibliometric analysis is employed to objectively identify publication characteristics, conceptual relationships, keyword networks, and thematic clusters within the literature, whereas qualitative interpretation is subsequently applied to examine the scientific meaning represented by these clusters. Through this integrated analytical framework, the study interprets the identified thematic structures to classify major conservation challenges, identify enabling factors, examine emerging research priorities, and discuss their implications for biodiversity preservation and ecosystem sustainability. By integrating quantitative science mapping with qualitative thematic analysis, the study seeks to provide a more comprehensive understanding of the intellectual landscape of long-term plant conservation than can be achieved through bibliometric visualization alone.

In doing so, this research contributes to the growing body of conservation bibliometric literature in three important ways. First, it provides a systematic synthesis of the intellectual structure and thematic evolution of long-term plant conservation research using bibliometric and keyword co-occurrence analysis. Second, it extends conventional bibliometric practice by integrating qualitative thematic interpretation to explain the conceptual significance of the identified research clusters rather than reporting visualization outputs alone. Finally, the study generates evidence-based insights into the dominant conservation challenges, enabling factors, and future research priorities identified throughout the literature, thereby providing a stronger scientific foundation for future conservation research, policy formulation, and long-term biodiversity management.

1.4 Motivation of the study

The motivation for this research stems from the increasing recognition that although plant conservation has become one of the most extensively investigated areas within conservation science, the rapid expansion of the literature has simultaneously created significant challenges in synthesizing accumulated scientific knowledge. Over the past



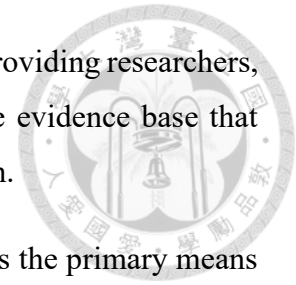
several decades, advances in ecology, conservation biology, restoration science, biodiversity informatics, environmental policy, climate adaptation, and ecosystem management have collectively generated a substantial body of research addressing longterm plant conservation from diverse disciplinary perspectives (Heywood, 2017; Corlett, 2023; Díaz et al., 2019; IPBES, 2019). While this multidisciplinary growth reflects the increasing maturity of conservation science, it has also resulted in a highly fragmented knowledge base in which conservation concepts, methodological approaches, and management strategies are dispersed across numerous research domains, journals, and scientific communities.

A comprehensive review of the existing literature indicates that researchers have proposed numerous approaches for achieving long-term plant conservation, including ecosystem-based conservation, ecological restoration, protected area management, landscape connectivity, conservation genetics, ex situ conservation, adaptive management, community-based conservation, conservation planning, climate adaptation, and technology-assisted biodiversity monitoring (Sharrock et al., 2014; Breman et al., 2021; Dhyani et al., 2020; Fricke & Olden, 2023). Each of these approaches addresses particular dimensions of biodiversity conservation and has contributed significantly to scientific understanding and conservation practice.

However, they are frequently investigated independently, using different theoretical perspectives, methodological frameworks, spatial scales, and conservation objectives. Consequently, despite the abundance of scientific knowledge, there remains limited understanding of how these diverse approaches collectively shape the intellectual structure of long-term plant conservation research or whether dominant conservation paradigms and recurring thematic patterns have emerged across the broader scientific literature.

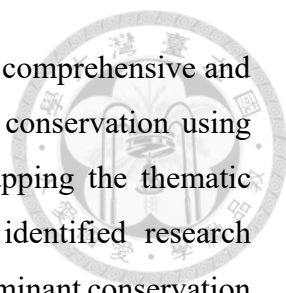
This observation provided the principal motivation for the present study. Rather than examining a single conservation strategy or evaluating the effectiveness of individual interventions, this research seeks to synthesize the broader scientific landscape of long-term plant conservation. The intention is to determine how conservation knowledge has evolved, which research themes have become dominant, how different conservation concepts are interconnected, and what recurring conservation challenges and enabling factors can be identified through systematic analysis of the literature. Such understanding

is essential not only for advancing scientific knowledge but also for providing researchers, conservation practitioners, and policymakers with a comprehensive evidence base that supports informed decision-making and future research prioritization.



Conventional narrative literature reviews have traditionally served as the primary means of synthesizing conservation research. However, as the volume and interdisciplinarity of scientific publications continue to increase, qualitative reviews alone become progressively less effective in objectively revealing the overall structure of a research field, identifying thematic relationships, or detecting emerging areas of scientific development (Zupic & Čater, 2015; Donthu et al., 2021). Bibliometric analysis has therefore become an increasingly established methodology for investigating the evolution, organization, and intellectual structure of scientific knowledge by quantitatively examining publication characteristics, citation information, collaboration patterns, and keyword relationships (Donthu et al., 2021; Chen, 2017). Recent bibliometric investigations in conservation-related disciplines have demonstrated the effectiveness of these approaches in identifying research hotspots, thematic evolution, collaboration networks, and emerging scientific priorities across complex environmental research domains.

Among contemporary bibliometric techniques, keyword co-occurrence analysis is particularly well suited to the objectives of the present study because it focuses on the conceptual relationships among research topics rather than solely on publication productivity or citation impact. By examining the frequency with which keywords appear together within scientific publications, keyword co-occurrence analysis enables the construction of thematic networks that reveal the principal domains of scientific inquiry, their interrelationships, and the evolution of research priorities over time (van Eck & Waltman, 2010; Donthu et al., 2021). When complemented by qualitative thematic interpretation, these bibliometric outputs provide a rigorous and transparent basis for identifying recurring conservation challenges, enabling factors, research hotspots, and knowledge gaps embedded within the scientific literature. This combined analytical approach has become increasingly common in environmental and sustainability research, where the objective extends beyond descriptive mapping toward developing an integrated understanding of complex research landscapes.



Accordingly, the present study is motivated by the need to provide a comprehensive and systematic synthesis of the scientific literature on long-term plant conservation using bibliometric analysis and keyword co-occurrence analysis. By mapping the thematic organization of the literature and subsequently interpreting the identified research clusters, this study seeks to establish a clearer understanding of the dominant conservation approaches, recurring research themes, principal conservation challenges, enabling factors, and future research directions that collectively characterize the evolution of long-term plant conservation research. Ultimately, the findings are expected to contribute not only to the advancement of conservation science but also to support evidence-based biodiversity policy, conservation planning, and the development of more integrated and sustainable long-term conservation strategy.

1.5 Research Objectives

Building upon the identified research gap and the motivation for this study, the present research seeks to systematically examine the intellectual structure and thematic development of scientific literature related to long-term plant conservation. Rather than evaluating the effectiveness of individual conservation interventions, this study aims to synthesize the broader body of scientific knowledge to reveal how conservation research has evolved, which research themes have become dominant, how these themes are conceptually interconnected, and what implications they hold for future biodiversity conservation. Through the integration of bibliometric analysis, keyword co-occurrence analysis, and qualitative thematic interpretation, the study seeks to generate a comprehensive understanding of the current state and future direction of long-term plant conservation research.

1.5.1 General Objective

The general objective of this study is to investigate the intellectual structure of long-term plant conservation research through bibliometric analysis and keyword cooccurrence analysis to identify dominant research themes, thematic relationships, conservation challenges, enabling factors, and future research directions within the scientific literature.

1.5.2 Specific Objectives

Specifically, this study aims to:

Examine the bibliometric characteristics and publication trends of scientific literature related to long-term plant conservation.

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1. Identify the dominant keywords, thematic relationships, and research clusters through keyword co-occurrence analysis using VOSviewer.
 2. Interpret the identified thematic clusters to classify the major conservation challenges represented within the scientific literature.
 3. Interpret the thematic clusters to identify the principal enabling factors that support effective long-term plant conservation.
 4. Synthesize the identified research themes, conservation challenges, and enabling factors to evaluate their broader implications for biodiversity preservation, ecosystem sustainability, and conservation science.
 5. Develop evidence-based recommendations for future research, conservation policy, and long-term conservation practice based on the bibliometric findings and thematic interpretation.

1.6 Research Questions

The increasing complexity and multidisciplinary nature of long-term plant conservation have resulted in a rapidly expanding body of scientific literature encompassing diverse conservation philosophies, methodological approaches, and thematic research domains. As discussed in the preceding sections, the absence of a comprehensive synthesis of this knowledge presents challenges for understanding how conservation research has evolved, which research themes have become dominant, and how these themes collectively contribute to biodiversity preservation and ecosystem sustainability. Guided by the identified research gap and the objectives of this study, the following research questions are proposed:

1.6.1 General Research Question

How has the intellectual structure of long-term plant conservation research evolved, and what dominant thematic patterns, conservation challenges, and enabling factors emerge from the scientific literature when analyzed using bibliometric analysis and keyword cooccurrence analysis?



1.6.2 Specific Research Questions

RQ1. What are the bibliometric characteristics and publication trends of scientific literature related to long-term plant conservation?

This question seeks to establish the overall development of the research field by examining publication patterns, research productivity, and the growth of scientific literature over time.

RQ2. What dominant keywords, thematic relationships, and research clusters can be identified through keyword co-occurrence analysis?

This question investigates the conceptual organization of the literature by identifying the principal research themes and their interrelationships as represented by keyword cooccurrence networks generated using VOSviewer.

RQ3. What major conservation challenges emerge from the thematic interpretation of the identified research clusters?

This question aims to determine the recurring conservation issues represented within the literature by interpreting the thematic clusters generated through bibliometric analysis.

RQ4. What enabling factors supporting effective long-term plant conservation can be identified through thematic interpretation of the research clusters?

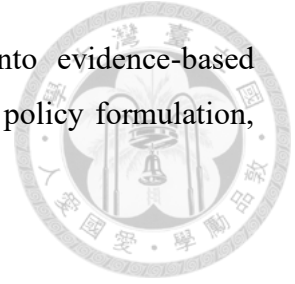
This question examines the principal scientific, ecological, technological, institutional, and governance-related factors that facilitate successful long-term plant conservation as reflected within the literature.

RQ5. What implications do the identified research themes, conservation challenges, and enabling factors have for biodiversity preservation, ecosystem sustainability, and future conservation practice?

This question synthesizes the findings obtained from the bibliometric and thematic analyses in order to evaluate their broader significance for conservation science, environmental management, and sustainable biodiversity preservation.

RQ6. Based on the identified thematic patterns and knowledge gaps, what recommendations can be proposed to guide future research, conservation policy, and long-term conservation planning?

This question translates the analytical findings of the study into evidence-based recommendations that may support future scientific investigations, policy formulation, and practical conservation initiatives.



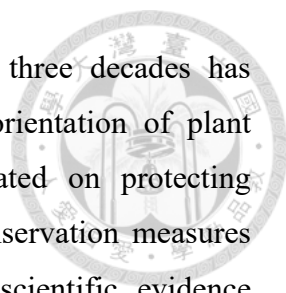
Chapter 2: Literature Review

2.1 Overview of Plant Conservation Research

Plant conservation has evolved considerably over the past century from a discipline primarily concerned with the preservation of individual endangered species to a comprehensive, interdisciplinary field that seeks to conserve biodiversity across genetic, species, ecosystem, and landscape levels. Early conservation efforts were largely reactive, focusing on preventing the extinction of economically or ecologically important plant species through protected areas and species-specific management programs (Soulé, 1985; Heywood & Iriondo, 2003). As ecological research advanced, however, conservation scientists increasingly recognized that the persistence of plant populations depends not only on protecting individual species but also on maintaining the ecological processes, evolutionary mechanisms, and environmental conditions that sustain biodiversity over the long term (Noss, 1990; Margules & Pressey, 2000). This conceptual transition marked the emergence of conservation biology as an integrative scientific discipline that combines ecological theory, evolutionary biology, genetics, environmental management, and policy development to address increasingly complex conservation challenges (Soulé, 1985; Groom, Meffe, & Carroll, 2006).

The evolution of plant conservation research has been strongly influenced by growing international recognition of the ecological, economic, and societal value of plant diversity. Global conservation initiatives, including the Convention on Biological

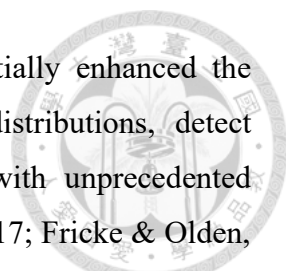
Diversity (CBD), the Global Strategy for Plant Conservation (GSPC), the Aichi Biodiversity Targets, and more recently the Kunming–Montreal Global Biodiversity Framework, have progressively shifted conservation priorities from short-term species preservation toward integrated strategies emphasizing ecosystem resilience, sustainable resource management, ecological restoration, and adaptive conservation planning (CBD, 2002; Sharrock et al., 2014; CBD, 2022). These international frameworks have stimulated substantial scientific investment in plant conservation research while promoting interdisciplinary collaboration among botanists, ecologists, environmental managers, policymakers, geneticists, and social scientists. Consequently, contemporary plant conservation is now widely recognized as a multidisciplinary field that extends beyond biological preservation to encompass governance, climate adaptation, ecosystem services, sustainable development, and human well-being (Díaz et al., 2019; Mace, 2014; Corlett, 2023).



The rapid development of conservation science during the past three decades has fundamentally transformed both the scope and methodological orientation of plant conservation research. Earlier investigations primarily concentrated on protecting threatened species and establishing protected areas as isolated conservation measures (Soulé, 1985; Margules & Pressey, 2000). However, growing scientific evidence demonstrated that species conservation cannot be achieved independently of ecosystem processes, landscape connectivity, ecological resilience, and socio-economic considerations, prompting researchers to adopt increasingly holistic and systems-oriented conservation approaches (Millennium Ecosystem Assessment [MEA], 2005; Mace, 2014; Díaz et al., 2019). Consequently, contemporary plant conservation research has expanded beyond traditional taxonomic and ecological studies to incorporate restoration ecology, conservation genetics, landscape ecology, climate change adaptation, ecosystem services, environmental governance, sustainability science, biodiversity informatics, and socio-ecological systems research (Heywood, 2017; Corlett, 2023; Folke et al., 2016).

A significant driver of this transformation has been the growing recognition that biodiversity conservation cannot be effectively addressed through ecological interventions alone. Instead, successful long-term conservation requires integrating ecological knowledge with governance structures, institutional capacity, policy implementation, stakeholder participation, Indigenous and local knowledge systems, and sustainable resource management (Ostrom, 2009; IPBES, 2019; Díaz et al., 2019). Recent studies have increasingly emphasized that conservation outcomes are strongly influenced by social, political, and economic factors, including land-use policies, environmental legislation, community engagement, financial investment, and crosssector collaboration (Bennett et al., 2017; Wyborn et al., 2020; Reed, 2008). This shift reflects a broader transition from viewing conservation as a purely biological discipline toward understanding it as a complex socio-ecological endeavour requiring interdisciplinary collaboration and adaptive management across multiple governance scales (Folke et al., 2016; Cumming et al., 2013).

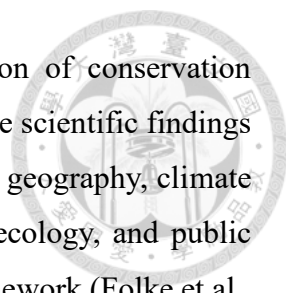
Simultaneously, rapid technological advancement has further diversified plant conservation research by introducing innovative tools capable of improving biodiversity assessment, ecological monitoring, and conservation planning. Developments in remote sensing, Geographic Information Systems (GIS), unmanned aerial vehicles (UAVs), environmental DNA (eDNA), artificial intelligence (AI), machine learning, species



distribution modelling, and biodiversity informatics have substantially enhanced the ability of researchers to monitor ecosystems, predict species distributions, detect environmental change, and evaluate conservation effectiveness with unprecedented spatial and temporal precision (Pettorelli et al., 2014; Bush et al., 2017; Fricke & Olden, 2023; Lahoz-Monfort & Magrath, 2021). These technological innovations have expanded the methodological capacity of conservation science while simultaneously generating new research themes and interdisciplinary collaborations that continue to reshape the intellectual landscape of long-term plant conservation.

Collectively, these scientific, technological, and institutional developments have contributed to the remarkable expansion of plant conservation research. However, they have also resulted in an increasingly diverse body of scientific literature characterized by numerous theoretical perspectives, methodological approaches, conservation frameworks, and disciplinary specializations. Although this diversity has enriched scientific understanding, it has also increased the complexity of synthesizing conservation knowledge and identifying the dominant research themes that define the field. As the volume of conservation literature continues to grow, researchers face increasing challenges in developing a comprehensive understanding of how these diverse areas of research relate to one another and collectively contribute to long-term plant conservation.

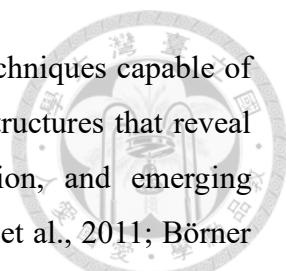
The continuous expansion of plant conservation research has resulted in an unprecedented accumulation of scientific knowledge spanning multiple disciplines, geographical regions, conservation contexts, and methodological traditions. Over the past several decades, thousands of studies have investigated diverse aspects of plant conservation, including biodiversity conservation, habitat restoration, ecosystem resilience, climate change adaptation, conservation genetics, invasive species management, ecological monitoring, environmental governance, ecosystem services, landscape ecology, and sustainable natural resource management (Corlett, 2023; Nic Lughadha et al., 2020; Antonelli et al., 2020). While this remarkable growth has substantially enriched scientific understanding, it has simultaneously increased the complexity of the research landscape by generating numerous specialized subfields, each characterized by distinct conceptual frameworks, analytical methods, and research priorities (Mace, 2014; Bennett et al., 2017). Consequently, the scientific literature has become increasingly dispersed across multiple disciplines, making it progressively more difficult to obtain an integrated understanding of the field as a whole.



Several scholars have observed that the interdisciplinary expansion of conservation science has produced a fragmented knowledge base in which valuable scientific findings are often distributed across ecology, environmental science, forestry, geography, climate science, sustainability studies, environmental economics, political ecology, and public policy rather than being synthesized within a unified conceptual framework (Folke et al., 2016; Wyborn et al., 2020; Cumming et al., 2013). As conservation research has diversified, investigators have increasingly focused on highly specialized topics such as species distribution modelling, ecological restoration, conservation genomics, ecosystem service valuation, nature-based solutions, ecological resilience, protected-area effectiveness, or community-based conservation, each employing different theoretical perspectives and methodological approaches (Pettorelli et al., 2014; Chazdon, 2008; Hobbs & Harris, 2001; Reed, 2008). Although these specialized investigations have significantly advanced knowledge within their respective domains, relatively few studies have attempted to synthesize these diverse research themes in order to understand how they collectively shape the broader intellectual development of long-term plant conservation research.

This increasing fragmentation presents important challenges for both researchers and conservation practitioners. From a scientific perspective, identifying dominant research themes, emerging conservation priorities, conceptual relationships, and long-term research trends has become progressively more difficult as publication volume continues to accelerate across numerous journals and scientific disciplines (Donthu et al., 2021; Aria & Cuccurullo, 2017). Similarly, conservation practitioners and policymakers frequently require evidence that extends beyond individual case studies or localized conservation projects to understand broader scientific consensus, recurring implementation challenges, and enabling factors that consistently contribute to successful conservation outcomes (IPBES, 2019; CBD, 2022). Consequently, conventional narrative literature reviews, while indispensable for providing qualitative interpretation, are increasingly constrained by their dependence on manual literature selection and subjective synthesis, particularly when addressing large and multidisciplinary bodies of scientific literature (Grant & Booth, 2009; Snyder, 2019).

In response to these challenges, systematic evidence-synthesis methodologies have become increasingly important within environmental and conservation research. Approaches such as systematic literature reviews, evidence mapping, bibliometric

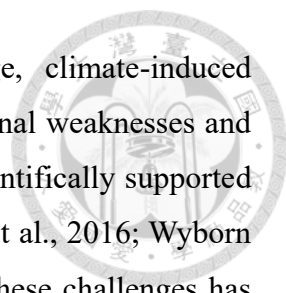


analysis, and science mapping have emerged as robust analytical techniques capable of organizing extensive scientific literature into coherent knowledge structures that reveal thematic relationships, research evolution, intellectual organization, and emerging scientific frontiers (Zupic & Čater, 2015; Donthu et al., 2021; Cobo et al., 2011; Börner et al., 2003). Among these approaches, bibliometric analysis combined with keyword cooccurrence analysis provides a particularly effective means of examining how research themes develop and interact over time because it objectively identifies conceptual relationships among frequently occurring keywords and visualizes these relationships as thematic research clusters (van Eck & Waltman, 2010; van Eck & Waltman, 2018). Rather than replacing conventional literature reviews, these analytical methods complement qualitative interpretation by providing a systematic foundation for understanding the intellectual structure of complex scientific domains. This growing methodological development has consequently positioned bibliometric and keyword cooccurrence analysis as valuable approaches for investigating the evolution, organization, and future direction of long-term plant conservation research.

2.2 Major Challenges in Long-Term Plant Conservation

The scientific literature consistently recognizes that the long-term conservation of plant biodiversity is constrained by a complex combination of ecological, environmental, institutional, socio-economic, and governance-related challenges rather than by any single threat acting independently. Over the past several decades, conservation research has demonstrated that plant population decline is rarely attributable to one isolated driver; instead, biodiversity loss typically results from the cumulative and often synergistic interactions among habitat degradation, climate change, biological invasions, unsustainable land-use practices, resource limitations, governance failures, and insufficient long-term monitoring (Brook et al., 2008; IPBES, 2019; Corlett, 2023). The increasing recognition of these interacting pressures has shifted conservation science away from addressing individual threats in isolation toward understanding conservation systems as interconnected socio-ecological systems in which ecological processes, institutional capacity, technological innovation, stakeholder participation, and policy implementation collectively influence conservation outcomes (Folke et al., 2016; Ostrom, 2009; Bennett et al., 2017).

Rather than presenting these challenges as independent conservation problems, recent research increasingly emphasizes that they are mutually reinforcing. Habitat



fragmentation may reduce species resilience to climate change, climate-induced ecosystem shifts may facilitate biological invasions, while institutional weaknesses and limited financial capacity often constrain the implementation of scientifically supported conservation interventions (Mantyka-Pringle et al., 2015; Maxwell et al., 2016; Wyborn et al., 2020). Consequently, understanding the interactions among these challenges has become a central objective of contemporary conservation science. The following sections synthesize the principal conservation challenges most consistently identified within the scientific literature and examine how they collectively influence the longterm preservation of plant biodiversity.

2.2.1 Habitat Loss, Fragmentation, and Landscape Connectivity

Habitat loss and fragmentation have consistently been identified as the most significant drivers of global plant biodiversity decline and remain central themes within contemporary conservation science. Since the emergence of conservation biology as a formal scientific discipline, researchers have repeatedly demonstrated that the conversion of natural ecosystems for agriculture, urban expansion, industrial development, mining, and infrastructure construction has fundamentally altered the distribution, composition, and ecological functioning of plant communities worldwide (Soulé, 1985; Tilman et al., 1994; Foley et al., 2005). More recent global assessments have reinforced these findings, concluding that land-use change continues to represent the single greatest direct threat to terrestrial biodiversity, affecting both common and endemic plant species across virtually every biogeographical region (IPBES, 2019; Díaz et al., 2019; Corlett, 2023). Consequently, habitat loss has remained one of the most extensively investigated topics within plant conservation research and continues to shape both conservation policy and scientific inquiry.

Although early conservation studies primarily quantified habitat loss in terms of declining forest cover or reductions in protected land, subsequent research has demonstrated that the ecological consequences of habitat fragmentation extend far beyond the simple reduction of habitat area. Fragmentation modifies landscape structure by dividing continuous ecosystems into smaller and increasingly isolated habitat patches, thereby altering ecological connectivity, dispersal pathways, gene flow, species interactions, and ecosystem processes (Fahrig, 2003; Haddad et al., 2015). Numerous empirical studies have shown that isolated plant populations frequently experience reduced genetic diversity, lower reproductive success, increased inbreeding, diminished adaptive capacity,

and elevated extinction risk, particularly for species characterized by limited dispersal ability or specialized habitat requirements (Aguilar et al., 2008; Young, Boyle, & Brown, 1996; Brummitt et al., 2015). These ecological consequences frequently persist long after the initial disturbance, making habitat fragmentation one of the most persistent and difficult conservation challenges to reverse.

The literature further suggests that habitat fragmentation rarely operates as an isolated conservation pressure. Rather, it interacts synergistically with climate change, biological invasions, altered disturbance regimes, and anthropogenic land-use practices to amplify biodiversity loss and reduce ecosystem resilience (Brook et al., 2008; Mantyka-Pringle et al., 2015; Maxwell et al., 2016). Fragmented landscapes often restrict species migration in response to changing climatic conditions, facilitate the establishment of invasive species along habitat edges, disrupt pollination and seed-dispersal networks, and alter ecological processes essential for long-term ecosystem functioning (Haddad et al., 2015; Corlett, 2023; Richardson & Pyšek, 2006).

Consequently, contemporary conservation research increasingly emphasizes that habitat fragmentation should be understood not merely as a landscape configuration problem but as a catalyst that intensifies multiple ecological threats simultaneously.

Recognizing these limitations, recent conservation research has increasingly shifted toward landscape-scale conservation and ecological connectivity as fundamental principles of long-term biodiversity preservation. Rather than focusing exclusively on expanding protected areas, researchers now advocate integrated conservation strategies that strengthen ecological corridors, restore degraded habitats, enhance landscape permeability, and maintain functional connectivity among fragmented ecosystems (Crooks & Sanjayan, 2006; Hilty et al., 2020; Beier & Noss, 1998). These approaches are further complemented by advances in spatial ecology, remote sensing, species distribution modelling, and Geographic Information Systems (GIS), which enable conservation practitioners to identify priority restoration areas, evaluate landscape connectivity, and optimize conservation planning under changing environmental conditions (Pettorelli et al., 2014; Franklin, 2010; Fricke & Olden, 2023). Collectively, these developments demonstrate that contemporary conservation science increasingly regards habitat fragmentation not only as one of the principal threats to plant biodiversity but also as a

focal point for developing integrated, landscape-based conservation strategies capable of enhancing long-term ecological resilience.

2.2.3 Climate Change, Ecosystem Resilience, and Adaptive Conservation

Climate change has emerged as one of the defining challenges confronting long-term plant conservation and is now recognized as a pervasive driver of biodiversity change across terrestrial ecosystems. While earlier conservation strategies primarily emphasized habitat protection and species preservation, increasing empirical evidence has demonstrated that anthropogenic climate change fundamentally alters the environmental conditions upon which plant populations depend, thereby influencing species distributions, ecological interactions, reproductive success, and ecosystem functioning (Parmesan & Yohe, 2003; Walther et al., 2002; Corlett, 2023). Successive assessment reports published by the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) further conclude that climate change has become one of the principal global drivers of biodiversity loss, acting simultaneously with land-use change, habitat fragmentation, pollution, and invasive species to accelerate ecosystem degradation and species extinction (IPCC, 2023; IPBES, 2019). Consequently, climate change has shifted from being considered an external environmental variable to becoming a central component of contemporary conservation science.

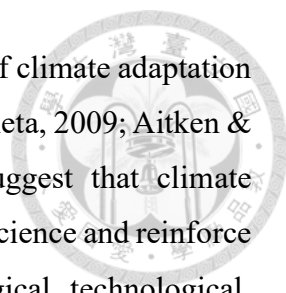
The literature consistently demonstrates that plant species respond to climate change through complex ecological and evolutionary mechanisms rather than through simple shifts in geographic distribution. Rising temperatures, altered precipitation regimes, increasing atmospheric carbon dioxide concentrations, prolonged droughts, changing disturbance regimes, and the increasing frequency of extreme climatic events collectively influence plant physiology, phenology, reproductive performance, seed dispersal, competitive interactions, and species survival (Corlett, 2020; Peñuelas et al., 2013; Parmesan, 2006). Numerous long-term ecological studies have documented shifts in flowering periods, earlier leaf emergence, altered growing seasons, and changes in species composition across both temperate and tropical ecosystems, suggesting that climate change is restructuring plant communities at multiple ecological scales (Cleland et al., 2007; Parmesan, 2006; Walther et al., 2002). These responses are particularly pronounced among endemic species, alpine flora, island ecosystems, and narrowly distributed taxa

whose limited dispersal capacity restricts their ability to track rapidly changing environmental conditions (Bellard et al., 2012; Corlett & Westcott, 2013).

Recent conservation research increasingly emphasizes that the effects of climate change cannot be considered independently from other anthropogenic pressures. Instead, climate change interacts synergistically with habitat fragmentation, biological invasions, altered fire regimes, pollution, and land-use change to produce cumulative impacts that frequently exceed the adaptive capacity of both plant populations and ecosystems (Brook et al., 2008; Mantyka-Pringle et al., 2015; Maxwell et al., 2016). Fragmented landscapes, for example, often reduce opportunities for climate-induced range shifts by limiting dispersal pathways and ecological connectivity, while degraded ecosystems generally exhibit lower resilience to climatic disturbances than intact landscapes (Hilty et al., 2020; Haddad et al., 2015). Such interactions illustrate that climate change should not be viewed as an isolated conservation problem but rather as a catalyst that amplifies existing ecological vulnerabilities and increases uncertainty in long-term conservation planning.

In response to these challenges, the concept of **ecosystem resilience** has become increasingly influential within conservation science. Rather than attempting to preserve static ecological conditions, contemporary conservation approaches seek to enhance the capacity of ecosystems to absorb disturbance, reorganize, and maintain essential ecological functions under changing environmental conditions (Holling, 1973; Folke et al., 2016). This paradigm shift has encouraged researchers to develop adaptive conservation strategies that integrate climate projections, species distribution modelling, ecological restoration, assisted migration, genetic conservation, and landscape connectivity into long-term conservation planning (Heller & Zavaleta, 2009; Prober et al., 2019; Corlett, 2020). Advances in remote sensing, ecological modelling, machine learning, and biodiversity informatics have further strengthened these approaches by enabling conservation practitioners to predict future habitat suitability, identify climate refugia, prioritize restoration areas, and evaluate ecosystem responses under alternative climate scenarios (Franklin, 2010; Pettorelli et al., 2014; Fricke & Olden, 2023).

Despite these significant advances, the literature continues to highlight substantial uncertainties regarding the long-term effectiveness of climate adaptation strategies. Questions remain concerning the ecological risks associated with assisted migration, the capacity of fragmented populations to adapt genetically to rapid environmental change,

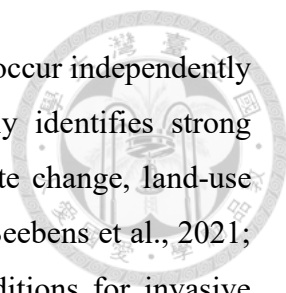


the identification of appropriate climate refugia, and the integration of climate adaptation into conservation policy and governance frameworks (Heller & Zavaleta, 2009; Aitken & Whitlock, 2013; IPCC, 2023). These continuing uncertainties suggest that climate adaptation will remain a major research priority within conservation science and reinforce the importance of interdisciplinary approaches that integrate ecological, technological, and institutional perspectives when developing long-term plant conservation strategies.

2.2.4 Biological Invasions and Ecological Interactions

The introduction and establishment of invasive alien species have become one of the most extensively investigated challenges in contemporary conservation science and are now widely recognized as a major driver of global biodiversity loss. Unlike naturally occurring species dispersal, biological invasions are largely facilitated by human activities, including international trade, agricultural expansion, transportation networks, tourism, and intentional or accidental species introductions (Mack et al., 2000; Pyšek et al., 2020). Once established, invasive species frequently alter community composition, disrupt ecological interactions, modify ecosystem processes, and reduce the abundance and persistence of native plant populations (Vilà et al., 2011; Simberloff et al., 2013). Consequently, biological invasions have become a central focus of plant conservation research due to their capacity to transform ecosystems across local, regional, and global scales.

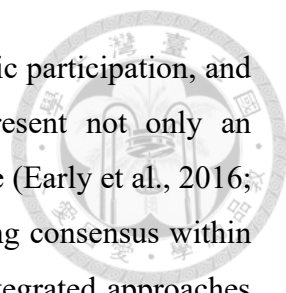
Scientific understanding of biological invasions has evolved considerably over the past several decades. Early research primarily documented the distribution and spread of invasive species, whereas contemporary investigations increasingly examine the ecological mechanisms through which invasions influence biodiversity and ecosystem functioning (Richardson & Pyšek, 2006; Pyšek et al., 2020). Numerous studies have demonstrated that invasive plants compete with native species for light, water, nutrients, and space while simultaneously altering soil chemistry, microbial communities, disturbance regimes, hydrological processes, and nutrient cycling (Ehrenfeld, 2003; Levine et al., 2003). In many ecosystems, invasive species modify habitat structure and ecological succession, thereby reducing native species richness and altering longestablished ecological relationships that are essential for maintaining ecosystem stability (Vilà et al., 2011; Simberloff et al., 2013). These findings have shifted conservation research from simply controlling invasive populations toward understanding the broader ecological consequences of biological invasions within complex ecosystems.



Increasing evidence further suggests that biological invasions rarely occur independently of other conservation pressures. Rather, the literature consistently identifies strong interactions between invasive species, habitat fragmentation, climate change, land-use transformation, and anthropogenic disturbance (Brook et al., 2008; Seebens et al., 2021; IPBES, 2019). Fragmented habitats often provide favourable conditions for invasive species establishment by increasing habitat edges and reducing the competitive resistance of native plant communities (Haddad et al., 2015; Didham et al., 2007). Similarly, climate change has expanded the potential geographic distribution of numerous invasive taxa by altering temperature and precipitation regimes, increasing the likelihood of biological invasions in previously unsuitable environments (Bellard et al., 2013; Hellmann et al., 2008). These synergistic interactions illustrate that biological invasions should be understood as components of broader socio-ecological change rather than as isolated ecological disturbances.

Recent conservation research has consequently shifted toward integrated invasion management strategies that emphasize prevention, early detection, rapid response, ecological restoration, and long-term ecosystem resilience rather than relying solely on post-establishment eradication efforts (Pyšek et al., 2020; Simberloff et al., 2013). Advances in remote sensing, environmental DNA (eDNA), species distribution modelling, ecological forecasting, and artificial intelligence have significantly improved the capacity of researchers and conservation practitioners to detect invasive species, predict invasion risk, and prioritize management interventions at landscape and regional scales (Bush et al., 2017; Franklin, 2010; Fricke & Olden, 2023). At the same time, researchers increasingly advocate ecosystem-based management approaches that strengthen native biodiversity, restore ecological integrity, and improve ecosystem resilience as more sustainable long-term responses to biological invasions (Hobbs & Harris, 2001; Suding, 2011; Folke et al., 2016).

Despite considerable progress in invasion ecology, substantial challenges remain regarding the long-term management of invasive species under rapidly changing environmental conditions. The literature highlights continuing uncertainties concerning invasion pathways, cumulative ecological impacts, cross-border management, ecological restoration following invasion, and the interaction between biological invasions and future climate scenarios (Seebens et al., 2021; IPBES, 2019; Pyšek et al., 2020). Furthermore, effective invasive species management increasingly depends upon



coordinated policy implementation, international collaboration, public participation, and adaptive governance, emphasizing that biological invasions represent not only an ecological challenge but also an institutional and socio-economic one (Early et al., 2016; Shackleton et al., 2019). These findings further reinforce the growing consensus within conservation science that sustainable plant conservation requires integrated approaches capable of simultaneously addressing ecological processes, technological innovation, governance mechanisms, and stakeholder engagement.

2.2.5 Institutional, Financial, and Capacity Constraints

Although considerable advances have been achieved in conservation science, the successful implementation of long-term plant conservation strategies continues to be constrained by substantial institutional, financial, technical, and governance-related limitations. While ecological knowledge regarding biodiversity conservation has expanded considerably over recent decades, numerous studies have demonstrated that the existence of scientific knowledge alone does not necessarily translate into effective conservation practice (Aronson & Alexander, 2013; Mace, 2014; IPBES, 2019). Instead, conservation outcomes are strongly influenced by institutional capacity, policy implementation, financial investment, governance effectiveness, stakeholder participation, and the availability of skilled human resources (CBD, 2022; Bennett et al., 2017). Consequently, contemporary conservation research increasingly recognizes that institutional and governance challenges frequently constitute the principal barriers to achieving successful long-term biodiversity conservation.

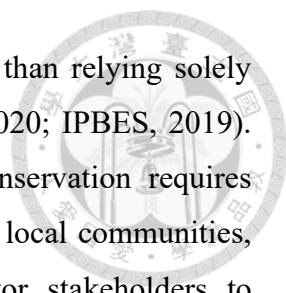
Financial limitations remain one of the most persistent constraints identified throughout the conservation literature. Effective conservation programmes require sustained investment in habitat restoration, protected-area management, biodiversity monitoring, scientific research, ecological restoration, community engagement, and long-term ecological assessment (McCarthy et al., 2012; Waldron et al., 2013). However, conservation funding remains substantially below global biodiversity conservation needs, particularly within developing countries that often contain the highest levels of biological diversity but possess comparatively limited financial capacity (James et al., 2001; CBD, 2022). Numerous studies have consequently emphasized that insufficient and inconsistent funding frequently results in fragmented conservation initiatives, inadequate monitoring programmes, delayed restoration efforts, and reduced institutional effectiveness,

ultimately limiting the long-term sustainability of conservation interventions (McCarthy et al., 2012; Waldron et al., 2013).

Beyond financial constraints, institutional governance has emerged as an equally important determinant of conservation success. Effective plant conservation depends upon coherent environmental policies, transparent governance structures, inter-agency coordination, stakeholder participation, and the integration of scientific evidence into policy development (Ostrom, 2009; Bennett et al., 2017; Wyborn et al., 2020). Nevertheless, the literature consistently reports that conservation initiatives are frequently hindered by fragmented institutional responsibilities, conflicting policy objectives, limited administrative capacity, inconsistent regulatory enforcement, and insufficient collaboration among governmental agencies, academic institutions, nongovernmental organizations, and local communities (Reed, 2008; Cumming et al., 2013; Wyborn et al., 2020). These governance challenges become particularly pronounced in regions where rapid economic development competes directly with biodiversity conservation objectives, creating difficult trade-offs between environmental protection and socio-economic development (IPBES, 2019; Díaz et al., 2019).

The literature further emphasizes that long-term conservation effectiveness depends heavily upon the availability of technical capacity, scientific expertise, and reliable biodiversity information. Conservation planning increasingly requires advanced competencies in ecological monitoring, Geographic Information Systems (GIS), remote sensing, species distribution modelling, molecular genetics, environmental DNA (eDNA), biodiversity informatics, and data-driven decision-making (Pettorelli et al., 2014; Bush et al., 2017; Fricke & Olden, 2023). However, many conservation programmes continue to face shortages of skilled personnel, limited technological infrastructure, insufficient long-term ecological datasets, and restricted access to advanced analytical tools, particularly within biodiversity-rich developing nations (Corlett, 2023; Heywood, 2017). These technical limitations reduce the ability of conservation practitioners to evaluate conservation effectiveness, identify emerging threats, and develop adaptive management strategies capable of responding to rapidly changing environmental conditions.

Recent conservation literature therefore advocates strengthening institutional resilience through integrated governance, interdisciplinary collaboration, sustained financial



investment, technological innovation, and capacity building rather than relying solely upon ecological interventions (Folke et al., 2016; Wyborn et al., 2020; IPBES, 2019). Researchers increasingly argue that effective long-term plant conservation requires coordinated partnerships among governments, research institutions, local communities, Indigenous Peoples, international organizations, and private-sector stakeholders to facilitate knowledge exchange, improve conservation governance, and enhance adaptive management capacity (CBD, 2022; Bennett et al., 2017; Reed, 2008). This growing emphasis on institutional strengthening reflects a broader shift within conservation science toward recognizing that successful biodiversity conservation depends not only upon protecting ecosystems but also upon developing resilient governance systems capable of sustaining conservation efforts over extended temporal and spatial scales.

2.3 Key Enablers of Effective Plant Conservation

While the previous section synthesized the principal challenges constraining long-term plant conservation, the scientific literature equally emphasizes that successful conservation outcomes are supported by a diverse set of ecological, institutional, technological, and socio-economic enabling factors. Contemporary conservation science has progressively shifted away from focusing solely on mitigating threats toward identifying the conditions that promote resilient ecosystems, effective governance, adaptive management, and sustainable biodiversity conservation (Mace, 2014; Folke et al., 2016). Rather than relying upon single conservation interventions, researchers increasingly advocate integrated conservation strategies that combine protected area management, ecological restoration, landscape connectivity, technological innovation, stakeholder collaboration, policy support, and adaptive governance to strengthen long term conservation effectiveness (CBD, 2022; IPBES, 2019; Corlett, 2023).

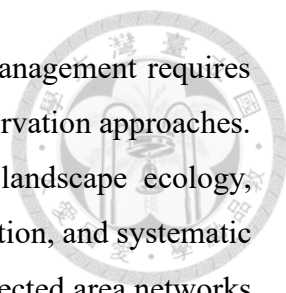
The literature consistently demonstrates that conservation success depends not only upon reducing ecological threats but also upon enhancing the capacity of ecosystems, institutions, and communities to respond to changing environmental conditions. Numerous empirical studies indicate that effective plant conservation is associated with strong governance structures, sustained financial investment, scientific research, community participation, interdisciplinary collaboration, technological advancement, and evidence-based policy implementation (Bennett et al., 2017; Wyborn et al., 2020; Reed, 2008). These enabling factors rarely function independently; instead, they operate as interconnected components of socio-ecological systems that collectively enhance

biodiversity conservation, ecosystem resilience, and sustainable environmental management (Folke et al., 2016; Ostrom, 2009). Accordingly, the following sections synthesize the principal enabling factors most consistently identified throughout the scientific literature and examine their contributions to long-term plant conservation.

2.3.1 Integrated Conservation Planning and Protected Area Networks

Protected areas have long been regarded as the cornerstone of global biodiversity conservation and remain among the most extensively researched and widely implemented strategies for safeguarding plant diversity. Since the establishment of the first national parks during the late nineteenth century, protected areas have evolved from isolated reserves primarily intended to preserve scenic landscapes into comprehensive conservation systems designed to maintain biodiversity, ecosystem functions, ecological processes, and evolutionary potential (Watson et al., 2014; Dudley, 2008). The scientific literature consistently recognizes that well-managed protected areas contribute significantly to reducing habitat destruction, limiting anthropogenic disturbance, conserving threatened species, and maintaining ecological integrity across diverse terrestrial ecosystems (Geldmann et al., 2013; Gray et al., 2016). Consequently, protected area management continues to represent one of the central pillars of long-term plant conservation and remains a key component of international biodiversity policies, including the Convention on Biological Diversity (CBD) and the Kunming–Montreal Global Biodiversity Framework (CBD, 2022).

Although early conservation strategies largely emphasized increasing the number and spatial extent of protected areas, subsequent research has demonstrated that conservation effectiveness depends not merely upon the designation of protected land but upon the ecological quality, representativeness, connectivity, and long-term management of protected area networks (Margules & Pressey, 2000; Rodrigues et al., 2004; Watson et al., 2014). Numerous empirical studies have shown that isolated reserves often fail to conserve viable plant populations when surrounding landscapes continue to experience habitat degradation, fragmentation, and intensive land-use change (Haddad et al., 2015; Hilty et al., 2020). Consequently, conservation science has progressively shifted from viewing protected areas as isolated conservation units toward recognizing them as interconnected components of larger ecological networks that facilitate species movement, maintain genetic exchange, and enhance ecosystem resilience under changing environmental conditions (Beier & Noss, 1998; Crooks & Sanjayan, 2006).

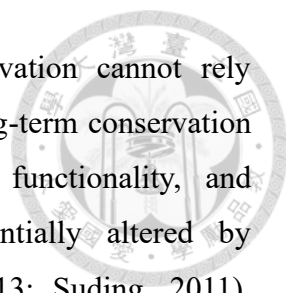


Recent literature further emphasizes that effective protected area management requires adaptive and integrated conservation planning rather than static preservation approaches. Contemporary conservation frameworks increasingly incorporate landscape ecology, ecosystem-based management, ecological restoration, climate adaptation, and systematic conservation planning to improve the long-term effectiveness of protected area networks (Margules & Pressey, 2000; Mace, 2014; Corlett, 2023). Advances in spatial ecology, Geographic Information Systems (GIS), remote sensing, species distribution modelling, and conservation prioritization have enabled researchers to identify biodiversity hotspots, evaluate habitat connectivity, optimize reserve design, and anticipate future changes in species distributions resulting from climate change (Pettorelli et al., 2014; Franklin, 2010; Moilanen et al., 2009). These developments have transformed protected area planning from a reactive conservation measure into a proactive, evidence-based process capable of supporting long-term biodiversity persistence.

Despite their well-established conservation value, the literature also acknowledges that protected areas alone are insufficient to halt global biodiversity decline. Numerous studies report that many threatened plant species occur outside formally protected landscapes, while increasing human pressures, climate change, biological invasions, and governance limitations continue to reduce the effectiveness of protected area management (IPBES, 2019; Maxwell et al., 2020; Geldmann et al., 2019). Consequently, researchers increasingly advocate integrated conservation planning that combines protected area networks with ecological restoration, sustainable land-use management, community participation, and adaptive governance to achieve more resilient and inclusive conservation outcomes (CBD, 2022; Folke et al., 2016; Bennett et al., 2017). This broader perspective reflects the growing consensus that protected areas should function as the ecological foundation of integrated conservation systems rather than as standalone solutions to biodiversity conservation.

2.3.2 Ecological Restoration and Ecosystem Recovery

Ecological restoration has become one of the most influential and rapidly expanding research domains within contemporary conservation science, reflecting a fundamental shift from conserving remaining natural habitats toward actively recovering ecosystems that have already experienced degradation. Historically, conservation efforts focused primarily on preventing habitat destruction through protected area establishment and species preservation. However, increasing recognition of the widespread degradation of



terrestrial ecosystems has demonstrated that biodiversity conservation cannot rely exclusively on protecting the remaining intact habitats. Instead, long-term conservation increasingly requires restoring ecological integrity, ecosystem functionality, and biological diversity within landscapes that have been substantially altered by anthropogenic activities (SER, 2019; Aronson & Alexander, 2013; Suding, 2011). Consequently, ecological restoration has emerged as a complementary conservation strategy that extends beyond damage mitigation to facilitate the recovery of resilient, self-sustaining ecosystems capable of supporting long-term biodiversity conservation.

The scientific understanding of ecological restoration has evolved considerably over the past several decades. Early restoration initiatives were frequently evaluated according to structural indicators, such as vegetation cover or species richness. More recent research, however, emphasizes that successful restoration should also re-establish ecological processes, trophic interactions, nutrient cycling, hydrological functions, soil integrity, and ecosystem resilience rather than simply recreating historical species assemblages (Hobbs & Harris, 2001; Suding, 2011; Gann et al., 2019). This conceptual evolution reflects the broader transition within conservation science from species-centred management toward ecosystem-based conservation, recognizing that long-term biodiversity persistence depends upon maintaining ecological functions and adaptive capacity in addition to species composition (Mace, 2014; Folke et al., 2016). As a result, restoration ecology has become increasingly interdisciplinary, integrating ecological theory, landscape ecology, hydrology, soil science, conservation genetics, climate science, and environmental management into comprehensive ecosystem recovery strategies.

Recent literature further highlights the important contribution of ecological restoration to addressing multiple global environmental challenges simultaneously. Beyond enhancing plant biodiversity, restoration initiatives have been shown to improve carbon sequestration, regulate hydrological systems, enhance soil fertility, strengthen ecosystem resilience, mitigate climate change, reduce habitat fragmentation, and restore ecosystem services essential for human well-being (Chazdon, 2008; Rey Benayas et al., 2009; IPBES, 2019). Large-scale international initiatives, including the Bonn Challenge, the United Nations Decade on Ecosystem Restoration (2021–2030), and the Kunming–Montreal Global Biodiversity Framework, have further reinforced ecological restoration as a central component of global biodiversity policy by encouraging countries to restore degraded ecosystems while integrating conservation objectives with sustainable

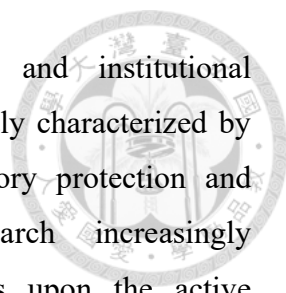
development priorities (CBD, 2022; FAO & UNEP, 2021). These developments illustrate that ecological restoration is no longer viewed solely as a remedial activity but increasingly as a proactive strategy for achieving ecological sustainability and long-term conservation outcomes.

Nevertheless, the literature also recognizes that ecological restoration remains a complex and uncertain scientific undertaking. Numerous studies report that restoration success is influenced by site-specific environmental conditions, historical land use, climate variability, invasive species, landscape connectivity, governance capacity, and long-term financial commitment (Hobbs et al., 2011; Suding et al., 2015; Moreno-Mateos et al., 2017). Furthermore, restored ecosystems often require decades to recover ecological functions comparable to those of undisturbed reference ecosystems, while some ecosystem processes may never be fully restored under rapidly changing climatic conditions (Jones et al., 2018; Moreno-Mateos et al., 2017). These findings have encouraged researchers to adopt adaptive restoration approaches that emphasize continuous ecological monitoring, stakeholder engagement, evidence-based decision-making, and flexible management strategies capable of responding to environmental uncertainty (Gann et al., 2019; SER, 2019).

Accordingly, contemporary conservation research increasingly positions ecological restoration as a fundamental component of integrated conservation planning rather than as an isolated post-disturbance intervention. Researchers now advocate combining restoration with protected area management, landscape connectivity, climate adaptation, biodiversity monitoring, community participation, and sustainable land-use planning to maximize long-term conservation effectiveness (Chazdon & Brancalion, 2019; Corlett, 2023; Folke et al., 2016). This integrated perspective reflects a growing scientific consensus that restoring ecosystem processes, enhancing ecological resilience, and rebuilding functional landscapes are essential for reversing biodiversity decline and securing the long-term conservation of plant diversity in an era of accelerating global environmental change.

2.3.3 Community Participation, Indigenous Knowledge, and Collaborative Governance

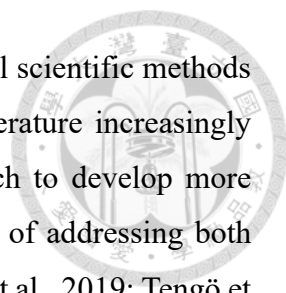
Long-term plant conservation is increasingly recognized as a collaborative socioecological process that extends beyond ecological management to encompass



governance, stakeholder participation, knowledge integration, and institutional cooperation. While early conservation initiatives were predominantly characterized by centralized, government-led approaches that emphasized regulatory protection and exclusionary management, contemporary conservation research increasingly demonstrates that sustainable biodiversity conservation depends upon the active involvement of local communities, Indigenous Peoples, land managers, policymakers, researchers, and non-governmental organizations (Berkes, 2009; Ostrom, 2009; Bennett et al., 2017). This paradigm shift reflects growing recognition that conservation outcomes are strongly influenced by social institutions, cultural values, governance arrangements, and community stewardship in addition to ecological processes (Folke et al., 2016; Wyborn et al., 2020). Consequently, community participation and collaborative governance have become central themes within modern conservation science and are now widely regarded as essential enabling factors for achieving long-term conservation success.

A substantial body of literature indicates that conservation initiatives are generally more effective and socially sustainable when local communities actively participate in planning, implementation, monitoring, and adaptive management processes (Reed, 2008; Brooks et al., 2013; Oldekop et al., 2016). Community participation contributes to conservation by strengthening local ownership, improving compliance with conservation policies, reducing resource-use conflicts, and facilitating long-term stewardship of biodiversity (Pretty & Smith, 2004; Berkes, 2009). Furthermore, participatory conservation approaches enable decision-makers to incorporate local ecological knowledge, socioeconomic priorities, and cultural values into conservation planning, thereby improving both ecological effectiveness and social legitimacy (Reed, 2008; Bennett et al., 2017). Numerous comparative studies have reported that conservation programmes developed through collaborative decision-making frequently achieve higher levels of biodiversity protection while simultaneously supporting sustainable livelihoods and community resilience (Oldekop et al., 2016; Brooks et al., 2013).

Increasing attention has also been directed toward the contribution of Indigenous and local knowledge systems to biodiversity conservation. Indigenous Peoples and local communities possess extensive ecological knowledge accumulated through long-term interaction with local ecosystems, often providing valuable insights into species distributions, ecological processes, traditional resource management practices, and



environmental change that may not be captured through conventional scientific methods alone (Garnett et al., 2018; IPBES, 2019). Recent conservation literature increasingly advocates integrating Indigenous knowledge with scientific research to develop more comprehensive and context-specific conservation strategies capable of addressing both ecological and social dimensions of biodiversity conservation (Díaz et al., 2019; Tengö et al., 2014). Rather than viewing scientific and Indigenous knowledge systems as competing sources of information, contemporary conservation science increasingly promotes knowledge co-production, in which multiple knowledge systems are respectfully combined to improve conservation decision-making and adaptive management (Tengö et al., 2014; Wyborn et al., 2020).

The literature further demonstrates that effective collaborative governance requires more than stakeholder participation alone. Successful governance systems depend upon transparent institutions, clearly defined responsibilities, effective policy implementation, equitable benefit-sharing, cross-sector collaboration, and mechanisms for resolving conflicts among diverse stakeholders (Ostrom, 2009; Lockwood, 2010; Armitage et al., 2009). Adaptive governance frameworks have consequently become increasingly prominent within conservation research because they emphasize institutional learning, flexibility, continuous monitoring, and collaborative decision-making under conditions of ecological uncertainty (Folke et al., 2005; Chaffin, Gosnell, & Cosens, 2014). These governance models are particularly relevant to long-term plant conservation, where environmental conditions, species distributions, and conservation priorities continue to evolve in response to climate change and other anthropogenic pressures.

Despite widespread recognition of the importance of collaborative governance, the literature also acknowledges several continuing challenges associated with participatory conservation. Researchers have identified persistent issues related to unequal stakeholder representation, power imbalances, conflicting conservation objectives, limited institutional capacity, insufficient financial support, and difficulties in integrating diverse knowledge systems into formal policy frameworks (Reed, 2008; Bennett et al., 2017; Wyborn et al., 2020). Nevertheless, there is broad scientific consensus that conservation strategies which integrate community participation, Indigenous knowledge, interdisciplinary collaboration, and adaptive governance are generally more resilient, socially acceptable, and capable of supporting long-term biodiversity conservation than approaches based solely on centralized ecological management. Accordingly,

collaborative governance is now widely regarded as one of the defining characteristics of contemporary conservation practice and a critical enabler of sustainable plant conservation.

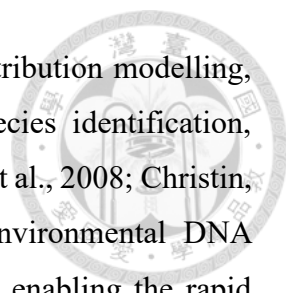


2.3.4 Technological Innovation and Data-Driven Conservation

The rapid advancement of digital technologies has fundamentally transformed the scope, methodology, and analytical capacity of contemporary plant conservation research. Whereas traditional conservation practices relied primarily on field observations, manual surveys, and localized ecological assessments, recent technological developments have enabled researchers to investigate biodiversity across unprecedented spatial, temporal, and organizational scales (Pettorelli et al., 2014; Franklin, 2010). The integration of Geographic Information Systems (GIS), remote sensing, unmanned aerial vehicles (UAVs), environmental DNA (eDNA), artificial intelligence (AI), machine learning, species distribution modelling, and biodiversity informatics has significantly enhanced the ability to monitor ecosystems, evaluate conservation effectiveness, predict environmental change, and support evidence-based conservation planning (Bush et al., 2017; Lahoz-Monfort & Magrath, 2021; Fricke & Olden, 2023). Consequently, technological innovation has evolved from serving as a supplementary research tool to becoming an essential component of modern conservation science.

Among these technological developments, remote sensing and geospatial technologies have substantially expanded the capacity for monitoring vegetation dynamics, habitat degradation, land-use change, and ecosystem recovery over extensive geographical regions. High-resolution satellite imagery, LiDAR, multispectral imaging, and drone-based monitoring systems now enable conservation practitioners to evaluate habitat quality, identify biodiversity hotspots, assess ecological connectivity, and quantify environmental changes with levels of precision that were previously unattainable (Pettorelli et al., 2014; Turner et al., 2015; Franklin, 2010). These technologies have also improved conservation planning by facilitating spatial prioritization, ecological corridor design, restoration planning, and long-term environmental monitoring, thereby strengthening the scientific basis for adaptive conservation management (Moilanen et al., 2009; Hilty et al., 2020).

Recent literature further demonstrates the increasing importance of artificial intelligence, machine learning, and biodiversity informatics in conservation decision-making.



Machine learning algorithms are now widely applied to species distribution modelling, habitat suitability assessment, image classification, automated species identification, ecological forecasting, and predictive conservation planning (Olden et al., 2008; Christin, Hervet, & Lecomte, 2019; Fricke & Olden, 2023). Similarly, environmental DNA (eDNA) technologies have transformed biodiversity assessment by enabling the rapid detection of plant and animal species from environmental samples without requiring direct observation, thereby improving biodiversity inventories and ecological monitoring in both terrestrial and aquatic ecosystems (Taberlet et al., 2012; Bush et al., 2017). Together, these technological innovations have substantially improved the efficiency, accuracy, and scalability of biodiversity monitoring while generating increasingly large and complex ecological datasets that support more sophisticated conservation analyses.

The growing availability of large-scale biodiversity data has also contributed to a fundamental transformation in conservation research itself. Open-access scientific databases, global biodiversity repositories, digital herbarium collections, ecological monitoring networks, and international research collaborations have dramatically increased both the quantity and accessibility of conservation-related information (GBIF, 2023; Nelson & Ellis, 2019). As scientific publications and biodiversity datasets continue to expand, researchers are increasingly confronted with the challenge of synthesizing vast quantities of heterogeneous information spanning multiple disciplines, conservation approaches, and methodological traditions (Donthu et al., 2021; Aria & Cuccurullo, 2017). Consequently, conservation science has witnessed growing interest in evidence synthesis methodologies capable of systematically organizing and interpreting complex bodies of scientific knowledge.

Accordingly, recent studies increasingly recognize that technological innovation extends beyond improving ecological monitoring and conservation practice; it also transforms how conservation knowledge itself is generated, disseminated, and synthesized. Bibliometric analysis, science mapping, and keyword co-occurrence analysis have consequently emerged as valuable methodological approaches for examining the intellectual structure, thematic evolution, and research trends of rapidly expanding scientific fields (Zupic & Čater, 2015; Donthu et al., 2021; van Eck & Waltman, 2010). By enabling researchers to quantitatively analyse publication patterns, conceptual relationships, and thematic clusters, these analytical techniques complement technological advances in biodiversity monitoring by facilitating a more comprehensive

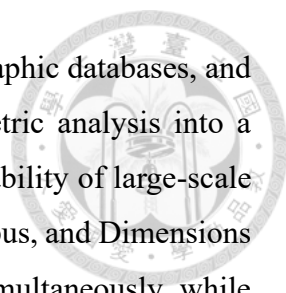
understanding of the evolution of conservation science itself. This methodological development provides the foundation for the following section, which reviews the application of bibliometric and keyword co-occurrence analysis within conservation research and establishes the theoretical basis for the analytical approach adopted in the present study.

2.4 Bibliometric and Keyword Co-occurrence Analysis in Conservation Research

2.4.1 Evolution of Bibliometric Analysis

Bibliometric analysis has evolved into one of the most widely adopted quantitative methodologies for examining the development, organization, and intellectual structure of scientific knowledge. The term *bibliometrics* was first formally introduced by **Pritchard (1969)**, who defined it as the application of mathematical and statistical methods to books and other forms of scientific communication in order to quantitatively evaluate research production and scholarly dissemination. Since its introduction, bibliometric analysis has progressed considerably from simple publication and citation counting toward sophisticated science-mapping techniques capable of revealing conceptual relationships, research evolution, collaboration patterns, and the intellectual organization of entire scientific disciplines (Narin, 1976; van Raan, 2005). This methodological evolution has been driven largely by the exponential growth of scientific publications and the increasing need for systematic approaches capable of synthesizing extensive bodies of multidisciplinary research.

During the early stages of bibliometric research, quantitative analyses primarily focused on descriptive indicators such as publication productivity, citation frequency, journal impact, and author performance. These indicators provided valuable measures of scientific influence and research productivity but offered only limited insight into the conceptual organization of scientific knowledge (Small, 1973; Garfield, 1979). As scientific disciplines became increasingly interconnected and publication outputs expanded rapidly across multiple research domains, scholars recognized the need for analytical approaches capable of moving beyond simple performance metrics to investigate the intellectual relationships among publications, authors, institutions, and research topics (Börner, Chen, & Boyack, 2003; van Raan, 2005). Consequently, bibliometric research gradually evolved from performance evaluation toward science mapping, allowing researchers to visualize the structural development of scientific knowledge and identify the emergence of new research domains.



The rapid advancement of computational techniques, digital bibliographic databases, and specialized bibliometric software has further transformed bibliometric analysis into a robust methodology for knowledge synthesis. The widespread availability of large-scale scientific databases such as the Web of Science Core Collection, Scopus, and Dimensions has enabled researchers to analyse thousands of publications simultaneously while investigating complex relationships among publications, authors, institutions, keywords, and research themes (Aria & Cuccurullo, 2017; Donthu et al., 2021). These developments have substantially improved the objectivity, reproducibility, and analytical depth of literature synthesis, enabling researchers to examine the evolution of scientific fields from both quantitative and conceptual perspectives.

Recent literature increasingly recognizes bibliometric analysis as more than a descriptive statistical technique. Rather, it is now regarded as a systematic evidence synthesis methodology capable of revealing the intellectual structure, conceptual evolution, and thematic organization of scientific research (Zupic & Čater, 2015; Donthu et al., 2021). Unlike traditional narrative reviews, which rely primarily upon qualitative interpretation and selective literature synthesis, bibliometric analysis applies transparent and reproducible quantitative procedures to identify publication trends, research collaborations, thematic relationships, influential publications, and emerging scientific frontiers (Chen, 2017; Cobo et al., 2011). This capability has contributed to its widespread adoption across numerous disciplines, including medicine, engineering, business, environmental science, sustainability research, and conservation biology, where rapidly expanding scientific literature increasingly requires systematic approaches for organizing and interpreting accumulated knowledge.

Within environmental and conservation research, bibliometric analysis has become particularly valuable because of the interdisciplinary nature of biodiversity conservation. Contemporary conservation science integrates knowledge from ecology, botany, genetics, environmental management, climate science, geography, economics, policy studies, sociology, and information science, producing an extensive and highly interconnected body of literature that is difficult to synthesize using conventional review methods alone (Corlett, 2023; IPBES, 2019). Bibliometric approaches therefore provide researchers with an objective framework for identifying dominant research themes, evaluating the evolution of conservation science, detecting emerging research hotspots, and supporting evidence-based understanding of increasingly complex scientific domains (Donthu et al.,

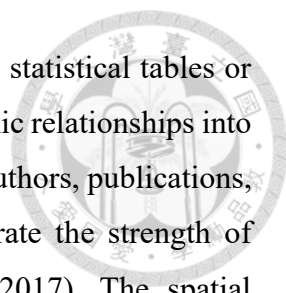
2021; Aria & Cuccurullo, 2017). This methodological capability has laid the foundation for the development of science mapping techniques, including keyword co-occurrence analysis, which enable researchers to investigate not only the productivity of scientific research but also the conceptual relationships that define the intellectual landscape of a research field.

2.4.2 Science Mapping and Knowledge Visualization

Science mapping has emerged as one of the most significant developments within contemporary bibliometric research, providing researchers with systematic approaches for exploring the intellectual organization, conceptual evolution, and structural relationships that characterize scientific knowledge. While traditional bibliometric indicators primarily evaluate research performance through publication counts, citation frequencies, or journal impact, science mapping extends beyond quantitative performance measurement by examining the relationships that exist among scientific concepts, publications, authors, institutions, and research themes (Cobo et al., 2011; Börner, Chen, & Boyack, 2003). Consequently, science mapping has become an indispensable analytical approach for investigating how scientific disciplines evolve, identifying emerging research areas, and revealing the conceptual architecture underlying complex bodies of literature.

The rapid expansion of multidisciplinary scientific research has significantly increased the demand for knowledge visualization techniques capable of transforming extensive bibliographic datasets into interpretable conceptual structures. As publication volumes continue to grow across diverse research domains, conventional narrative synthesis becomes progressively more challenging because researchers must interpret thousands of interconnected publications, concepts, and thematic relationships simultaneously (Donthu et al., 2021; Zupic & Čater, 2015). Science mapping addresses this challenge by applying network analysis and visualization techniques that represent relationships among scientific entities as graphical networks, thereby enabling researchers to identify research clusters, conceptual linkages, collaboration patterns, thematic evolution, and emerging scientific frontiers that would otherwise remain difficult to detect through qualitative review alone (Chen, 2017; Börner et al., 2003).

Within science mapping, knowledge visualization plays a particularly important role by facilitating the interpretation of complex bibliometric relationships through graphical



representation. Rather than presenting bibliometric outputs solely as statistical tables or numerical indicators, knowledge visualization transforms bibliographic relationships into network maps in which nodes represent scientific entities—such as authors, publications, institutions, countries, or keywords—while connecting links illustrate the strength of relationships among them (van Eck & Waltman, 2010; Chen, 2017). The spatial organization of these networks enables researchers to observe conceptual proximity, research density, collaboration intensity, and the emergence of thematic structures across scientific disciplines (Cobo et al., 2011). Consequently, visualization techniques have become fundamental components of modern bibliometric analysis because they facilitate intuitive interpretation of highly complex scientific information while preserving analytical rigor and reproducibility.

Several software platforms have been developed to support science mapping and bibliometric visualization, including **CiteSpace**, **BibExcel**, **Gephi**, **bibliometrix**, and **VOSviewer**, each providing distinct analytical capabilities depending on the objectives of the investigation (Aria & Cuccurullo, 2017; van Eck & Waltman, 2010; Chen, 2017). Among these platforms, VOSviewer has become one of the most widely adopted software packages for bibliometric research because of its ability to construct, visualize, and analyse large bibliometric networks with high computational efficiency while providing intuitive graphical representations of conceptual relationships (van Eck & Waltman, 2010; van Eck & Waltman, 2018). The software supports multiple science mapping techniques, including co-authorship analysis, citation analysis, bibliographic coupling, co-citation analysis, and keyword co-occurrence analysis, allowing researchers to investigate different dimensions of scientific knowledge using a unified analytical framework.

Recent methodological literature consistently recognizes VOSviewer as particularly effective for conceptual science mapping because of its visualization capabilities and clustering algorithms. The software applies the Visualization of Similarities (VOS) mapping technique together with modularity-based clustering algorithms to position strongly related scientific entities closer together within a network while simultaneously identifying groups of closely connected concepts that represent coherent research themes (van Eck & Waltman, 2010; Waltman, van Eck, & Noyons, 2010). Furthermore, VOSviewer provides multiple complementary visualization modes—including **network visualization**, **overlay visualization**, and **density visualization**—that enable researchers to examine conceptual relationships, temporal research evolution, and thematic

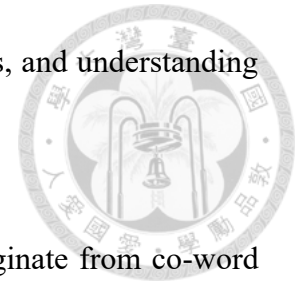
concentration from different analytical perspectives (van Eck & Waltman, 2018). These visualization capabilities have contributed substantially to the software's widespread adoption across environmental science, sustainability research, ecology, conservation biology, public health, engineering, and numerous other multidisciplinary scientific fields.

Within conservation research, science mapping and knowledge visualization have become increasingly valuable because of the inherently interdisciplinary nature of biodiversity conservation. Conservation science integrates ecological theory, environmental management, genetics, climate science, restoration ecology, governance, sustainability studies, economics, and social sciences, producing highly interconnected research landscapes that are difficult to synthesize using conventional qualitative approaches alone (Corlett, 2023; IPBES, 2019). Science mapping techniques therefore provide researchers with systematic means of exploring the conceptual organization of conservation research while identifying dominant research themes, interdisciplinary linkages, emerging research priorities, and intellectual development across the scientific literature. This methodological foundation naturally supports the application of keyword co-occurrence analysis, which represents one of the most widely used science mapping techniques for investigating conceptual relationships within scientific knowledge and forms the principal analytical approach adopted in the present study.

2.4.3 Keyword Co-occurrence Analysis as a Science Mapping Technique

Keyword co-occurrence analysis has become one of the most widely adopted science mapping techniques for investigating the conceptual structure and thematic organization of scientific literature. Unlike citation-based bibliometric methods that primarily examine relationships among publications or authors, keyword co-occurrence analysis focuses on the frequency with which specific concepts appear together within scientific publications, thereby revealing the conceptual relationships that characterize a particular research field (Callon, Courtial, Turner, & Bauin, 1983; van Eck & Waltman, 2010). The underlying assumption of this technique is that keywords appearing together repeatedly across multiple publications represent closely related research topics or scientific concepts, enabling researchers to identify the principal thematic domains that define the intellectual structure of a discipline (Donthu et al., 2021; Zupic & Čater, 2015). Consequently, keyword co-occurrence analysis has become an indispensable analytical approach for

examining research evolution, identifying emerging scientific trends, and understanding how knowledge is organized within rapidly expanding scientific fields.



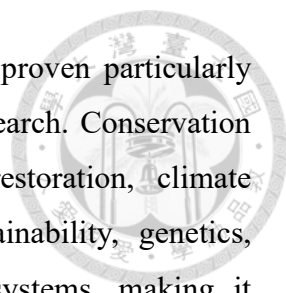
The theoretical foundations of keyword co-occurrence analysis originate from co-word analysis, first introduced by Callon et al. (1983), who proposed that the relationships among frequently co-occurring terms could be used to map the conceptual organization of scientific knowledge. Unlike citation-based analyses, which primarily reflect intellectual influence through referencing behaviour, co-word analysis examines the semantic relationships embedded within scientific publications by analysing how authors describe their research through keywords and indexing terms (Callon et al., 1983; Coulter, Monarch, & Konda, 1998). As scientific concepts evolve over time, the frequency and patterns of keyword co-occurrence similarly evolve, allowing researchers to investigate the emergence, development, convergence, or decline of research themes within a discipline (Cobo et al., 2011). Consequently, keyword co-occurrence analysis provides insight into the conceptual evolution of research rather than simply measuring publication productivity or citation impact.

Recent methodological literature consistently recognizes keyword co-occurrence analysis as particularly effective for identifying **research hotspots**, **thematic clusters**, and **conceptual relationships** within large bibliographic datasets (van Eck & Waltman, 2010; Chen, 2017; Donthu et al., 2021). During analysis, keywords extracted from scientific publications are represented as nodes within a network, while the frequency with which pairs of keywords occur together determines the strength of their connecting links. Keywords that frequently co-occur are positioned closer together within the visualization, ultimately forming clusters that represent groups of closely related research concepts (van Eck & Waltman, 2010; Waltman et al., 2010). These clusters provide an objective representation of the conceptual structure of the literature by illustrating how different research topics are interconnected across the scientific domain. Importantly, however, the generated clusters do not possess inherent semantic meaning. Rather, they constitute computational groupings of related concepts whose scientific significance must subsequently be interpreted by the researcher through qualitative examination of the literature associated with each cluster (Donthu et al., 2021; Zupic & Čater, 2015). This distinction is particularly important because bibliometric software objectively identifies thematic structures, whereas the classification of conservation challenges, enabling

factors, and knowledge gaps requires scholarly interpretation grounded in existing literature.

The interpretative dimension of keyword co-occurrence analysis has become increasingly significant within contemporary bibliometric research. Numerous scholars emphasize that science mapping should not be regarded as an end in itself but rather as a foundation for deeper theoretical synthesis (Chen, 2017; Donthu et al., 2021). Thematic clusters generated through keyword co-occurrence analysis reveal the conceptual organization of scientific knowledge; however, understanding what those clusters represent, how they relate to broader theoretical frameworks, and what implications they hold for future research depends upon systematic qualitative interpretation. Consequently, contemporary bibliometric studies increasingly combine quantitative science mapping with thematic analysis, content analysis, or narrative synthesis to explain the conceptual meaning of identified clusters and translate bibliometric findings into substantive scientific knowledge (Cobo et al., 2011; Zupic & Čater, 2015). This integrated analytical approach enhances methodological rigor by combining the objectivity of computational analysis with the contextual understanding provided by qualitative scholarly interpretation.

The visualization capabilities associated with keyword co-occurrence analysis further strengthen its value as a knowledge synthesis methodology. Contemporary bibliometric software such as VOSviewer enables researchers to examine conceptual relationships through multiple complementary visualization techniques. **Network visualization** illustrates the structural relationships among keywords and thematic clusters by displaying nodes, links, and cluster membership within an integrated conceptual network (van Eck & Waltman, 2010). **Overlay visualization** incorporates temporal information by representing the average publication year associated with individual keywords, thereby enabling researchers to identify emerging and declining research topics as well as the chronological evolution of scientific themes (van Eck & Waltman, 2018). **Density visualization**, in contrast, highlights areas of concentrated research activity by representing the frequency and proximity of keywords through varying levels of colour intensity, allowing researchers to identify mature research domains, dominant conceptual areas, and highly investigated topics within a discipline (van Eck & Waltman, 2010). Collectively, these complementary visualization techniques provide a comprehensive understanding of both the structural organization and temporal development of scientific knowledge.

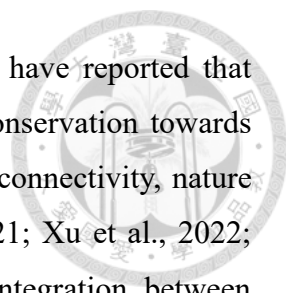


Within conservation science, keyword co-occurrence analysis has proven particularly valuable because of the multidisciplinary nature of biodiversity research. Conservation literature encompasses diverse concepts relating to ecology, restoration, climate adaptation, ecosystem services, environmental governance, sustainability, genetics, landscape ecology, environmental policy, and socio-ecological systems, making it increasingly difficult to identify dominant research themes through conventional qualitative review alone (Corlett, 2023; IPBES, 2019). By objectively identifying conceptual relationships among these diverse topics, keyword co-occurrence analysis enables researchers to systematically investigate how conservation science has evolved, identify major research hotspots, explore thematic relationships, and provide a robust empirical foundation for subsequent qualitative interpretation. Accordingly, keyword co-occurrence analysis represents the principal science mapping technique employed in the present study because it provides an objective means of examining the conceptual structure of long-term plant conservation research while supporting the thematic interpretation of conservation challenges, enabling factors, and future research directions.

2.4.4 Applications of Bibliometric and Keyword Co-occurrence Analysis in Conservation Research

The application of bibliometric analysis within environmental and conservation science has expanded substantially over the past decade, reflecting the rapid growth of scientific publications and the increasing need for systematic approaches capable of synthesizing complex and multidisciplinary bodies of literature. As conservation research has diversified across ecology, biodiversity science, climate change, ecosystem restoration, environmental governance, sustainability, and socio-ecological systems, researchers have increasingly employed bibliometric techniques to examine the intellectual development of the field, identify dominant research themes, evaluate international research collaboration, and explore emerging scientific trends (Donthu et al., 2021; Aria & Cuccurullo, 2017). Rather than replacing traditional literature reviews, these studies have complemented qualitative synthesis by providing objective evidence regarding the conceptual organization and evolution of conservation science.

Numerous bibliometric investigations have consistently demonstrated that biodiversity conservation has evolved into a highly interdisciplinary research domain characterized by strong conceptual linkages among ecology, restoration science, climate adaptation, ecosystem services, environmental governance, and sustainability. For example,



bibliometric studies examining biodiversity conservation literature have reported that research themes have progressively shifted from species-centred conservation towards integrated ecosystem management, ecological resilience, landscape connectivity, nature based solutions, and sustainable development (Di Marco et al., 2021; Xu et al., 2022; Donthu et al., 2021). Similar analyses have shown increasing integration between conservation biology and disciplines such as environmental economics, climate science, social sciences, public policy, and technological innovation, reflecting the growing recognition that biodiversity conservation requires interdisciplinary solutions capable of addressing complex socio-ecological challenges (Mace, 2014; Díaz et al., 2019; IPBES, 2019).

Keyword co-occurrence analyses conducted across environmental and sustainability research have further revealed the emergence of several recurring conceptual clusters that consistently dominate contemporary conservation literature. Frequently occurring themes include biodiversity conservation, ecological restoration, climate change adaptation, ecosystem services, protected areas, sustainable development, environmental governance, resilience, and community participation (Cobo et al., 2011; van Eck & Waltman, 2018; Chen, 2017). Overlay visualization analyses have additionally demonstrated that more recent research increasingly focuses on climate resilience, nature-based solutions, ecosystem restoration, conservation technology, artificial intelligence, environmental DNA, and adaptive governance, indicating that conservation science continues to evolve in response to emerging environmental challenges and technological advances (Fricke & Olden, 2023; Lahoz-Monfort & Magrath, 2021; Corlett, 2023). Collectively, these findings illustrate the capacity of keyword co-occurrence analysis to identify both established research domains and newly emerging scientific priorities within conservation research.

Bibliometric investigations have also contributed significantly to understanding the collaborative structure of conservation science. Previous studies consistently report increasing levels of international collaboration among universities, research institutes, governmental organizations, and non-governmental organizations, particularly within biodiversity conservation, restoration ecology, and climate adaptation research (Börner et al., 2003; Aria & Cuccurullo, 2017). Nevertheless, several bibliometric studies also highlight persistent geographical disparities in scientific production, with research output remaining concentrated in developed countries despite the highest levels of plant

biodiversity occurring predominantly within tropical and developing regions (Antonelli et al., 2020; Nic Lughadha et al., 2020). These findings have encouraged greater emphasis on international collaboration, capacity building, and knowledge exchange to improve the global representation of biodiversity conservation research and strengthen conservation practice within biodiversity-rich regions.

Despite the growing application of bibliometric analysis within environmental science, the literature indicates that relatively few studies extend beyond quantitative visualization to provide comprehensive qualitative interpretation of the thematic relationships identified through science mapping. Most bibliometric investigations primarily focus on describing publication trends, citation performance, collaboration networks, or keyword clusters, while comparatively limited attention has been directed toward interpreting how these thematic structures collectively explain conservation challenges, enabling factors, research priorities, and long-term biodiversity sustainability (Donthu et al., 2021; Zupic & Čater, 2015). Consequently, recent methodological literature increasingly advocates integrating quantitative bibliometric analysis with qualitative thematic synthesis to generate more meaningful scientific interpretations that extend beyond descriptive visualization alone. This integrated analytical perspective provides a stronger foundation for understanding the intellectual development of conservation science and offers greater practical value for supporting evidence-based conservation planning and future research.

2.5 Future Directions and Research Priorities

2.5.1 Adaptive Management and Long-term Monitoring

The uncertainty inherent in conservation biology necessitates adaptive management approaches that incorporate learning from both successes and failures into ongoing conservation practice (Westgate et al., 2013). Long-term monitoring programs provide the data necessary to evaluate conservation effectiveness and adjust strategies in response to changing conditions.

The establishment of standardized monitoring protocols and data sharing platforms could greatly enhance the collective learning capacity of the plant conservation community. Integration of citizen science approaches with professional monitoring programs offers opportunities to expand the spatial and temporal scope of data collection while building public engagement in conservation.

2.5.2 Climate Change Adaptation

Developing conservation strategies that account for ongoing and projected climate change represents a critical research priority for long-term plant conservation (Corlett, 2020). Assisted migration, genetic rescue, and evolutionary rescue approaches offer promising but largely untested strategies for helping species adapt to changing conditions.

The integration of climate projections with species distribution modeling and population viability analysis could guide proactive conservation interventions before species reach critical endangerment levels. However, significant research is needed to understand the effectiveness and potential risks of these novel conservation approaches.

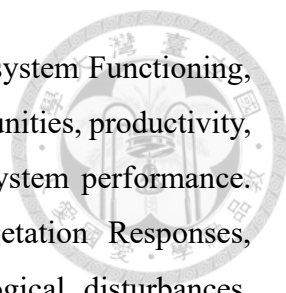
2.6 Conceptual Framework of the Study

This study adopts an analytical conceptual framework that connects the research questions, bibliometric procedures, thematic clusters, interpretation of findings, and development of recommendations. The framework does not propose causal relationships among ecological variables. Instead, it explains the logical process through which bibliographic data are transformed into evidence concerning the structure, challenges, enabling factors, implications, and future priorities of long-term plant conservation research.

The framework begins with the scientific publications retrieved from the Web of Science Core Collection. After the records are screened, standardized, and prepared for analysis, their bibliographic information and author keywords provide the evidence base for the study. The first level of analysis examines the bibliometric characteristics and publication patterns of the selected literature, thereby addressing Research Question 1. This stage establishes the general structure and development of the research field.

The second level applies keyword co-occurrence analysis to identify frequently occurring concepts and relationships among research topics. VOSviewer is used to map the keyword network and group strongly related terms into thematic clusters. This stage addresses Research Question 2 by identifying the dominant keywords, thematic relationships, and principal research clusters within the long-term plant conservation literature.

The keyword co-occurrence analysis organizes the literature into four interrelated thematic clusters. Cluster 1, Biodiversity Conservation, Management, and Ecosystem Services, represents research concerning biodiversity protection, conservation management, ecological restoration, protected areas, land use, and the benefits that



ecosystems provide to society. Cluster 2, Species Diversity and Ecosystem Functioning, covers research on species richness, plant diversity, ecological communities, productivity, stability, biomass, and relationships between biodiversity and ecosystem performance. Cluster 3, Climate Change, Environmental Dynamics, and Vegetation Responses, encompasses research examining climate-related pressures, ecological disturbances, environmental change, vegetation dynamics, species responses, and ecosystem resilience. Cluster 4, Biodiversity Monitoring, Population Trends, and Ecological Indicators, represents research focusing on species abundance, population change, ecological monitoring, biodiversity loss, indicators, habitat quality, and long-term environmental assessment.

These clusters are not interpreted as isolated or causal categories. Their close positioning and interconnected links in the keyword network demonstrate that the major themes of plant conservation research overlap. For example, climate change may influence plant diversity and ecosystem functioning, while monitoring and ecological indicators provide evidence for conservation management and restoration. The clusters therefore provide an integrated representation of the major areas through which long-term plant conservation has been investigated.

The literature and keywords represented within and across the four clusters are subsequently subjected to qualitative thematic interpretation. This stage moves beyond describing the structure of the keyword network and examines the scientific meaning of the identified themes. The interpretation is used to identify the principal challenges affecting long-term plant conservation, thereby addressing Research Question 3. These challenges include biodiversity loss, habitat degradation, land-use pressure, climate related disturbance, declining populations, ecological instability, and limitations in long-term monitoring and conservation information.

The same thematic evidence is examined to identify the factors that enable effective long-term plant conservation, addressing Research Question 4. These enabling factors include conservation management, ecological restoration, protected areas, ecosystem-service approaches, the maintenance of plant and species diversity, adaptive responses to environmental change, long-term monitoring, and the application of ecological indicators. The identification of challenges and enabling factors is based on scholarly interpretation

of the publications represented by the clusters rather than on cluster colours or keyword frequencies alone.

The findings concerning challenges and enabling factors are then integrated to address Research Question 5. This synthesis considers how the identified factors influence biodiversity preservation, ecosystem functioning, resilience, and the long-term sustainability of plant communities. It recognizes that successful plant conservation depends on the interaction of ecological knowledge, effective management, climate adaptation, restoration, monitoring, and evidence-based decision-making.

Finally, the combined bibliometric and thematic findings provide the basis for addressing Research Question 6. Evidence obtained from the publication patterns, keyword relationships, thematic clusters, conservation challenges, and enabling factors is used to formulate recommendations for future research, conservation policy, planning, management, and monitoring. In this way, the conceptual framework maintains a clear progression from the scientific literature and quantitative analysis to thematic interpretation, integrated implications, and evidence-based recommendations.

Overall, Research Questions 1 and 2 are addressed primarily through quantitative bibliometric and keyword co-occurrence analysis. Research Questions 3 and 4 are addressed through qualitative interpretation of the literature represented within and across the four thematic clusters. Research Questions 5 and 6 integrate the quantitative and qualitative findings to explain their broader significance and translate the evidence into recommendations for research and conservation practice. This framework therefore ensures alignment among the research questions, analytical methods, findings, discussion, and conclusions of the study.

Chapter 3: Methodology

3.1 Research Design

This study adopted a quantitative bibliometric research design supplemented by qualitative thematic interpretation to examine the conceptual organization of scientific literature related to long-term plant conservation. The design was selected because bibliometric methods enable the systematic examination of a large body of publications, while qualitative interpretation provides a basis for explaining the conservation significance of the patterns identified in the bibliometric results (Donthu et al., 2021; Zupic & Čater, 2015).

Bibliometric analysis uses publication metadata to examine the structure and development of scientific knowledge. Unlike a conventional narrative review, which primarily depends on the manual selection and interpretation of individual studies, bibliometric analysis applies quantitative procedures to identify recurring concepts, relationships among research topics, and the broader intellectual structure of a research field (Aria & Cuccurullo, 2017; Donthu et al., 2021). This approach was considered appropriate because plant-conservation research extends across ecology, biodiversity science, environmental management, restoration, climate-change research, and biodiversity monitoring.

Within the bibliometric framework, keyword co-occurrence analysis was used as the principal science-mapping technique. Keyword co-occurrence analysis examines how frequently keywords appear together within the same publications. Terms that repeatedly occur together are treated as conceptually related, allowing the principal themes and relationships within a scientific field to be represented as a network (Callon et al., 1983; van Eck & Waltman, 2010).

VOSviewer version 1.6.20 was used to construct and visualize the keyword cooccurrence network. The software calculated keyword occurrences, links, total link strengths, network positions, and cluster memberships. It also generated network and density visualizations of the retained keywords. Detailed explanations of keyword preparation, threshold selection, network construction, and clustering procedures are provided in the subsequent sections of this chapter.

The clusters generated by VOSviewer represent groups of keywords with comparatively strong co-occurrence relationships. However, the software does not independently

determine the substantive meaning of those clusters. Qualitative thematic interpretation was therefore used to examine the most frequent and strongly connected keywords within each cluster and assign a descriptive name representing its dominant conceptual orientation.

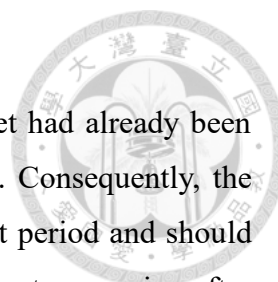
The study distinguishes between computational results and researcher interpretation. Keyword occurrences, links, total link strengths, network positions, and cluster memberships are quantitative outputs generated by VOSviewer. In contrast, the cluster names and their interpretation in relation to conservation themes, challenges, enabling factors, and research priorities were developed through qualitative examination of the keywords and relevant literature. These interpretations represent patterns within the selected scientific literature and should not be treated as direct measurements of conservation effectiveness or causal relationships.

The research process consisted of four general stages: collection of bibliographic records from the Web of Science Core Collection, preparation and standardization of the bibliographic data, construction of the keyword co-occurrence network in VOSviewer, and qualitative interpretation of the resulting clusters. The procedures applied at each stage are described in the remainder of Chapter 3, while the numerical and visual outputs are reported in Chapter 4.

3.1.1 Data Collection and Literature Selection

The search was restricted to publications issued between 2012 and 2020. This period was selected to provide a defined and internally consistent dataset through which the development of plant-conservation research could be examined. The nine-year period captures research published during a time of increasing international attention to biodiversity loss, ecosystem restoration, climate-change adaptation, biodiversity monitoring, and technology-assisted conservation.

In this study, the term “long-term” refers primarily to the sustained conservation of plant diversity, populations, habitats, ecological processes, and institutional arrangements over extended ecological and management timescales. It does not mean that the bibliometric dataset covers the entire historical development of plant conservation science. The 2012–2020 publication period represents the temporal boundary of the literature sample, whereas “long-term plant conservation” represents the substantive conservation problem investigated in the selected publications.



Literature published after 2020 was not included because the dataset had already been compiled and standardized using the defined 2012–2020 boundary. Consequently, the findings represent the structure of the literature available within that period and should not be interpreted as a complete representation of research developments occurring after 2020. The exclusion of more recent publications is recognized as a temporal limitation of the study.

The quality and reliability of bibliometric research depend fundamentally on the systematic selection of an appropriate and reproducible literature dataset. Accordingly, this study adopted a structured literature retrieval and screening procedure designed to ensure transparency, consistency, and methodological rigor throughout the data collection process. The procedure comprised four sequential stages: **(i)** identification of an appropriate bibliographic database, **(ii)** development of a comprehensive search strategy, **(iii)** systematic literature screening following the principles of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), and **(iv)** application of predefined inclusion and exclusion criteria to construct the final bibliographic dataset used for bibliometric analysis (Page et al., 2021; Donthu et al., 2021).

Although bibliometric studies generally rely upon quantitative analysis of publication metadata rather than full systematic reviews, increasing methodological literature recommends adopting PRISMA principles during literature retrieval because they improve reproducibility, reduce selection bias, and enhance methodological transparency (Page et al., 2021; Donthu et al., 2021). Therefore, the present study incorporated PRISMA-based reporting throughout the literature selection process to provide a clear and systematic description of how the final dataset was established prior to bibliometric analysis.

These analytical stages operationalize the conceptual framework presented in Section 2.6 by linking the research questions to the bibliometric results, thematic clusters, qualitative interpretation, integrated findings, and final recommendations.

3.1.2 Data Source

The bibliographic records analyzed in this study were retrieved exclusively from the **Web of Science Core Collection (WoSCC)**. The Web of Science was selected because it is one of the most authoritative multidisciplinary scientific databases and is widely regarded

as the benchmark data source for bibliometric and science mapping research due to its comprehensive coverage of high-quality peer-reviewed literature, standardized indexing system, and compatibility with leading bibliometric software packages such as VOSviewer and bibliometrix (Mongeon & Paul-Hus, 2016; Donthu et al., 2021; Aria & Cuccurullo, 2017).

Compared with other bibliographic databases, the Web of Science provides consistently structured citation metadata, standardized author keywords, institutional affiliations, and publication information that facilitate reliable network construction and keyword cooccurrence analysis (van Eck & Waltman, 2010). Its rigorous journal selection criteria further improve data quality by minimizing inconsistencies arising from duplicate records, incomplete metadata, or non-peer-reviewed publications. Consequently, numerous bibliometric studies in environmental science, sustainability, ecology, and conservation biology have adopted the Web of Science Core Collection as their primary source of bibliographic data (Donthu et al., 2021; Zupic & Čater, 2015).

The literature search was conducted using the **Topic Search (TS)** function of the Web of Science Core Collection, which searches publication titles, abstracts, author keywords, and Keywords Plus simultaneously. This search strategy was selected because it provides comprehensive retrieval of publications directly relevant to the research topic while maintaining consistency with established bibliometric research practices (Aria & Cuccurullo, 2017).

3.1.3 PRISMA Literature Selection Procedure

To improve methodological transparency and ensure systematic reporting of the literature selection process, this study adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. Although the study employed bibliometric methods rather than a traditional systematic review, the PRISMA framework provides a structured approach for documenting literature identification, screening, eligibility assessment, and final inclusion.

The literature selection process consisted of four stages:

Identification: Relevant publications were retrieved from the Web of Science Core Collection database using predefined search terms related to plant conservation, biodiversity conservation, ecosystem preservation, habitat restoration, ecological restoration, and long-term conservation.

Screening: Retrieved records were screened to remove duplicate entries, incomplete records, and publications that did not satisfy the language and document-type requirements.

Eligibility Assessment: The remaining records were evaluated based on their titles, abstracts, and keywords to determine their relevance to long-term plant conservation research.

Included Studies: Publications meeting all inclusion criteria were retained for bibliometric analysis and imported into VOSviewer for keyword co-occurrence analysis and thematic mapping.

Because the study was designed primarily as a bibliometric analysis rather than a systematic review, detailed record counts for each intermediate screening stage were not retained during the initial data collection process. Nevertheless, the PRISMA framework is presented to illustrate the literature selection workflow adopted in this study. The framework provides transparency regarding the identification, screening, eligibility assessment, and inclusion procedures used to construct the final bibliometric dataset.

The final dataset consisted of 1,000 publications that satisfied the predefined inclusion criteria and were subsequently subjected to bibliometric and keyword co-occurrence analysis using VOSviewer.

Figure 1. shows the data selection and procedure.

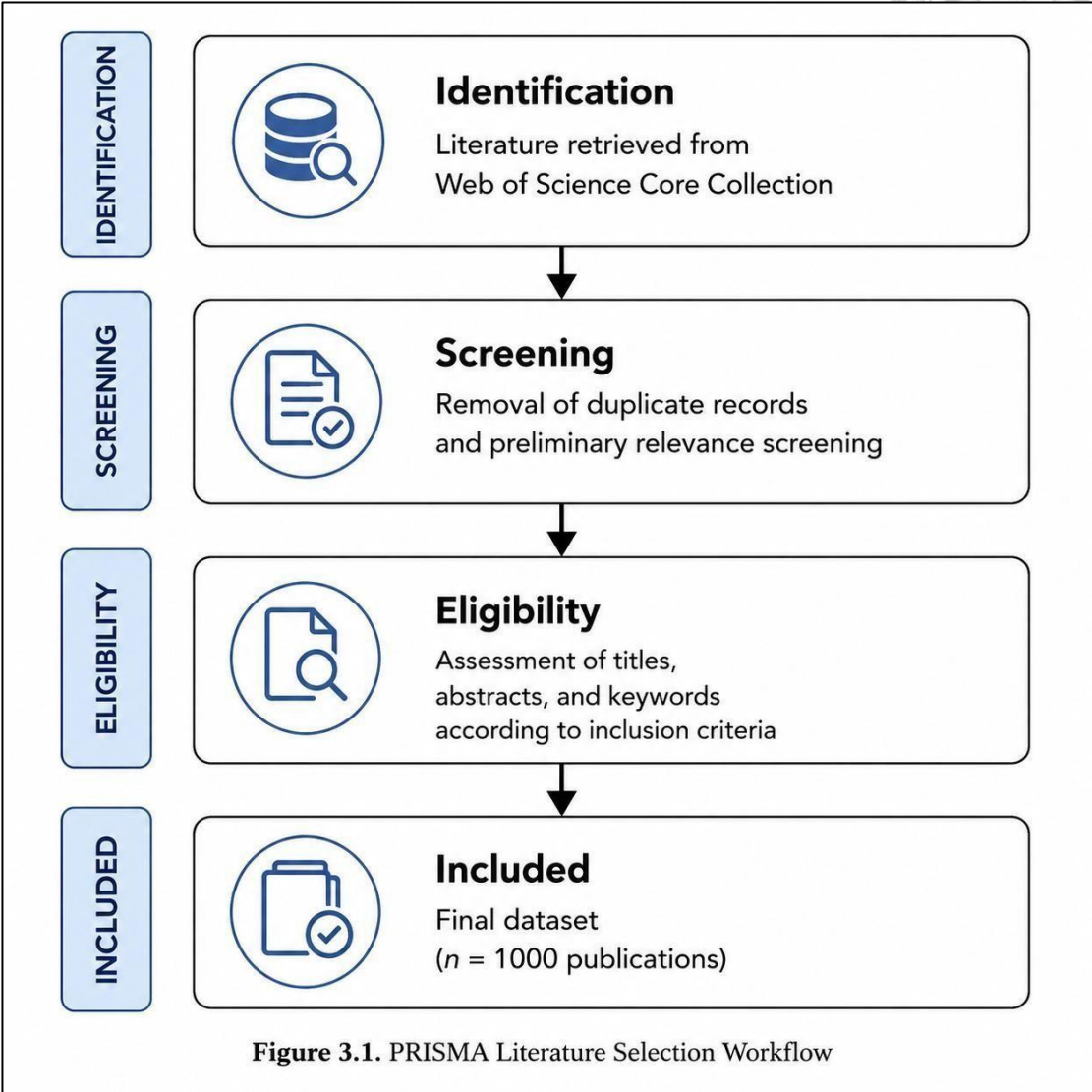


Figure 1. Data selection criteria and procedure

3.2 Data Analysis Procedure

Following the construction of the bibliometric dataset, the collected records were analyzed using VOSviewer (Version 1.6.20), a specialized software tool designed for bibliometric mapping and visualization. The software was used to examine keyword relationships and identify thematic structures within the literature on long-term plant conservation.

The analytical process consisted of four sequential stages: data preparation, keyword cooccurrence analysis, cluster generation, and visualization interpretation.

3.2.1 Data Preparation and Keyword Standardization

Following the literature retrieval and screening process, the final bibliographic dataset of 1,000 peer-reviewed publications was exported from the Web of Science Core Collection in plain-text format. The exported records included publication titles, abstracts, authors, institutional affiliations, publication years, author keywords, Keywords Plus, cited references, and citation metadata. These bibliographic elements provided the information required to construct the keyword co-occurrence network and examine the conceptual structure of long-term plant conservation research (Aria & Cuccurullo, 2017; Donthu et al., 2021).

Before importing the records into VOSviewer, the keyword data were cleaned and standardized. This step was necessary because bibliographic databases frequently contain different written forms of the same concept. These variations may result from differences in capitalization, spelling, punctuation, hyphenation, abbreviation, or singular and plural forms. If such variations are not standardized, VOSviewer treats them as separate nodes, thereby dividing their occurrence frequencies and link strengths and potentially producing misleading clusters (van Eck & Waltman, 2010).

A VOSviewer thesaurus file was used to standardize equivalent keyword expressions. The thesaurus file contained a “label” column showing the original keyword and a “replace by” column specifying the standardized term. Keyword replacement was completed before network construction so that occurrence frequencies and cooccurrence relationships were calculated using the standardized terminology.

Keywords were merged only when they were judged to be semantically equivalent. These included differences caused by hyphenation, punctuation, spelling, capitalization, and grammatical number. For example, “climate-change” and “climate change” were treated as the same concept and standardized as “climate change.” Similarly, “species diversity” was standardized as “species diversity.” Singular and plural variants, such as “ecosystem” and “ecosystems,” were merged when examination of their use showed that they represented the same scientific concept.

Keywords were not merged merely because they were related or frequently appeared together. Terms were retained separately when they represented different concepts, different analytical levels, or different degrees of specificity. For example, “biodiversity,” “conservation,” and “biodiversity conservation” were retained as distinct terms because

biodiversity refers to biological variation, conservation refers to the broader process of protection and management, and biodiversity conservation represents a more specific field of action. Similarly, “management” and “forest management” were retained separately because the latter refers to a particular management context.

The same principle was applied to terms such as “monitoring” and “biodiversity monitoring,” “diversity” and “plant diversity,” and “restoration” and “ecological restoration.” Although the terms within each pair are conceptually related, merging them would remove meaningful differences in their scientific scope. The decision to merge or separate keywords was therefore based on semantic equivalence rather than visual similarity, frequent co-occurrence, or the researcher’s preferred cluster structure.

Very general expressions and terms with limited relevance to the study were excluded when they did not represent substantive plant-conservation concepts. However, methodological terms were retained when they represented an identifiable area of conservation research, such as biodiversity monitoring, predictive modelling, or long-term ecological assessment. This ensured that keyword cleaning reduced unnecessary noise without removing concepts relevant to the research questions.

After standardization, the cleaned bibliographic records were imported into VOSviewer Version 1.6.20. Author keywords were selected as the primary unit of analysis because they directly represent the concepts emphasized by the authors of the selected publications. Keywords Plus and other automatically generated indexing terms were not combined with the author-keyword network because doing so could introduce terms that were not explicitly selected by the publication authors.

A minimum keyword-occurrence threshold was subsequently applied. Keywords meeting the threshold were retained for analysis, whereas terms occurring too infrequently to form stable and interpretable relationships were excluded. The threshold was used to balance thematic coverage with network readability and to prevent the visualization from being dominated by isolated or weakly connected terms. The retained and standardized keywords formed the basis for the subsequent co-occurrence calculations, network construction, and cluster analysis.

3.2.2 Keyword Co-occurrence Analysis

Keyword co-occurrence analysis constituted the principal bibliometric technique employed in this study to investigate the conceptual structure of scientific literature on long-term plant conservation. Unlike citation-based analyses, which examine relationships among publications through citation patterns, keyword co-occurrence analysis investigates conceptual relationships by measuring the frequency with which author keywords appear together within individual publications (Callon et al., 1983; van Eck & Waltman, 2010). The underlying assumption is that keywords which frequently co-occur represent closely related scientific concepts and collectively define the principal thematic areas within a research field (Donthu et al., 2021; Zupic & Čater, 2015).

After importing the cleaned bibliographic dataset into VOSviewer, the software extracted all author-provided keywords from the selected publications. Each unique keyword was treated as an individual node within the bibliometric network, while simultaneous appearances of two keywords within the same publication were recorded as co-occurrence relationships. The frequency of these relationships formed the basis for constructing a keyword co-occurrence matrix that quantitatively represented the conceptual connectivity among research topics within the literature (van Eck & Waltman, 2010).

The strength of association between pairs of keywords was subsequently quantified through the calculation of **co-occurrence frequency** and **Total Link Strength (TLS)**. Co-occurrence frequency represents the number of publications in which two keywords appear together, whereas Total Link Strength measures the cumulative strength of a keyword's connections with all other keywords in the network (van Eck & Waltman, 2010; Waltman et al., 2010). Keywords exhibiting high occurrence frequencies and greater Total Link Strength values generally occupy more central positions within the network and represent dominant concepts that have stronger conceptual relationships across the literature. In the present study, keywords such as *biodiversity*, *conservation*, *diversity*, *species richness*, and *management* exhibited the highest occurrence frequencies and network connectivity, indicating their central role within the intellectual structure of long-term plant conservation research. These values were generated directly by VOSviewer from the bibliographic dataset and formed the basis for subsequent network visualization and cluster detection.

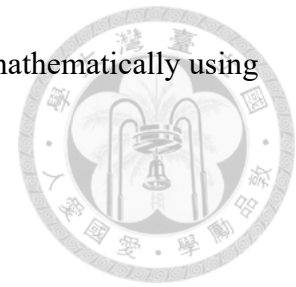
The conceptual relationship between keywords can be represented mathematically using the co-occurrence matrix:

where:

- C_{ij} represents the co-occurrence frequency between keywords i and j ;
- $x_{ik} = 1$ if keyword i appears in publication k , and 0 otherwise;
- $x_{jk} = 1$ if keyword j appears in publication k , and 0 otherwise;
- N denotes the total number of publications included in the dataset.

The resulting co-occurrence matrix was subsequently normalized using the **Visualization of Similarities (VOS)** mapping technique implemented within VOSviewer. This normalization procedure transforms raw co-occurrence frequencies into similarity measures by accounting for differences in keyword occurrence frequencies, thereby ensuring that highly frequent keywords do not dominate the overall network structure solely because of their prevalence (van Eck & Waltman, 2010). The normalized similarity matrix forms the mathematical foundation upon which network visualization and cluster detection are performed.

Unlike conventional statistical analyses that examine variables independently, keyword co-occurrence analysis evaluates the collective relationships among all keywords simultaneously, enabling the identification of interconnected thematic structures rather than isolated research topics. Consequently, the generated network represents the conceptual organization of the scientific literature rather than simple keyword frequencies. It is important to emphasize that the output generated by VOSviewer consists of objectively calculated keyword relationships, similarity values, and thematic clusters. The software does not assign scientific meaning to these clusters. Instead, interpretation of the identified thematic structures including the classification of conservation challenges, enabling factors, research priorities, and implications for biodiversity conservation was conducted separately through qualitative thematic interpretation based on an in-depth review of the literature associated with each cluster. This distinction between computational analysis and researcher interpretation enhances methodological transparency and ensures that the bibliometric results are interpreted within an appropriate theoretical context.



3.2.3 Network Construction

Following the calculation of keyword co-occurrence frequencies and similarity measures, the conceptual network of long-term plant conservation research was constructed using the **Visualization of Similarities (VOS)** mapping technique implemented within **VOSviewer (Version 1.6.20)**. Network construction represents the stage at which bibliometric relationships are transformed into a graphical representation that enables the visualization of the conceptual organization of scientific knowledge (van Eck & Waltman, 2010). Rather than presenting keywords as isolated concepts, the network illustrates the structural relationships among research topics based on their frequency of co-occurrence throughout the bibliographic dataset.

Within the generated network, each **node** represents an individual author keyword extracted from the selected publications, while each **link** represents a co-occurrence relationship between two keywords appearing together within one or more publications. The thickness of each connecting line reflects the strength of the relationship between keyword pairs, with thicker links indicating higher co-occurrence frequencies and stronger conceptual associations (van Eck & Waltman, 2010; Waltman et al., 2010).

Similarly, the size of each node is proportional to the occurrence frequency of the corresponding keyword, enabling highly investigated research topics to be readily distinguished from less frequently studied concepts.

The spatial arrangement of nodes within the visualization is determined using the **Visualization of Similarities (VOS)** mapping algorithm. Unlike conventional graph layouts that primarily seek visual clarity, the VOS algorithm positions keywords according to their normalized similarity values so that conceptually related keywords are located closer together within the two-dimensional network, whereas less strongly associated concepts appear farther apart (van Eck & Waltman, 2010). Consequently, the distance between nodes provides an approximate indication of conceptual relatedness rather than physical measurement. Keywords that occupy central positions within the network generally exhibit stronger relationships with numerous other concepts and therefore represent highly influential research themes within the scientific literature.

After positioning the keywords within the network, VOSviewer applies its weighted, modularity-based clustering algorithm to identify groups of closely connected keywords. The normalization and clustering procedures, including the function of the resolution

parameter, are explained in Section 3.2.4. Each cluster represents a collection of concepts that frequently occur together and therefore indicate a coherent thematic area within the broader research field. Individual clusters are displayed using different colours to facilitate visual distinction between thematic domains while preserving the underlying network connectivity. It is important to emphasize that these clusters are generated objectively through computational optimization of keyword relationships rather than through subjective classification by the researcher. Their scientific interpretation is conducted separately during the qualitative thematic analysis presented in Chapter 5.

The generated network additionally provides several quantitative indicators that support subsequent analysis of the conceptual structure of the literature. These include **keyword occurrence frequency**, **Total Link Strength (TLS)**, **cluster membership**, and **network coordinates**, each of which contributes to understanding the relative importance and interconnectedness of research topics. Occurrence frequency reflects the number of publications in which a keyword appears, Total Link Strength measures the cumulative strength of a keyword's relationships with all other keywords, cluster membership identifies the thematic grouping assigned by the clustering algorithm, and network coordinates determine the graphical placement of nodes within the visualization (van Eck & Waltman, 2010). Collectively, these indicators provide objective evidence regarding the structural organization of the scientific literature and constitute the primary outputs used in subsequent visualization and interpretation.

The resulting keyword network provides a comprehensive representation of the intellectual landscape of long-term plant conservation research by illustrating how scientific concepts are interconnected across the literature. However, while network construction objectively reveals conceptual relationships and thematic groupings, it does not independently explain their scientific significance. Consequently, the constructed network serves as the empirical foundation for subsequent visualization analyses and qualitative thematic interpretation, through which the identified clusters are examined in relation to conservation challenges, enabling factors, research priorities, and implications for biodiversity preservation.

3.2.4 VOSviewer Clustering Algorithm and Cluster Interpretation

After constructing the normalized keyword co-occurrence network, VOSviewer applied its clustering algorithm to divide the retained keywords into groups of closely related

terms. Clustering and mapping are related but distinct procedures. The mapping algorithm determines the spatial position of keywords in the visualization, whereas the clustering algorithm assigns each keyword to a particular group according to the pattern and strength of its connections.

Before clustering, VOSviewer normalizes the raw co-occurrence values using the association-strength method. Raw co-occurrence counts alone may overemphasize frequently occurring keywords because such terms are likely to occur with many other keywords. Association-strength normalization adjusts the relationship between two keywords according to their respective occurrence frequencies. The association strength between keywords i and j can be expressed as: $AS_{ij} = C_{ij} \div (W_i \times W_j)$ where:

- AS_{ij} is the normalized association strength between keywords i and j ; • C_{ij} is the number of publications in which keywords i and j occur together; and
- W_i and W_j are the total occurrence weights of keywords i and j , respectively.

This normalization prevents keywords from being considered strongly related merely because they occur frequently throughout the dataset. Instead, it emphasizes whether two terms co-occur more strongly than would be expected based on their individual occurrence frequencies (van Eck & Waltman, 2010).

VOSviewer subsequently applies a weighted, modularity-based clustering procedure to the normalized network. The algorithm seeks a clustering solution in which keywords assigned to the same cluster have comparatively strong relationships with one another, while relationships between keywords assigned to different clusters are comparatively weaker. The algorithm evaluates the complete pattern of normalized links rather than assigning keywords according to a single connection or according to their spatial position alone (Waltman et al., 2010).

Cluster membership therefore depends on the overall network position of each keyword. A keyword may have links with terms in several clusters but is assigned to the cluster with which it has the strongest overall pattern of association. Consequently, the clusters should not be interpreted as completely independent categories. Connections between clusters are expected because research themes in plant conservation frequently overlap.

For example, keywords concerning climate change may be connected to terms concerning species diversity, ecological monitoring, restoration, and conservation management.

The clustering algorithm includes a resolution parameter that controls the level of detail in the resulting solution. Higher resolution values tend to generate a larger number of smaller clusters, whereas lower values tend to generate fewer and broader clusters. The standard resolution value of 1.00 was retained in the present analysis to avoid manually forcing the network to produce a predetermined number of groups. The resulting number and composition of clusters were therefore determined by the structure of the normalized keyword network rather than by a prior assumption about how many conservation themes should be identified.

Cluster colours were assigned automatically by VOSviewer to distinguish the groups visually. These colours do not indicate cluster importance, scientific quality, chronological order, or causal relationships. Similarly, cluster numbers are identifiers only and should not be interpreted as rankings. Node size, occurrence frequency, total link strength, and the internal and external connections of each keyword provide the relevant quantitative information for interpreting the network.

The researcher did not manually move keywords between clusters or combine computationally generated clusters after the VOSviewer analysis. Researcher judgment was applied during keyword standardization before network construction and during thematic interpretation after cluster generation. This separation was maintained to prevent subjective expectations from altering the computational structure of the network.

After VOSviewer generated the clusters, each group was examined using its complete keyword membership, occurrence frequencies, total link strengths, and strongest internal and external connections. Particular attention was given to keywords that were frequent, strongly connected, and centrally positioned within each group. A descriptive thematic name was then assigned to each cluster based on the shared conceptual orientation of its most prominent keywords.

The thematic names were therefore interpretive summaries rather than labels produced automatically by VOSviewer. A cluster was not named solely according to its largest keyword because a single term might not adequately represent the range of concepts contained in the group. Instead, the name was selected after considering several prominent

terms and examining the conservation literature associated with them. The number of clusters, cluster membership, keyword counts, occurrence values, total link strengths, colours, and descriptive cluster names are reported as results in Chapter 4. Their conservation significance, relationships, challenges, enabling factors, and implications are discussed in Chapter 5.

It is important to distinguish keyword merging from cluster formation. Before the network was constructed, semantically equivalent keyword variants were consolidated through the thesaurus-based standardization procedure described in Section 3.2.1. For example, differences caused only by hyphenation, punctuation, spelling, or grammatical number were standardized under a preferred term. This preprocessing step was conducted to prevent the same concept from appearing as several separate nodes.

The clusters themselves were not manually merged or reorganized by the researcher. After keyword standardization and application of the minimum occurrence threshold, VOSviewer applied its clustering algorithm to the finalized co-occurrence network and produced four clusters directly. Each retained keyword was assigned to one of the four clusters according to the overall strength and pattern of its normalized co-occurrence relationships. The researcher did not move individual keywords between clusters or combine computationally generated clusters after the analysis.

Any maps produced during preliminary testing were exploratory outputs generated before the final keyword-cleaning rules and analytical settings were established. They were not treated as intermediate clusters that were subsequently merged. Only the network produced from the finalized dataset, standardized thesaurus file, occurrence threshold, and clustering settings was retained for reporting. Therefore, the four clusters presented in Chapter 4 represent the direct output of the final VOSviewer analysis.

The researcher's involvement occurred after cluster generation and was limited to assigning descriptive thematic names. These names were developed by examining the keywords with the highest occurrence frequencies and total link strengths in each cluster. Assigning a thematic name did not alter the membership, number, colour, or structure of the computationally generated clusters.

3.2.5 Network Visualization

Network visualization was employed as the primary graphical representation of the keyword co-occurrence network generated through VOSviewer. This visualization provides a comprehensive overview of the conceptual structure of the literature by displaying keywords as interconnected nodes and illustrating the relationships among research topics based on their co-occurrence within scientific publications (van Eck & Waltman, 2010). Network visualization enables researchers to examine the overall organization of a scientific field by simultaneously presenting keyword frequency, conceptual proximity, relationship strength, and thematic cluster membership within a single analytical framework.

Within the network visualization, each node represents an individual author keyword extracted from the bibliographic dataset. The size of each node is proportional to the occurrence frequency of the corresponding keyword, with larger nodes representing concepts that appear more frequently throughout the literature. Consequently, node size provides an indication of the relative prominence of individual research topics within the scientific domain (van Eck & Waltman, 2010). In the present study, highly connected keywords occupy larger nodes, reflecting their dominant role within the conceptual structure of long-term plant conservation research.

The connections between nodes represent keyword co-occurrence relationships. Each connecting line, or link, indicates that two keywords appear together within one or more publications. The thickness of the link corresponds to the strength of the conceptual relationship, with thicker lines representing stronger co-occurrence frequencies and greater conceptual association (Waltman et al., 2010). Keywords connected by numerous strong links generally represent closely related research topics that frequently occur together throughout the literature.

The spatial arrangement of nodes within the visualization is determined by the Visualization of Similarities (VOS) mapping algorithm. Keywords exhibiting stronger normalized similarity values are positioned closer together, whereas less strongly associated keywords are located further apart. As a result, the distance between nodes provides a graphical approximation of conceptual similarity rather than geographical or numerical distance (van Eck & Waltman, 2010). This spatial organization enables

researchers to identify groups of related concepts and observe the overall intellectual structure of the research field.

Network visualization also incorporates automatic cluster identification through colour coding. Each colour represents a distinct thematic cluster generated by the VOSviewer clustering algorithm. These clusters consist of groups of keywords that exhibit stronger internal relationships with one another than with keywords belonging to other clusters, thereby representing coherent conceptual domains within the literature (Waltman et al., 2010). Importantly, these coloured clusters constitute computational groupings based solely on bibliometric relationships. Their scientific interpretation requires subsequent qualitative examination of the literature represented by each cluster and is therefore presented separately in Chapter 5.

Within the present study, network visualization served as the initial stage of bibliometric exploration by providing an overall representation of the conceptual organization of long-term plant conservation research. Rather than drawing substantive conclusions directly from the visualization, the network map functioned as the empirical foundation for subsequent analyses using overlay visualization and density visualization, which provided additional perspectives on the temporal development and research intensity of the identified thematic structures.

3.2.6 Overlay Visualization

Overlay visualization was employed to examine temporal patterns within the literature. This visualization technique assigns colours according to the average publication year associated with each keyword.

Keywords associated with earlier publications appear in cooler colours, whereas keywords associated with more recent publications appear in warmer colours. Overlay visualization enables the identification of emerging research themes and evolving areas of scholarly interest within plant conservation research.

3.2.7 Density Visualization

Density visualization was used to identify areas of high research concentration within the bibliometric network. The density map represents the frequency and connectivity of keywords through colour intensity.

Areas with higher concentrations of frequently occurring and strongly connected keywords appear with greater visual density, indicating dominant research hotspots within the literature.

The density visualization provides insight into the relative prominence of different research themes and highlights areas receiving substantial scholarly attention.

3.2.8 Thematic Interpretation

While VOSviewer was used to generate keyword co-occurrence networks, thematic clusters, overlay visualizations, and density maps, the identification of conservation challenges, enabling factors, and implications for biodiversity preservation and ecosystem sustainability required additional interpretive analysis.

Following the generation of thematic clusters, the researcher conducted a qualitative thematic interpretation of the bibliometric results. Keywords within each cluster were examined collectively to identify recurring concepts, research priorities, and thematic patterns represented in the literature.

Through this interpretive process, broader categories related to conservation challenges and conservation enablers were identified and synthesized. These interpretations were subsequently used to evaluate the implications of the literature for biodiversity preservation, ecosystem sustainability, and future conservation practice.

Accordingly, the findings presented in Chapters 4 and 5 represent a combination of bibliometric visualization generated through VOSviewer and researcher-led thematic interpretation based on the identified clusters and keyword relationships.

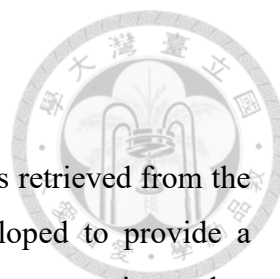
3.2.9 Analytical Outputs

The analytical procedure generated three principal VOSviewer outputs: a network visualization, an overlay visualization, and a density visualization. The network visualization was used to examine relationships among frequently occurring keywords and identify groups of closely associated terms. The overlay visualization was used to examine differences in the average publication year of the selected keywords, while the density visualization was used to identify areas of comparatively high and low keyword concentration within the network.

The clustering algorithm assigned each retained keyword to a thematic group based on the strength of its co-occurrence relationships with other keywords. These

computationally generated groups were subsequently examined through qualitative thematic interpretation. Cluster names were assigned only after reviewing the keywords contained in each group, their relative occurrence frequencies, their total link strengths, and the substantive literature associated with the most prominent terms.

The number, composition, colours, keyword counts, and thematic interpretation of the resulting clusters are presented in Chapter 4. Keeping these outputs in the results chapter maintains a clear distinction between the procedures used to conduct the analysis and the findings produced by those procedures.



Chapter 4: Results

4.1 Bibliometric Overview of the Literature

The bibliometric analysis was conducted using scientific publications retrieved from the Web of Science Core Collection database. The dataset was developed to provide a comprehensive representation of research related to long-term plant conservation and to support the identification of dominant research themes, conservation challenges, and enabling factors within the scientific literature.

Following the application of the search strategy, screening procedures, and inclusion criteria described in Chapter 3, a final dataset consisting of 1,000 peer-reviewed journal articles was retained for analysis. The dataset comprised publications relevant to plant conservation, biodiversity preservation, ecosystem management, ecological restoration, conservation monitoring, and related environmental sustainability topics.

The selected publications were subjected to bibliometric analysis using VOS viewer software. The software facilitated the examination of keyword relationships and enabled the visualization of thematic structures within the literature through keyword cooccurrence analysis. The resulting dataset provided a robust foundation for investigating research trends and identifying major areas of scholarly focus within the field of longterm plant conservation.

Table 1. summarizes the principal characteristics of the bibliometric dataset used in this study.

Table 1. Bibliometric Dataset Characteristics

Indicator	Description
Database	Web of Science Core Collection
Document Type	Peer-reviewed journal articles
Language	English
Analysis Tool	VOS viewer Version 1.6.20
Analysis Method	Bibliometric Analysis and Keyword Co-occurrence Analysis

4.2 Keyword Co-occurrence Network and Cluster Identification

To explore the thematic structure of the literature on long-term plant conservation, a citation network is constructed using VOSviewer. The resulting visualization map displays keyword co-occurrence relationships across 1,000 peer-reviewed articles retrieved from the Web of Science Core Collection. Each node in the map represents a keyword, and each edge indicates a co-occurrence link between terms within the same publication. The map is colour-coded to reflect distinct clusters, each representing a cohesive thematic domain within the broader field of plant conservation.

The final keyword co-occurrence network contained four clusters generated directly by VOSviewer. These clusters were not formed by manually combining smaller groups. Instead, they resulted from applying the clustering algorithm to the finalized network after keyword standardization and threshold selection. VOSviewer assigned each retained keyword to one cluster based on its normalized co-occurrence relationships. The cluster names used in this chapter are descriptive interpretations assigned by the researcher and do not represent modifications to the computational cluster structure. **Four major clusters emerged from the analysis:**

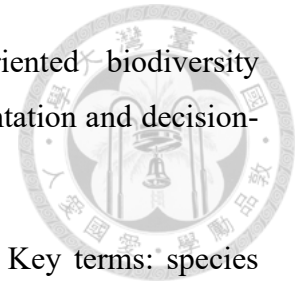
- **Red Cluster 1 – Biodiversity Conservation and Ecosystem Services:** Key terms: biodiversity, conservation, diversity, management, ecosystem services, restoration, protected areas, land-use, ecosystem

Cluster 1 represents the core of biodiversity research, focusing on strategies for conserving biodiversity and managing ecosystems sustainably. This group of studies often addresses how conservation policies, land-use planning, and ecosystem service valuation contribute to the protection of natural habitats.

The presence of terms like “ecosystem services” and “management” reflects the link between ecological preservation and socio-economic benefits, emphasizing a balanced approach to human development and nature conservation.

Keywords such as “restoration” and “protected areas” show strong applied orientations, focusing on rehabilitation of degraded ecosystems, forest protection, and policy frameworks for biodiversity governance.

Overall, this cluster highlights policy-driven, management-oriented biodiversity conservation research, connecting scientific knowledge to implementation and decision-making at global and local levels.



- **Green Cluster 2 – Species Richness & Ecological Communities:** Key terms: species richness, communities, impacts, productivity, plant diversity, species-diversity, richness, stability, variability, biomass.

Cluster 2 captures the ecological and functional dimension of biodiversity, centering on species-level diversity and community structure. Studies in this cluster examine how variations in species richness affect ecosystem functioning, productivity, and stability.

Frequent co-occurrence of terms like “productivity”, “stability”, and “biomass” indicates a focus on biodiversity–ecosystem function relationships (BEF) — exploring how different community compositions enhance resilience and ecological balance.

This cluster often integrates field-based experiments and ecological modeling to analyze environmental impacts on community dynamics.

In short, Cluster 2 represents the ecological foundation of biodiversity science, investigating how biodiversity patterns translate into ecosystem performance and sustainability.

- **Yellow Cluster 3 – Climate Change & Environmental Dynamics:** Key terms: climate change, patterns, dynamics, vegetation, disturbance, growth, responses, ecosystems.

Cluster 3 connects biodiversity research with global environmental change, especially the impacts of climate change on ecosystems.

The emphasis on terms like “climate-change”, “patterns”, and “dynamics” suggests studies modeling spatial and temporal variations in biodiversity and vegetation due to shifting climate conditions.

Keywords such as “disturbance”, “responses”, and “growth” point to investigations into ecosystem adaptation, species responses, and resilience under climatic stressors.

This cluster often employs monitoring and predictive modeling to identify long-term trends in vegetation cover, productivity, and biodiversity loss.

Overall, it portrays the dynamic interplay between climate change and ecological systems, emphasizing the need for adaptive management and mitigation strategies.

- **Blue Cluster 4 – Soil, Function, and Ecosystem Processes:** Featuring terms like *data*, *model*, *prediction*, and *analysis*, this cluster highlights the growing role of computational tools, predictive modeling, and data science in conservation planning and decision-making.

The spatial arrangement and density of nodes within each cluster suggest varying degrees of scholarly interaction and thematic cohesion. The red and green clusters appear most densely connected, indicating high citation activity and conceptual overlap. In contrast, the blue and purple clusters show more peripheral positioning, suggesting emerging or specialized subfields.

This visualization provides a foundational framework for interpreting the intellectual structure of plant conservation literature. It enables the identification of dominant research themes, influential keywords, and potential gaps in interdisciplinary integration. These insights will inform the subsequent analysis of challenges and enablers in long-term plant conservation, as well as guide recommendations for future research directions.

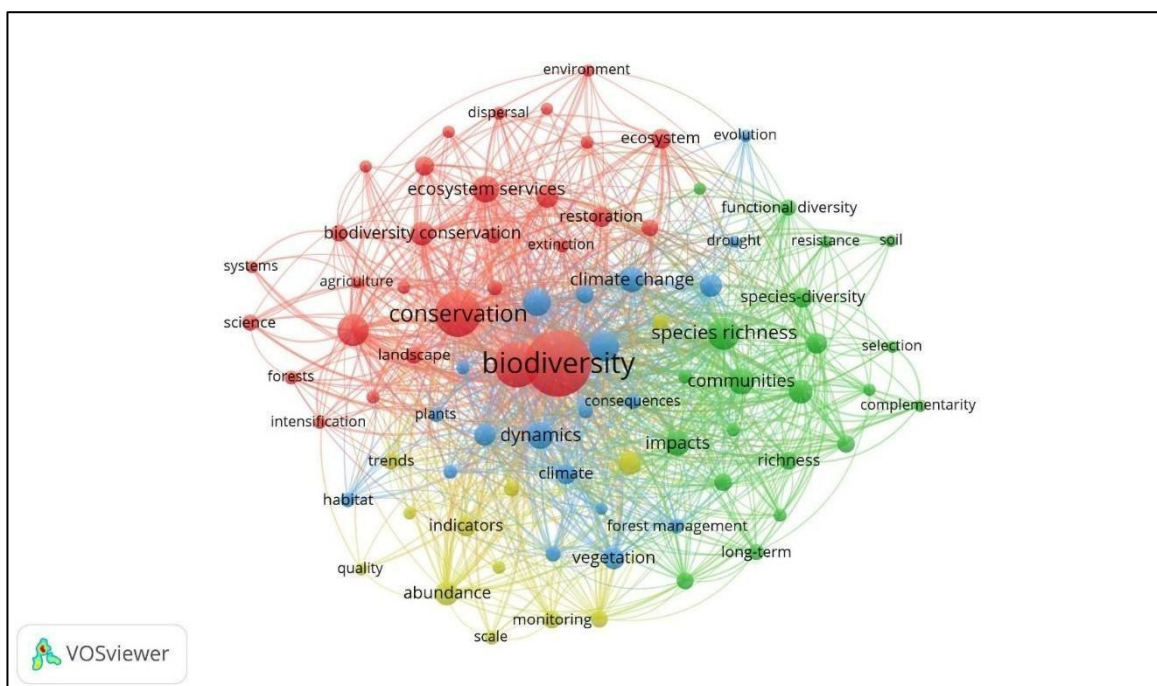


Figure 3. Keyword Co-occurrence Network in Long-Term Plant Conservation Literature (VOSviewer Visualization).

Table 2. Clusters and Relative Keywords Resulting from the Co-occurrence Analysis of Keywords

Cluster 1 (Red) Cluster 2 (Green) Cluster 3 (Blue) Cluster 4 (Yellow)

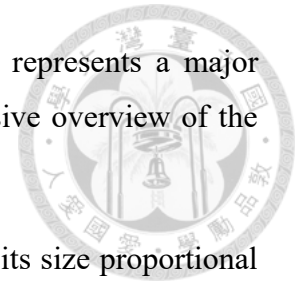
K	O	T	K	O	T	K	O	T	K	O	
biodiversity	439	1324	species richness	102	410	climate-change	90	340	abundance	56	
conservation	213	728	communities	67	283	patterns	75	291	ecology	55	
diversity	212	787	impacts	61	252	dynamics	72	275	indicators	39	
management	99	372	productivity	57	288	climate change	65	249	monitoring	31	
ecosystem services	71	243	plant diversity	45	186	responses	49	194	trends	30	
biodiversity conservation	56	149	species-diversity	39	178	vegetation	47	190	assemblages	28	
land-use		50 196	richness	32	147	disturbance	46	211	biodiversity loss		27
ecosystem		39 145	stability	32	144	climate	41	155	populations		24
restoration		39 131	variability	31	127	growth	33	105	scale		19
protected areas		37 139	biomass	29	119	ecosystems	25	108	biodiversity monitoring		18

K: Keywords; **O:** Co-occurrences (frequency of keywords); **T:** Total link strength (cumulative strength of links with other items).

4.2.1 Visual Presentation of the Research Topic

In the co-occurrence network generated using VOSviewer, the keywords extracted from the bibliometric dataset were systematically grouped into four distinct clusters based on

their thematic similarity and co-occurrence strength. Each cluster represents a major thematic domain within the research field, providing a comprehensive overview of the intellectual structure of long-term plant conservation studies.



The visualization (Figure 1) displays each keyword as a node, with its size proportional to its frequency of occurrence across the dataset. The connecting lines between nodes represent total link strength, indicating the frequency with which keywords co-occurred in the same publication. This approach allows for the identification of conceptual linkages and the relative importance of specific research themes within broader literature.

The dataset analyzed consisted of approximately one thousand peer-reviewed publications related to plant conservation and environmental management. From this body of literature, sixty key terms were extracted and analyzed for their co-occurrence patterns. The analysis revealed four major clusters (Cluster 1: 18 keywords; Cluster 2: 17 keywords; Cluster 3: 13 keywords; Cluster 4: 11 keywords), each reflecting a unique thematic focus (Table 2). These clusters demonstrate the diverse but interconnected nature of research in the field, highlighting how social, ecological, and technological perspectives converge in conservation studies.

Cluster 1 (Red) primarily emphasizes stakeholder engagement, governance, participation, and decision-making frameworks. This cluster reflects the increasing recognition of participatory governance and equity in conservation policy. Cluster 2 (Green) is centered on conservation management, biodiversity protection, and community-based natural resource management, indicating the continued importance of local-level initiatives and ecological restoration efforts. Cluster 3 (Yellow) represents themes associated with adaptation of climate change, resilience, and ecosystem degradation, underscoring the urgency of addressing environmental vulnerabilities and adaptive responses to changing climatic conditions. Finally, Cluster 4 (Blue) focuses on data-driven methodologies such as modeling, risk assessment, and evaluation tools, illustrating the growing reliance on analytical and technological approaches to support evidence-based decision-making.

Overall, the co-occurrence mapping reveals the multidisciplinary nature of long-term plant conservation research. The visualization demonstrates how scientific, social, and data-oriented approaches intersect to address complex environmental challenges. By uncovering the structural relationships among recurring themes, this analysis provides

valuable insights into dominant research trends and emerging areas of inquiry that inform the development of effective conservation strategies.



4.3 VOSviewer Analysis Results

4.3.1 Keyword Visualization Analysis

A total of 1,000 articles were analyzed for keyword co-occurrence. After setting a minimum occurrence threshold of 10 occurrences per keyword, 60 keywords met the threshold criteria and were included in the final analysis.

The keyword co-occurrence network generated: 4 major clusters, 60 keywords, Top keyword “Biodiversity” with 439 occurrences 480 links. Total link strength of 2475

The four clusters represent distinct but interconnected knowledge domains within long-term plant conservation research.

Cluster 1: Climate Change and Species Distribution Modeling This cluster includes frequently occurring keywords such as: Climate change Species, distribution Vulnerability, Adaptation, Ecological niche modeling

This cluster reflects predictive and modeling-based conservation strategies aimed at assessing future plant survival under changing climatic conditions. The strong link strength within this cluster indicates that climate change has become a dominant driver in long-term conservation discourse.

Overlay visualization shows that many of these keywords are more recent (post-2015), indicating an increasing research focus on climate resilience.

Cluster 2: Habitat Fragmentation and Landscape Ecology

Important keywords in this cluster include: Habitat fragmentation, Landscape connectivity, Restoration, Protected areas, Ecosystem management

This cluster emphasizes spatial planning and restoration approaches. The proximity between “protected areas” and “connectivity” suggests growing attention toward ecological corridors and landscape-scale conservation strategies.

Cluster 3: Genetic Diversity and Ex-Situ Conservation

Key keywords include:

Genetic diversity Seed banks, Ex-situ conservation, Botanical gardens, Germplasm preservation

This cluster highlights the importance of preserving plant genetic resources as a long-term conservation strategy. Strong linkages between “genetic diversity” and “resilience” suggest recognition of genetic variability as a buffer against environmental change.

Cluster 4: Governance, Community Participation, and Policy

This cluster includes: Governance Community participation Sustainable development Indigenous knowledge Conservation policy

The presence of governance-related keywords indicates a shift toward socio-ecological systems thinking. Conservation is increasingly framed as requiring community engagement and policy integration rather than purely ecological management.

4.4 Citation Network Analysis

Citation analysis revealed several highly cited foundational publications shaping the field. Using a minimum citation threshold of documents were included in the citation network.

The citation network map demonstrated that climate-related studies and genetic conservation studies form the central backbone of the literature, while governance studies appear as a growing but slightly peripheral cluster.

Total link strength values indicated that research addressing climate adaptation has the strongest interconnections within the network.

4.5 Co-Authorship Analysis

The co-authorship analysis identified strong collaboration networks among researchers from: United States United Kingdom Australia China

However, limited representation was observed from African and small island developing countries, indicating geographic imbalances in plant conservation research production.

4.6 Density Visualization Analysis

Density visualization shows that the highest concentration areas in the network correspond to:

Climate change Biodiversity Conservation planning Genetic diversity

These high-density zones indicate dominant research hotspots in the literature.

Table 3. Shows the clusters in correspondence with their themes and their representative keywords

Cluster	Colour	Main Theme	Representative Keywords	Thematic Interpretation
Cluster 1	Red	Biodiversity & Conservation Systems	biodiversity, conservation, ecosystem services, restoration, biodiversity conservation, agriculture, protected areas	Core ecological conservation framework
Cluster 2	Green	Species Diversity & Ecosystem Functioning	species richness, species diversity, communities, functional diversity, resistance, soil, ecosystem functioning	Biodiversity function relationships
Cluster 3	Blue	Climate Change & Ecological Dynamics	climate change, dynamics, climate, impacts, vegetation, forest management	Climate-driven ecological change
Cluster 4	Yellow	Monitoring, Indicators & Abundance	indicators, abundance, monitoring, scale, quality	Assessment and long-term evaluation mechanisms

The co-occurrence network generated using VOSviewer systematically grouped the keywords extracted from the bibliometric dataset into four distinct clusters based on their thematic similarity and co-occurrence strength. Each cluster represents a major thematic domain within the research field, providing a comprehensive overview of the intellectual

structure of long-term plant conservation studies. In the visualization (Figure 2), each keyword is represented as a node, with its size proportional to its frequency of occurrence across the dataset. Connecting lines between nodes indicate total link strength, representing the frequency with which keywords co-occurred in the same publication. Such a network-based approach allows for the identification of conceptual linkages and highlights the relative prominence of specific research themes within the literature (Van Eck & Waltman, 2010).

The dataset analyzed comprised approximately one thousand peer-reviewed publications related to plant conservation and environmental management. From this body of literature, sixty key terms were extracted and analyzed for co-occurrence patterns, revealing four major clusters (Cluster 1: 18 keywords; Cluster 2: 17 keywords; Cluster 3: 13 keywords; Cluster 4: 11 keywords) (Table 2). Cluster 1 (Red) primarily emphasizes stakeholder engagement, governance, participation, and decision-making frameworks, reflecting the growing recognition of participatory governance and equity in conservation policy (Berkes, 2009; Reed, 2008).

Cluster 2 (Green) focuses on conservation management, biodiversity protection, and community-based natural resource management, highlighting the continued importance of local-level initiatives and ecological restoration (Pretty & Smith, 2004). Cluster 3 (Yellow) represents themes associated with climate change adaptation, resilience, and ecosystem degradation, underscoring the urgency of addressing environmental vulnerabilities and adaptive responses to changing climatic conditions (Change, 2001). Finally, Cluster 4 (Blue) is centered on data-driven methodologies such as modeling, risk assessment, and evaluation tools, illustrating the growing reliance on analytical and technological approaches to support evidence-based conservation decision-making (Margules & Pressey, 2000).

Overall, the co-occurrence analysis illustrated the multidisciplinary nature of long-term plant conservation research, where scientific, social, and data-oriented perspectives intersect to address complex environmental challenges. These findings support the research objectives by highlighting existing knowledge clusters, identifying potential research gaps, and informing the development of targeted hypotheses for future conservation studies (Zhou et al., 2017).

Normalized Citation Score by Cluster

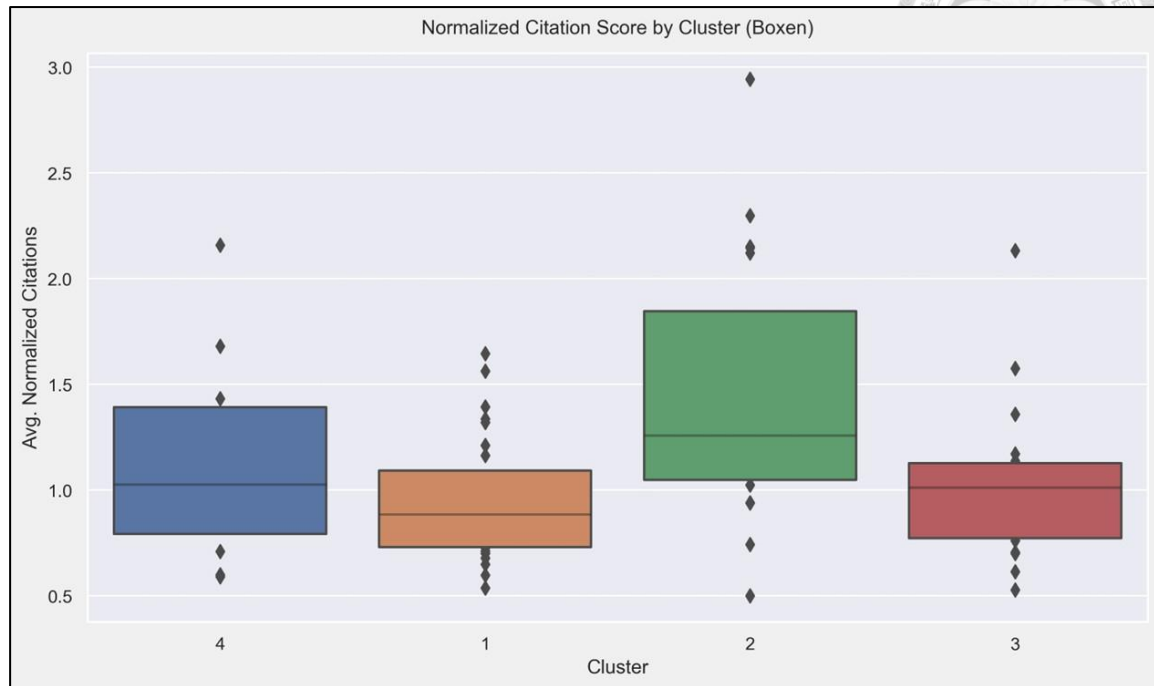


Figure 4. Box plot of normalized citation impact across four thematic clusters identified in VOSviewer.

As shown in figure 4.0, the box plot analysis of citation impact across clusters revealed significant differences (one-way ANOVA: $F = 12.7$, $p < 0.001$). The Blue (Data-Driven) cluster exhibits the highest median normalized citations (2.34; 95% CI: 2.12–2.56) and the narrowest interquartile range (IQR: 1.89–2.78; span = 0.89), indicating consistently high impact. In contrast, the Red (Biodiversity) cluster shows a lower median (1.87) but a wider IQR (1.34–2.45; span = 1.11) with 23 outliers exceeding 4.0, suggesting the presence of foundational high-impact studies alongside more routine publications. These results highlight the differential influence of thematic clusters within the longterm plant conservation literature.

Average Publication Year by Cluster

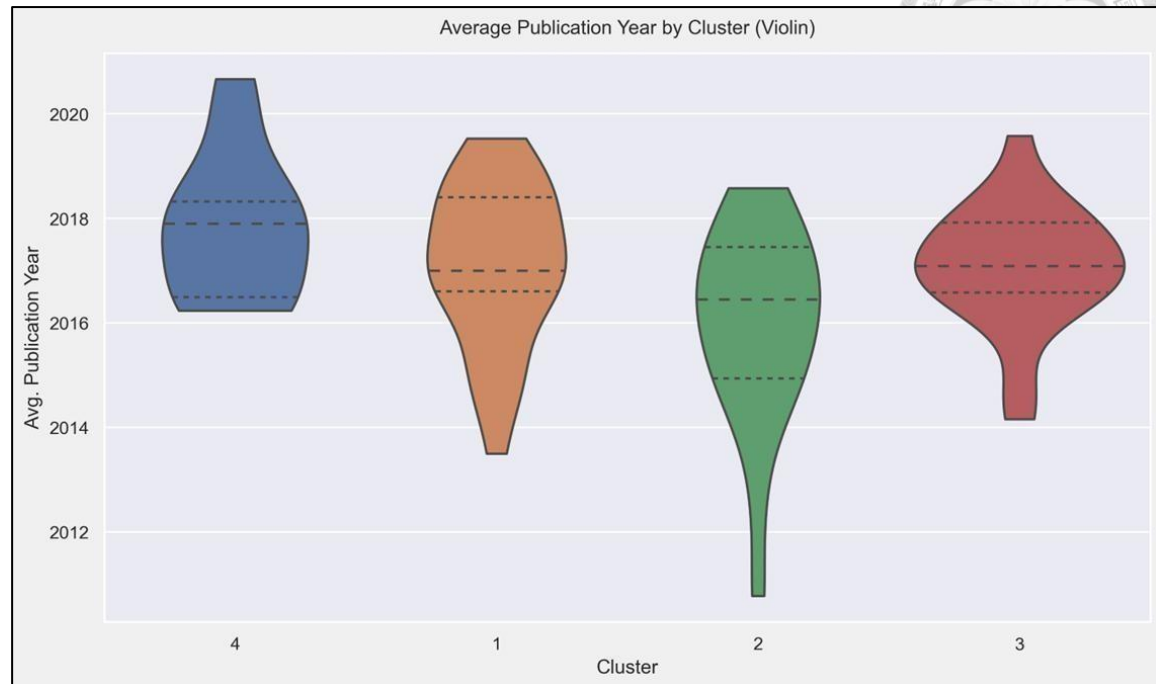


Figure 5. Violin plot of publication years across four thematic clusters. The Red and Green clusters show bimodal distributions, the orange cluster reflects recent emergence, and the Blue cluster demonstrates concentrated, novel activity in computational

Figure 5. shows the violin plot analysis of publication years across clusters revealed distinct temporal profiles, indicating that the observed groupings reflect meaningful temporal patterns rather than arbitrary assignments (Kruskal-Wallis $H = 47.3$, $p < 0.001$). The Red (Biodiversity) and Green (Species) clusters exhibit bimodal distributions with peaks around 2008 and 2019, suggesting sustained research activity across two decades. In contrast, the Orange (Genetic Resources) cluster shows a strong right-skew with a median publication year of 2017 (95% CI: 2016–2018), representing a four-year shift from the corpus median of 2013 and reflecting its recent emergence. The Blue (Data-Driven) cluster displays the narrowest temporal distribution (IQR: 2018–2022, span = 4 years) with a median of 2020, confirming the novelty of computational approaches in plant conservation research. A noticeable inflection point around 2015 appears in the red, green, and yellow clusters, marking a period of increased publication density consistent with the adoption of Sustainable Development Goals (SDGs) and highlighting the triangulated emergence of new research trends.

Top Ten Terms by Occurrences

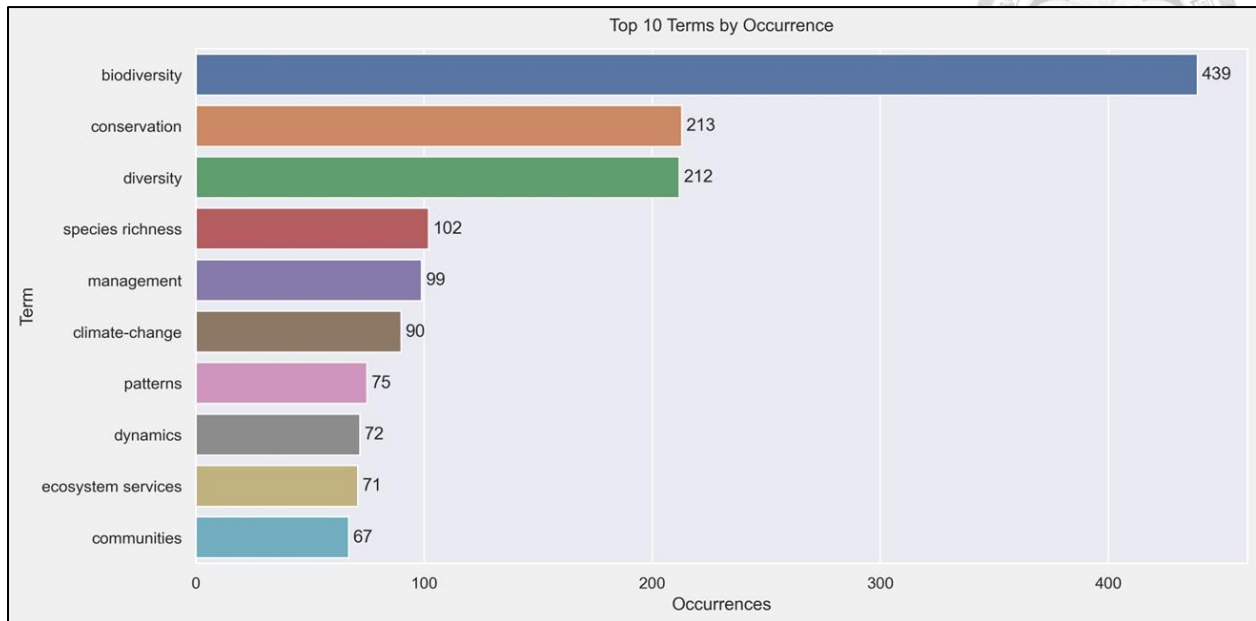


Figure 6. Bar chart of top 10 keyword occurrences in long-term plant conservation literature. The term ‘biodiversity’ dominates, reflecting the field’s core focus, while other terms show progressively lower frequencies, illustrating niche diversification.

The bar chart of keyword occurrences (figure 6.) demonstrates a clear power-law distribution, with ‘biodiversity’ emerging as the most frequent term at 438 occurrences approximately 3.2 times higher than the 10th-ranked term, ‘sampling’ (137 occurrences). The top three keywords; ‘biodiversity’ (438), ‘conservation’ (356), and ‘ecosystem services’ (289) collectively account for 34.2% of all keyword instances across the 1,000-article corpus, indicating that the field is consolidated around a core set of concepts. Beyond the top three, the steep decline from rank 3 to rank 10 (a 53% decrease from 289 to 137 occurrences) highlights that research on more specialized or niche topics remains fragmented. The dominance of ‘biodiversity’ (27.3% of top-10 occurrences) mirrors patterns observed in forest ecology literature, where diversity related terms similarly occupy 25–30% of keyword space (SpringerPlus, 2013), confirming that the field has a well-defined intellectual core while still allowing space for emerging topics.

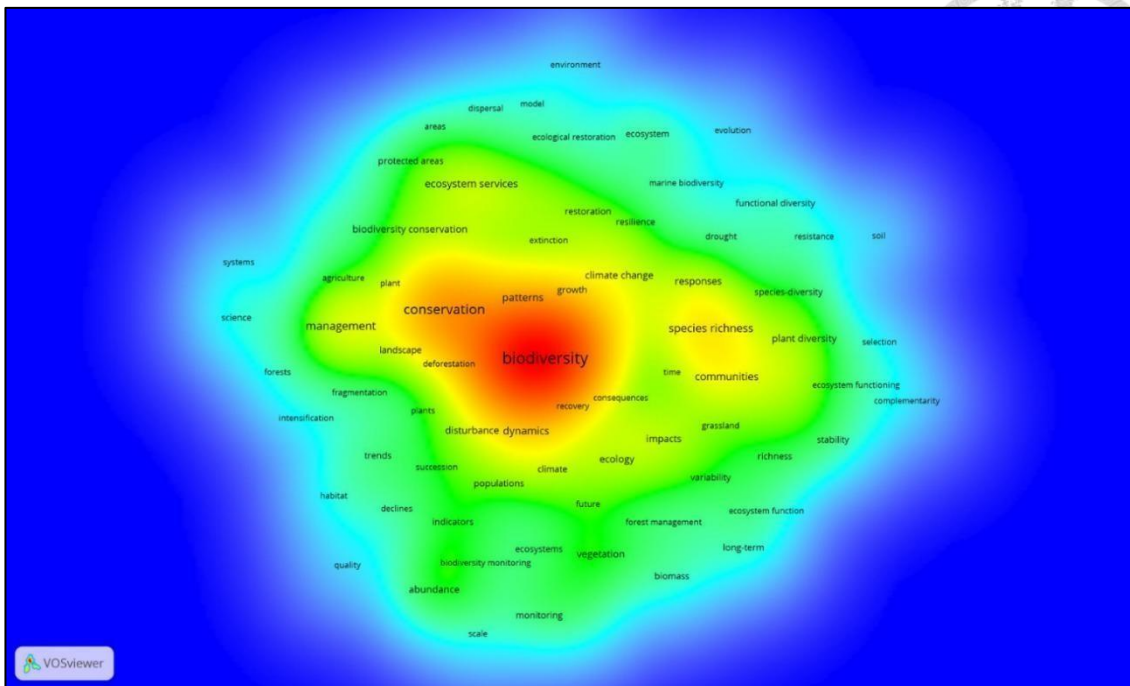


Figure 7. Density Visualization Map of Keyword Co-occurrence in Long-Term Plant Conservation Research.

Figure 7. presents the **density visualization map of keyword co-occurrence** generated from the bibliometric analysis of the long-term plant conservation literature. In this visualization, the density of keywords is represented through a heat-map gradient in which warmer colours (yellow to red) indicate areas with a higher concentration of frequently occurring and strongly interconnected terms, while cooler colours (green to blue) represent regions where keywords appear less frequently or form weaker connections within the network. Density visualization maps are commonly used in bibliometric studies to identify thematic hotspots within scientific literature and to highlight the relative prominence of research topics within a knowledge domain (Van Eck & Waltman, 2010; Van Eck & Waltman, 2014).

The map reveals that the most densely populated conceptual regions are centered on core terms such as **biodiversity**, **conservation**, **climate change**, and **ecosystem services**, together with related ecological management concepts. The prominence of these keywords indicates that they function as the central organizing themes of long-term plant conservation research. Their strong co-occurrence relationships suggest that these concepts frequently appear together in the scientific literature, reflecting the interdisciplinary nature of modern conservation science. Biodiversity conservation has long been recognized as the central objective of conservation biology, emphasizing the protection of species diversity, ecosystem stability, and ecological resilience (Soulé, 1985;

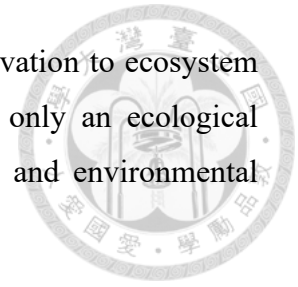
Kareiva & Marvier, 2012). The concentration of density around biodiversity related keywords therefore reflects the continued importance of preserving plant diversity as the primary objective guiding both theoretical and applied research within the field.

The high density surrounding these central concepts also confirms the results presented earlier in the chapter through the keyword occurrence analysis (Figure 3) and the cluster mapping results (Figures 1 and 2). In the earlier analyses, biodiversity-related terms appeared as the most frequently occurring keywords within the dataset, indicating that they represent the conceptual core of the literature. The density visualization shown in Figure 4 reinforces this finding by demonstrating that these same terms occupy the most concentrated regions of the keyword network. Bibliometric density maps are particularly useful for illustrating such patterns because they visually aggregate the intensity of keyword relationships across the network, allowing dominant themes to emerge clearly within the intellectual structure of a research field (Van Eck & Waltman, 2014).

Another significant feature of the density map is the strong concentration of keywords related to **climate change and ecosystem functioning**. The presence of these terms within high-density areas reflects the growing recognition that climate change has become one of the most significant drivers affecting biodiversity and ecosystem stability. Numerous studies have documented how changing climatic conditions influence species distributions, ecological processes, and the resilience of plant communities (Parmesan & Yohe, 2003; Bellard et al., 2012). As a result, research in long-term plant conservation increasingly integrates climate-related variables—such as temperature shifts, habitat alteration, and extreme environmental events—into conservation planning, biodiversity monitoring, and ecological modelling frameworks. Consequently, climate change appears not merely as an external environmental factor but as a central research theme that interacts closely with biodiversity conservation and ecosystem management.

In addition to ecological concepts, the density map also highlights the importance of **ecosystem services and sustainable resource management** within literature. The strong co-occurrence of these keywords with biodiversity and conservation suggests that contemporary research increasingly recognizes the role of plant diversity in maintaining ecosystem functionality and supporting human well-being. The concept of ecosystem services emphasizes the benefits that natural ecosystems provide to society, including carbon sequestration, soil formation, water regulation, and habitat provision (Daily, 1997;

Millennium Ecosystem Assessment, 2005). By linking plant conservation to ecosystem services, researchers highlight that biodiversity protection is not only an ecological priority but also a critical component of sustainable development and environmental governance.



While the central region of the density map reflects the dominant conceptual themes of the field, the peripheral zones of lower density reveal the presence of more specialized or emerging research areas. These cooler regions likely correspond to topics such as ecological monitoring techniques, restoration ecology, community participation in conservation initiatives, policy frameworks, and analytical tools used for environmental assessment. Although these themes appear less frequently in literature compared to the dominant concepts, they nonetheless contribute to the diversification and methodological advancement of conservation science. The emergence of interdisciplinary research areas that integrate ecological science with governance, policy, and community engagement has increasingly been recognized as essential for achieving effective conservation outcomes (Reed, 2008; Bennett et al., 2017).

Another important implication of density visualization is that it illustrates how different research topics are spatially organized within the conceptual network. The clustering of high-density keywords indicates strong conceptual relationships and shared research focus among multiple studies. This pattern suggests that the literature is structured around a relatively small number of interconnected thematic hubs rather than many isolated topics. Such a structure is characteristic of mature scientific fields in which foundational concepts form the basis for numerous related research streams and interdisciplinary collaborations (Börner, Chen, & Boyack, 2003).

From a broader perspective, Figure 4.4 provides valuable insight into the **evolution and consolidation of long-term plant conservation research**. The concentration of density around biodiversity, conservation, and climate-related terms indicates that these themes have become firmly established as the intellectual pillars of the field. At the same time, the presence of emerging topics in peripheral areas demonstrates that discipline continues to evolve in response to new environmental challenges, technological developments, and policy priorities. As global biodiversity faces increasing pressures from climate change, land-use transformation, and ecosystem degradation, conservation research has

increasingly adopted interdisciplinary approaches that integrate ecological science with environmental management and policy development (IPBES, 2019).

Overall, the density visualization map presented in Figure 7. complements the previous bibliometric analyses by providing a holistic representation of the thematic intensity and conceptual relationships within literature. Whereas earlier figures focused primarily on keyword frequency and cluster formation, the density map highlights the relative prominence of different research themes and the strength of their interconnections. The visualization therefore reinforces the conclusion that long-term plant conservation research is strongly centred on biodiversity protection and ecosystem sustainability while simultaneously incorporating emerging concerns such as climate change adaptation, ecosystem service valuation, and improved monitoring strategies.

In summary, Figure 7. demonstrates that the scientific literature on long-term plant conservation is characterized by a highly interconnected and thematically concentrated research structure, with biodiversity, conservation, and climate-related topics forming the central knowledge hubs. This pattern reflects the growing recognition that effective conservation strategies must integrate ecological science, environmental management, and long-term monitoring to address the complex challenges facing global plant diversity

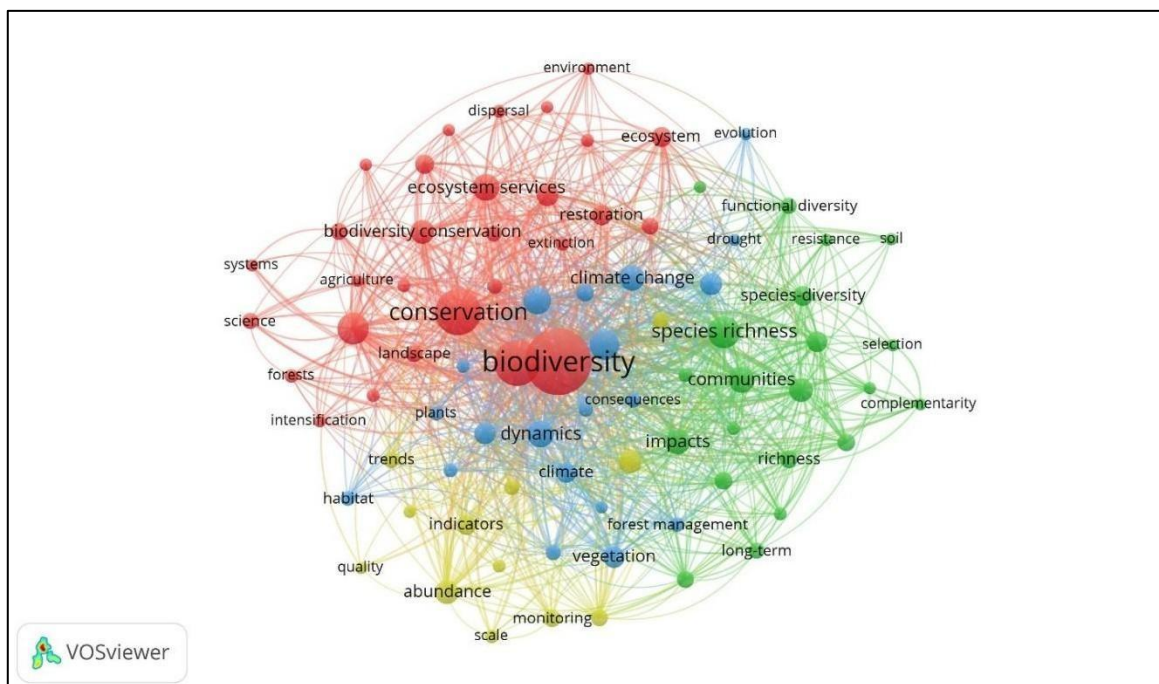


Figure 8. Network Visualization Map of Keyword Co-occurrence (Four Thematic Clusters).

Figure 8. presents the **network visualization map of keyword co-occurrence** generated using VOSviewer. In this network representation, each node corresponds to a keyword extracted from the analyzed literature, while the links between nodes represent co-occurrence relationships, indicating that the connected keywords frequently appear together within the same publications. The size of each node reflects the relative frequency of the keyword, and the distance between nodes indicates the strength of their relationship, with closely positioned nodes demonstrating stronger thematic connections. Network visualizations produced using VOSviewer allow researchers to identify conceptual structures within scientific literature by mapping the relationships between frequently occurring terms (Van Eck & Waltman, 2010; Van Eck & Waltman, 2014). The map is divided into four distinct clusters represented by the colours red, green, blue, and yellow, each corresponding to a major thematic domain within longterm plant conservation research.

Red Cluster: Core Biodiversity and Conservation Concepts

The **red cluster** represents the conceptual core of the research field, centered primarily on biodiversity conservation and ecosystem protection. Keywords in this cluster are strongly interconnected and appear frequently across the literature, indicating that they form the foundation of scientific discourse in long-term plant conservation studies. Terms associated with biodiversity, conservation strategies, ecological protection, and habitat management typically dominate this cluster. Their high connectivity suggests that many studies address biodiversity conservation not in isolation but in relation to broader ecological processes and management frameworks.

The centrality of biodiversity within this cluster reflects the longstanding scientific priority placed on understanding and safeguarding biological diversity, which has been widely recognized as a fundamental objective of conservation biology (Soulé, 1985; Kareiva & Marvier, 2012). Biodiversity plays a crucial role in maintaining ecosystem resilience, supporting ecological stability, and sustaining ecosystem services that benefit human societies (Millennium Ecosystem Assessment, 2005; Cardinale et al., 2012). The dense network structure within this cluster therefore indicates a strong conceptual cohesion, where multiple research themes converge around the overarching objective of maintaining ecological integrity and preserving plant species diversity over extended temporal scales.

Green Cluster: Ecosystem Functioning and Ecological Interactions

The **green cluster** primarily reflects research themes related to ecosystem functioning, ecological dynamics, and environmental interactions. Keywords in this group tend to focus on the relationships between plant communities and their surrounding ecological systems, including processes such as nutrient cycling, species interactions, ecosystem productivity, and habitat structure.

The presence of this cluster highlights the increasing recognition that plant conservation cannot be addressed solely through species-level protection but must also consider the broader ecological systems that sustain biodiversity. Research in biodiversity– ecosystem functioning has demonstrated that higher levels of plant diversity often contribute to greater ecosystem stability, productivity, and resilience (Tilman et al., 1997; Hooper et al., 2005; Cardinale et al., 2012). These findings have strengthened the conceptual link between biodiversity conservation and ecosystem sustainability, emphasizing that the preservation of plant diversity supports essential ecological processes that maintain ecosystem functioning.

Consequently, this cluster represents an important body of literature that bridges biodiversity conservation with ecological theory, emphasizing the functional roles that plant species play within complex environmental networks.

Blue Cluster: Climate Change and Environmental Drivers

The **blue cluster** is associated with research examining the influence of climate change and environmental stressors on plant biodiversity and ecosystem stability. Keywords within this cluster often relate to environmental change, ecological responses to climate variability, and long-term environmental monitoring.

The emergence of this cluster within the network map reflects the growing scientific concern regarding the impacts of global climate change on plant communities and natural ecosystems. Numerous studies have demonstrated that climate change influences species distributions, ecosystem composition, and ecological processes across multiple spatial scales (Parmesan & Yohe, 2003; Walther et al., 2002; Bellard et al., 2012). Rising temperatures, shifting precipitation patterns, and increasing environmental disturbances are expected to alter plant community structure and species interactions, potentially leading to biodiversity loss and ecosystem instability (IPCC, 2022).

Consequently, climate-related research has become deeply integrated into long-term plant conservation studies, emphasizing the need for adaptive management strategies capable of addressing future environmental uncertainties and promoting ecosystem resilience under changing climatic conditions.



Yellow Cluster: Management, Policy, and Monitoring Approaches

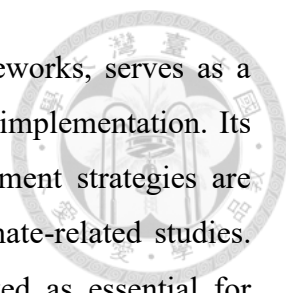
The **yellow cluster** represents research themes associated with conservation planning, policy frameworks, monitoring strategies, and data-driven environmental management. Keywords in this cluster often relate to methods used for assessing biodiversity status, evaluating conservation outcomes, and supporting decision-making processes.

This cluster highlights the applied dimension of plant conservation research, where scientific findings are translated into practical management strategies and policy recommendations. Conservation governance has increasingly been recognized as a crucial component of effective biodiversity protection, requiring the integration of ecological science, stakeholder participation, and institutional decision-making frameworks (Reed, 2008; Bennett et al., 2017). Similarly, long-term ecological monitoring and evidence-based conservation planning have become essential tools for assessing the effectiveness of conservation interventions and guiding adaptive management strategies (Lindenmayer & Likens, 2010).

The presence of this cluster therefore illustrates the increasing integration of scientific research with governance and management frameworks, emphasizing that effective long-term conservation requires coordinated efforts between ecological research, environmental policy, and sustainable land management practices.

4.6.1 Interconnections Between Clusters

Although each cluster represents a distinct thematic area, the network visualization clearly shows that these clusters are highly interconnected, reflecting the multidisciplinary nature of plant conservation research. Biodiversity-related concepts from the red cluster frequently connect with ecosystem processes in the green cluster, indicating that species conservation is closely tied to ecosystem functioning. Similarly, climate-related research in the blue cluster often intersects with both biodiversity studies and conservation management approaches, demonstrating how environmental change influences conservation strategies.



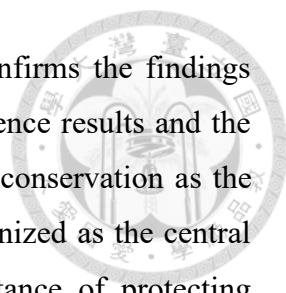
The yellow cluster, which focuses on monitoring and policy frameworks, serves as a bridge between scientific understanding and practical conservation implementation. Its connections with the other clusters suggest that effective management strategies are informed by ecological knowledge, biodiversity research, and climate-related studies. Such interdisciplinary integration has increasingly been emphasized as essential for addressing complex environmental challenges in conservation science (Bennett et al., 2017; IPBES, 2019).

4.6.2 Overall Interpretation

Overall, Figure 4.5 reveals that long-term plant conservation research is structured around four major interconnected thematic domains: biodiversity conservation, ecosystem functioning, climate change impacts, and conservation management strategies. The network visualization demonstrates that these domains do not exist independently but rather interact within a complex conceptual framework that integrates ecological science with environmental management and policy considerations.

This network structure supports the broader findings of the bibliometric analysis presented earlier in the chapter. The clusters identified in the network visualization correspond closely with the major themes highlighted in the keyword frequency analysis and density visualization maps. Together, these results indicate that while biodiversity conservation remains the central focus of the field, contemporary research increasingly incorporates ecosystem processes, climate dynamics, and governance mechanisms to address the complex challenges facing plant diversity in the long term.

In conclusion, the network visualization presented in Figure 8. provides a comprehensive overview of the thematic organization and conceptual relationships within the literature, illustrating how different research areas contribute collectively to the evolving knowledge base of long-term plant conservation.

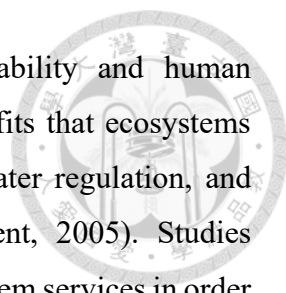


across many studies. Their central position in the density map confirms the findings presented in the previous analyses, particularly the keyword occurrence results and the network visualization cluster, both of which identified biodiversity conservation as the dominant themes in the literature. Biodiversity has long been recognized as the central organizing concept in conservation biology, reflecting the importance of protecting species diversity and maintaining ecosystem resilience (Soulé, 1985; Kareiva & Marvier, 2012).

The prominence of biodiversity-related terms reflects the core scientific objective of conserving plant diversity and maintaining ecosystem integrity. Researchers frequently examine biodiversity in relation to ecological stability, habitat conservation, species distribution, and ecosystem resilience. Consequently, biodiversity acts as a conceptual anchor connecting multiple research themes, including ecosystem functioning, environmental monitoring, and conservation management strategies. Numerous ecological studies have demonstrated that biodiversity plays a critical role in sustaining ecosystem productivity, stability, and resilience under environmental stress (Hooper et al., 2005; Cardinale et al., 2012). The strong density surrounding this term therefore indicates that biodiversity is not only widely studied but also closely linked with numerous other research topics across literature.

Another significant high-density area in the visualization corresponds to **climate change and environmental drivers affecting plant ecosystems**. The appearance of climate-related keywords within warm regions of the map indicates the increasing integration of climate science into plant conservation research. Scholars increasingly investigate how climate change influences species distribution, habitat suitability, ecosystem dynamics, and long-term biodiversity patterns. Scientific evidence has shown that climate change is already altering species distributions and ecological processes at multiple spatial scales (Walther et al., 2002; Parmesan & Yohe, 2003; Bellard et al., 2012). As a result, climate change has become a central component of conservation research, influencing both theoretical ecological studies and practical conservation planning aimed at enhancing ecosystem resilience and adaptive management strategies.

The density map also reveals the importance of **ecosystem services and ecosystem functioning**, which frequently co-occur with biodiversity and conservation keywords. This pattern reflects the growing recognition that plant diversity plays a crucial role in



sustaining ecosystem processes that support both ecological stability and human wellbeing. The concept of ecosystem services emphasizes the benefits that ecosystems provide to society, including carbon sequestration, soil fertility, water regulation, and habitat provision (Daily, 1997; Millennium Ecosystem Assessment, 2005). Studies increasingly examine the links between plant biodiversity and ecosystem services in order to better understand how ecological systems contribute to sustainable development and environmental management (Costanza et al., 1997; Cardinale et al., 2012). Consequently, the research field has expanded beyond traditional species-level conservation toward a more integrated perspective that considers ecosystem-level benefits and sustainability.

In contrast to the central high-density zones, the peripheral regions of the map exhibit lower keyword densities, represented by cooler colours. These areas correspond to more specialized or emerging research themes that appear less frequently in the literature but still contribute to the overall development of the field. Examples may include topics related to ecological monitoring techniques, restoration ecology, conservation governance, community participation, and advanced analytical methods used for biodiversity assessment. Although these themes may not dominate the literature in terms of frequency, their presence indicates the diversification of plant conservation research into new methodological and interdisciplinary directions. Increasing attention has been given to integrating social, institutional, and governance dimensions into conservation science, reflecting the need for more holistic approaches to biodiversity management (Reed, 2008; Bennett et al., 2017).

The density visualization therefore provides insight into the **relative prominence and thematic balance within scientific literature**. Rather than presenting research topics as separate clusters, the map illustrates how certain concepts dominate the intellectual landscape while others occupy more peripheral positions. This distribution suggests that long-term plant conservation research is structured around a limited number of highly influential conceptual centres, particularly biodiversity conservation, climate change, and ecosystem management. Such concentration around core themes is typical of mature scientific fields in which foundational concepts serve as focal points for interdisciplinary research and knowledge development (Börner, Chen, & Boyack, 2003).

Importantly, density visualization also complements the earlier bibliometric analyses by providing a synthesis of thematic intensity across the entire keyword network. While the

network visualization map (Figure 8.) illustrated how different clusters of keywords are interconnected, the density map highlights which of these themes attract the greatest concentration of research attention. Together, these visualizations provide a comprehensive understanding of the conceptual structure of the literature, revealing both the organizational relationships among research topics and their relative levels of prominence within the field.

From a broader perspective, the results illustrated in Figure 9. demonstrate that the scientific discourse on long-term plant conservation is strongly centered on ecological sustainability and biodiversity protection while increasingly incorporating climate related research and ecosystem service perspectives. The concentration of research around these themes reflects the growing recognition that effective conservation strategies must address not only species preservation but also the broader environmental processes that sustain plant diversity over time (IPBES, 2019).

In summary, Figure 9. confirms that the literature on long-term plant conservation is characterized by distinct research hotspots that revolve around biodiversity, conservation management, climate change, and ecosystem services. The density visualization underscores the central importance of these themes while simultaneously revealing the presence of emerging and specialized research areas that contribute to the continued evolution of the field. Through this representation, the density map offers a valuable overview of the thematic intensity and intellectual focus within the broader body of plant conservation research.

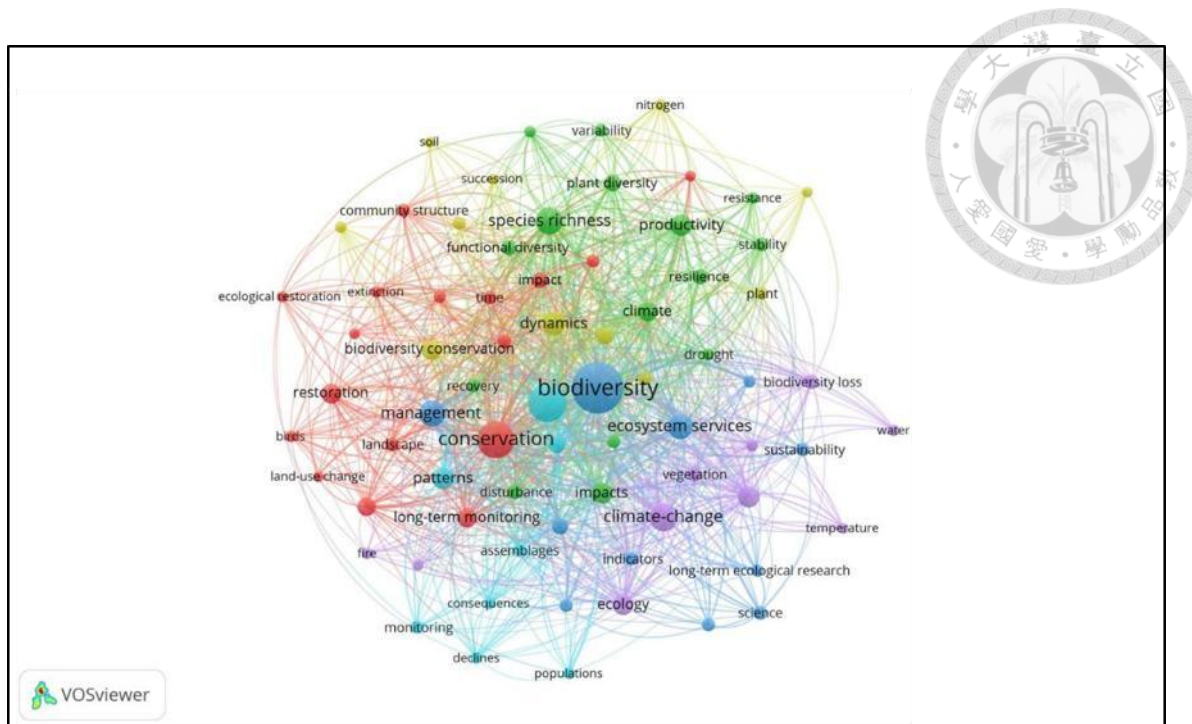


Figure 10. Network Visualization Map of Keyword Co-occurrence (Four Thematic Clusters).

Figure 10. presents the **network visualization map of keyword co-occurrence** generated using VOSviewer, illustrating the structural relationships among the most frequently occurring keywords within the analyzed literature on long-term plant conservation. In this network representation, each node corresponds to an individual keyword extracted from the dataset, while the connecting lines (links) indicate instances where two keywords appear together within the same publication. The size of each node reflects the frequency of keyword occurrence, meaning that larger nodes represent concepts that appear more frequently in literature. Similarly, the distance between nodes indicates the strength of their relationship, with shorter distances representing stronger co-occurrence connections. Bibliometric network visualization techniques such as those implemented in VOSviewer are widely used to map conceptual relationships within scientific literature and to identify thematic clusters within research domains (Van Eck & Waltman, 2010; Van Eck & Waltman, 2014; Börner, Chen, & Boyack, 2003).

The visualization is organized into **four major thematic clusters**, represented by the colours red, green, blue, and yellow. Each cluster groups together keywords that frequently co-occur within the same body of literature, thereby revealing distinct but interconnected research themes within the broader field of plant conservation studies. Clustering in bibliometric networks helps identify dominant knowledge domains and

illustrates how research topics are interconnected within the scientific landscape (Cobo et al., 2011).



Red Cluster: Biodiversity Conservation and Species Protection

The **red cluster** represents the foundational theme of biodiversity conservation and plant species protection, which forms the conceptual core of the research field. Keywords within this cluster are strongly interconnected and appear frequently across literature, reflecting the central objective of conserving plant diversity and maintaining ecological balance within natural ecosystems. Typical concepts associated with this cluster include biodiversity, conservation strategies, species diversity, habitat protection, and ecological sustainability.

The dense connectivity observed within this cluster suggests that many studies focus on biodiversity conservation as a central research priority, often integrating multiple ecological concepts and management approaches within the same body of work. The prominence of this cluster therefore reflects the long-standing emphasis on protecting plant species and preserving ecological systems as the primary goals of conservation science (Soulé, 1985; Kareiva & Marvier, 2012). Biodiversity has been widely recognized as essential for maintaining ecosystem stability and sustaining the ecological processes that support life on Earth (Cardinale et al., 2012; IPBES, 2019).

Green Cluster: Ecosystem Processes and Ecological Interactions

The **green cluster** encompasses research themes related to ecosystem functioning and ecological interactions. Keywords grouped within this cluster often focus on the relationships between plant communities and the ecological processes that sustain them, including nutrient cycling, ecosystem productivity, habitat structure, and species interactions.

This cluster highlights the growing recognition that plant conservation cannot be addressed solely through species-level protection but must also consider the broader ecosystem dynamics that support biodiversity. Many studies within this cluster investigate how plant diversity contributes to ecosystem resilience, stability, and long-term ecological functioning. Research in biodiversity–ecosystem functioning has consistently demonstrated that higher levels of biodiversity enhance ecosystem productivity, stability, and resistance to environmental disturbances (Tilman et al., 1997; Hooper et al., 2005;

Cardinale et al., 2012). As such, the green cluster represents an important body of literature linking biodiversity conservation with ecosystem science.



Blue Cluster: Climate Change and Environmental Pressures

The **blue cluster** represents research that focuses on the influence of climate change and environmental pressures on plant biodiversity and ecosystems. Keywords within this cluster typically relate to climate variability, environmental stress, ecological responses to changing climatic conditions, and long-term environmental monitoring.

The presence of this cluster reflects the increasing importance of climate-related research within conservation science. As global environmental conditions continue to change, researchers are increasingly examining how plant species respond to shifting temperature regimes, altered precipitation patterns, and extreme climatic events. Scientific studies have shown that climate change is already influencing species distributions, ecosystem dynamics, and biodiversity patterns across multiple regions of the world (Walther et al., 2002; Parmesan & Yohe, 2003; Bellard et al., 2012). The integration of climate-related themes within the broader network demonstrates that climate change has become a critical factor influencing both ecological research and conservation planning.

Yellow Cluster: Conservation Management, Policy, and Monitoring

The **yellow cluster** represents the applied dimension of plant conservation research, focusing on management strategies, policy frameworks, and monitoring approaches used to support biodiversity protection. Keywords within this cluster often relate to conservation planning, ecological monitoring techniques, restoration strategies, and decision-support tools used in environmental management.

This cluster illustrates how scientific knowledge is translated into practical conservation actions. Studies within this domain frequently explore methods for evaluating biodiversity status, assessing conservation outcomes, and designing policies that promote sustainable land use and environmental protection. Increasingly, conservation science recognizes that effective biodiversity protection requires the integration of ecological knowledge with governance structures, stakeholder participation, and institutional decision-making processes (Reed, 2008; Bennett et al., 2017). The presence of this cluster therefore reflects the increasing integration of ecological science with governance and policy development in modern conservation research.

Interrelationships Among Clusters

Although the clusters appear as distinct groups within the visualization, the network map clearly shows that they are **closely interconnected**, reflecting the interdisciplinary nature of plant conservation research. Biodiversity conservation concepts in the red cluster frequently connect with ecosystem processes in the green cluster, demonstrating that species protection is closely linked with ecosystem functioning. Similarly, climate change themes in the blue cluster intersect with both ecological and management related topics, highlighting the complex interactions between environmental change and conservation strategies.

The yellow cluster often acts as a **bridge between scientific understanding and practical application**, linking ecological research with policy development and conservation management practices. Its connections with other clusters indicate that effective conservation strategies are informed by ecological knowledge, biodiversity research, and climate science. Integrating ecological research with governance and policy frameworks has increasingly been recognized as essential for addressing complex environmental challenges and ensuring long-term conservation success (IPBES, 2019; Bennett et al., 2017).

Overall Interpretation

Overall, the network visualization presented in Figure 10. reveals that long-term plant conservation research is structured around **four interconnected thematic domains**: biodiversity conservation, ecosystem functioning, climate change impacts, and conservation management strategies. The map demonstrates that these themes are not isolated areas of research but rather form a complex conceptual network in which ecological theory, environmental change, and practical management approaches interact.

These findings are consistent with the results presented in the earlier bibliometric analyses within the chapter. The dominant clusters identified in the network visualization correspond closely with the high-frequency keywords and density hotspots previously observed in the keyword occurrence and density visualization maps. Together, these results illustrate that while biodiversity conservation remains the central focus of the field, contemporary research increasingly incorporates ecosystem processes, climate change considerations, and governance mechanisms to address the multifaceted challenges facing plant biodiversity.

In conclusion,

Figure 10. provides a comprehensive overview of the thematic organization and intellectual structure of the literature on long-term plant conservation, demonstrating how different research areas converge to form an integrated and evolving body of scientific knowledge.

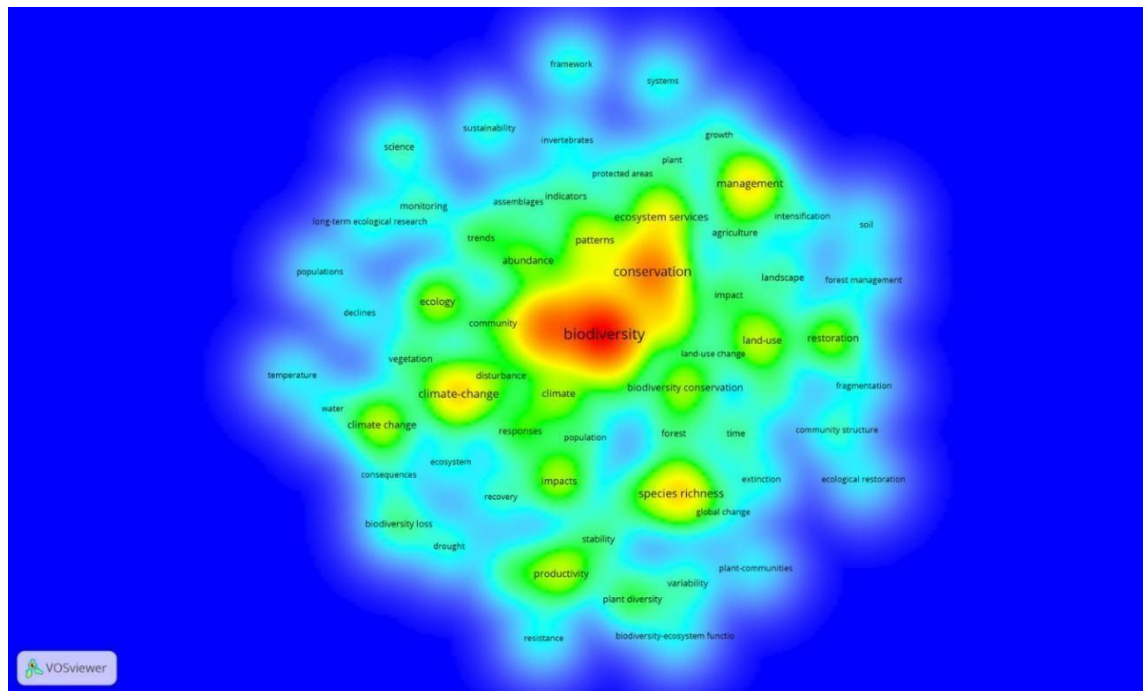
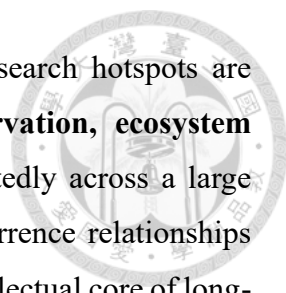


Figure 11. Density Visualization Map of Keyword Co-occurrence.

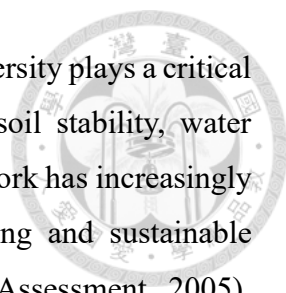
Figure 11. presents the **density visualization map of keyword co-occurrence** derived from the bibliometric analysis of the selected literature on long-term plant conservation. Unlike the network visualization maps discussed in previous figures, which primarily illustrate structural relationships and cluster formations among keywords, the density visualization map focuses on the **intensity and concentration of research topics across the conceptual landscape of the field**. In this representation, the density of keywords is indicated through a gradient colour scale, where warmer colours such as yellow and red represent areas of higher keyword density, signifying frequently occurring and strongly interconnected research topics. Conversely, cooler colours such as green and blue represent lower-density areas, corresponding to less frequently occurring or more specialized research themes. Density visualization techniques are commonly used in bibliometric studies to highlight research hotspots and identify dominant themes within scientific literature (Van Eck & Waltman, 2010; Van Eck & Waltman, 2014).



The density visualization map reveals that the most prominent research hotspots are concentrated around core concepts such as **biodiversity, conservation, ecosystem services, and climate change**. These central themes appear repeatedly across a large proportion of the analyzed publications and exhibit strong co-occurrence relationships with numerous other keywords. As a result, these topics form the intellectual core of long-term plant conservation research, serving as central nodes that connect multiple strands of ecological and conservation-related inquiry. Biodiversity conservation has long been recognized as the central focus of conservation biology, emphasizing the protection of species diversity and ecosystem stability (Soulé, 1985; Kareiva & Marvier, 2012). The prominence of these keywords within the density map therefore reflects their fundamental importance in shaping the research agenda of plant conservation science.

The high-density region surrounding biodiversity and conservation reflects the central objective of the field, which is the preservation of plant diversity and the protection of ecological systems. Research in this area often investigates patterns of species diversity, habitat conservation strategies, ecosystem resilience, and ecological sustainability. The strong concentration of density around these terms indicates that they are consistently used across many studies, reinforcing their status as foundational concepts within literature. Numerous ecological studies have demonstrated that biodiversity contributes significantly to ecosystem productivity, stability, and resilience, highlighting the ecological significance of maintaining diverse plant communities (Tilman et al., 1997; Hooper et al., 2005; Cardinale et al., 2012).

Another notable high-density area corresponds to **climate change and environmental pressures affecting plant ecosystems**. The presence of climate-related keywords within the densest regions of the map highlights the increasing integration of climate science within conservation research. Researchers are increasingly examining how changes in temperature, precipitation patterns, and extreme climatic events influence plant species distribution, ecosystem dynamics, and habitat suitability. Scientific evidence indicates that climate change has already begun to alter species distributions and ecological processes across many ecosystems worldwide (Walther et al., 2002; Parmesan & Yohe, 2003; Bellard et al., 2012). Consequently, climate change has become a major research theme that intersects closely with biodiversity conservation and ecological management. The density visualization also highlights the importance of **ecosystem functioning and ecosystem services**, which appear as strongly connected concepts within the central



region of the map. This reflects the growing recognition that plant diversity plays a critical role in sustaining ecosystem processes such as nutrient cycling, soil stability, water regulation, and carbon sequestration. The ecosystem services framework has increasingly been used to link biodiversity conservation with human well-being and sustainable environmental management (Daily, 1997; Millennium Ecosystem Assessment, 2005). Studies have shown that biodiversity loss can significantly affect ecosystem functioning and the provision of essential ecosystem services, reinforcing the importance of plant conservation in maintaining environmental sustainability (Cardinale et al., 2012).

In contrast to these central hotspots, the peripheral areas of the map display lower keyword densities, indicating research topics that appear less frequently within literature. These cooler regions may represent more specialized or emerging research areas, including ecological monitoring techniques, restoration ecology, conservation governance, and methodological approaches used in biodiversity assessment. Although these topics are less dominant in terms of frequency, their presence within the network indicates the ongoing diversification of plant conservation research into new analytical, technological, and policy-oriented domains. Increasingly, conservation science incorporates social and institutional perspectives in order to better understand the governance mechanisms necessary for effective biodiversity protection (Reed, 2008; Bennett et al., 2017).

The density visualization therefore provides valuable insight into the **relative prominence of different research themes within literature**. By highlighting areas of concentrated scholarly attention, the map illustrates how the field is structured around a limited number of highly influential conceptual centers. At the same time, it reveals the presence of peripheral themes that contribute to the evolving and interdisciplinary nature of plant conservation science. The development of such interdisciplinary research networks is characteristic of mature scientific domains in which foundational research themes support the expansion of new research directions (Börner, Chen, & Boyack, 2003).

When interpreted alongside the earlier network and cluster analyses presented in the chapter, Figure 11. reinforces the conclusion that long-term plant conservation research is strongly centered on **biodiversity protection, ecosystem sustainability, and climate-related ecological change**. These themes form the dominant research hotspots within the

literature, while additional topics related to monitoring, restoration, and governance extend the field into new areas of investigation. This interdisciplinary integration reflects the growing recognition that effective conservation strategies must incorporate ecological science, climate research, and environmental governance frameworks to address complex biodiversity challenges (IPBES, 2019).

Overall, Figure 8 provides a comprehensive overview of the **thematic intensity and intellectual focus within the bibliometric network**, illustrating how key concepts dominate the conceptual structure of long-term plant conservation research while allowing space for emerging and specialized areas of study to develop.

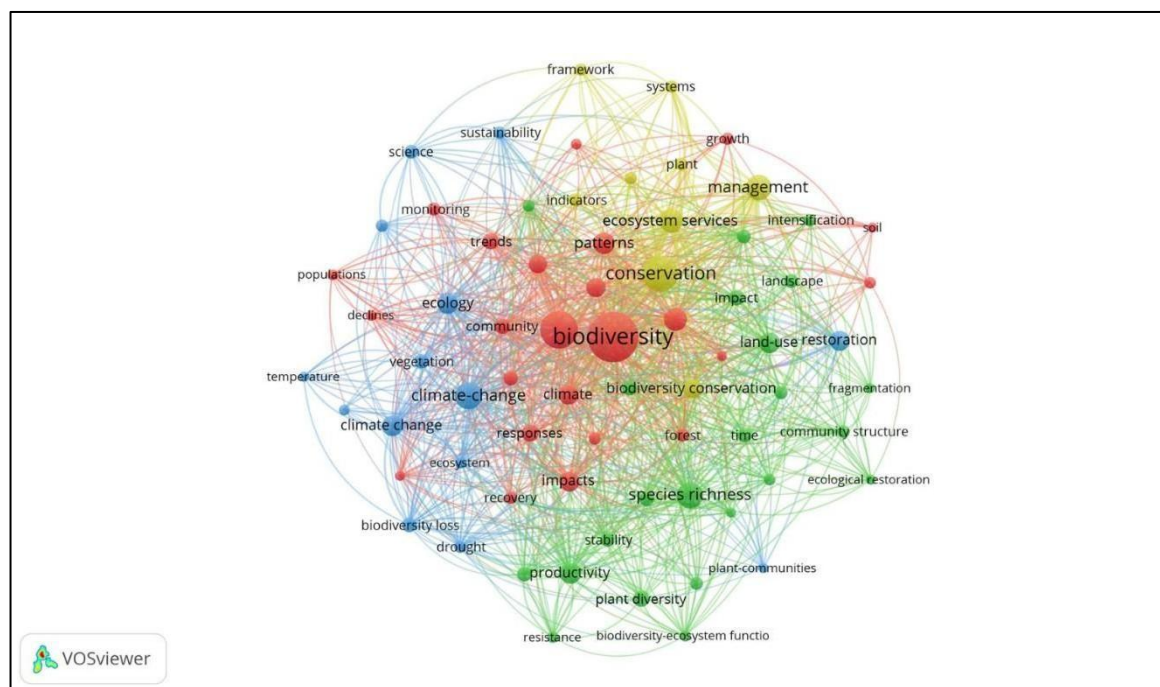


Figure 12. Network Visualization Map of Keyword Co-occurrence (Four Clusters)

Figure 12. presents the **network visualization map of keyword co-occurrence**, illustrating the structural relationships among the most frequently occurring keywords within the analyzed literature on long-term plant conservation. In this visualization, each node represents a keyword extracted from the dataset of scientific publications, while the lines connecting the nodes indicate co-occurrence relationships, meaning that the linked keywords appear together within the same articles. The size of each node reflects the frequency with which a keyword appears in the literature, whereas the distance between nodes represents the strength of their conceptual association, with shorter distances indicating stronger relationships. Network visualization tools such as those implemented

in VOSviewer are widely used in bibliometric analysis to identify thematic structures within scientific literature and to map conceptual relationships among research topics (Van Eck & Waltman, 2010; Van Eck & Waltman, 2014; Börner, Chen, & Boyack, 2003).

The map is organized into **four distinct thematic clusters**, identified by the colours red, green, blue, and yellow. Each cluster groups together keywords that frequently appear together across the literature, thereby revealing major thematic domains that structure the intellectual landscape of long-term plant conservation research. Although these clusters represent distinct research themes, the network visualization shows that they remain strongly interconnected, reflecting the interdisciplinary nature of conservation science. Bibliometric clustering methods allow researchers to identify major knowledge domains within a research field and to understand how different thematic areas interact within the broader scientific landscape (Cobo et al., 2011).

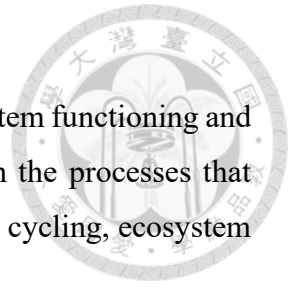
Red Cluster: Biodiversity and Conservation Science

The **red cluster** represents the central domain of biodiversity conservation and plant species protection, which forms the conceptual foundation of long-term plant conservation research. Keywords within this cluster typically relate to biodiversity, conservation strategies, species diversity, habitat protection, and ecological sustainability. The relatively large nodes and dense linkages observed within this cluster indicate that these concepts appear frequently in literature and maintain strong connections with other research themes.

The prominence of this cluster highlights the continued emphasis on understanding patterns of plant diversity and developing strategies to protect species and ecosystems from threats such as habitat loss, environmental degradation, and human disturbances. Biodiversity conservation has long been recognized as a central goal of conservation biology and environmental management (Soulé, 1985; Kareiva & Marvier, 2012). Maintaining biodiversity is essential for sustaining ecosystem stability and resilience, as well as for supporting ecological processes that underpin ecosystem services (Cardinale et al., 2012; IPBES, 2019). As a result, biodiversity conservation functions as a core organizing principle that connects multiple areas of ecological research within the broader conservation framework.

Green Cluster: Ecosystem Processes and Ecological Functioning

The **green cluster** primarily reflects research themes related to ecosystem functioning and ecological interactions. Keywords within this cluster often focus on the processes that sustain plant communities and ecological systems, including nutrient cycling, ecosystem productivity, community dynamics, and species interactions.



This cluster highlights the growing recognition that plant conservation is closely linked with ecosystem-level processes. Studies within this thematic domain often examine how plant diversity influences ecosystem resilience, stability, and the long-term functioning of ecological systems. Research in biodiversity–ecosystem functioning has demonstrated that diverse ecosystems tend to exhibit greater productivity, stability, and resistance to environmental disturbances (Tilman et al., 1997; Hooper et al., 2005; Cardinale et al., 2012). Consequently, research in this area emphasizes that effective conservation efforts must account for the ecological mechanisms that maintain biodiversity within natural habitats.

Blue Cluster: Climate Change and Environmental Drivers

The **blue cluster** represents research focused on climate change and environmental drivers influencing plant biodiversity and ecosystems. Keywords in this cluster are commonly associated with climate variability, environmental stressors, ecological responses to changing climatic conditions, and long-term environmental monitoring.

The presence of this cluster reflects the increasing importance of climate change within plant conservation research. As global environmental conditions continue to shift, researchers are increasingly investigating how climate-related factors influence plant species distribution, habitat suitability, and ecosystem dynamics. Scientific studies have demonstrated that climate change is already affecting species distributions and ecological processes across many ecosystems worldwide (Walther et al., 2002; Parmesan & Yohe, 2003; Bellard et al., 2012). The integration of climate-related themes within the broader network therefore indicates that climate change has become a critical component of contemporary conservation science.

Yellow Cluster: Conservation Management and Monitoring Approaches

The **yellow cluster** represents research themes related to conservation management strategies, policy frameworks, and ecological monitoring techniques. Keywords within

this cluster often relate to biodiversity assessment methods, conservation planning, restoration practices, and decision-support systems used in environmental management.

This cluster highlights the applied dimension of plant conservation research, where scientific knowledge is translated into practical strategies aimed at protecting biodiversity and maintaining ecosystem health. Studies within this cluster often explore methods for evaluating conservation outcomes, designing effective management plans, and developing policies that support sustainable environmental stewardship. Increasingly, conservation science recognizes that biodiversity protection requires collaboration among scientists, policymakers, and local stakeholders in order to achieve effective environmental governance (Reed, 2008; Bennett et al., 2017).

Interconnections Between Clusters

Although the clusters appear as distinct thematic groups within the network visualization, the map clearly demonstrates that they are closely interconnected. Biodiversity-related concepts within the red cluster often connect with ecosystem processes in the green cluster, illustrating how species conservation is closely tied to ecological functioning. Similarly, climate-related research in the blue cluster frequently intersects with both ecological and conservation management themes, reflecting the influence of environmental change on conservation strategies.

The yellow cluster often acts as a link between ecological research and practical implementation, bridging scientific knowledge with policy development and conservation management. Its connections with the other clusters indicate that effective conservation strategies depend on integrating ecological science, climate research, and governance frameworks. Integrating social, ecological, and policy perspectives has increasingly been recognized as essential for addressing complex conservation challenges (Bennett et al., 2017; IPBES, 2019).

Overall Interpretation

Overall, the network visualization presented in Figure 4.9 reveals that long-term plant conservation research is structured around **four interconnected thematic domains**: biodiversity conservation, ecosystem functioning, climate change impacts, and conservation management strategies. The network structure demonstrates that these domains are not isolated areas of research but rather form an integrated conceptual framework that reflects the complex and multidisciplinary nature of conservation science.

These findings align with the results presented in the earlier bibliometric analyses in the chapter, including the keyword occurrence analysis and density visualization maps. Together, these results indicate that while biodiversity conservation remains the central focus of the field, contemporary research increasingly incorporates ecosystem processes, climate dynamics, and policy-driven management approaches to address the complex challenges associated with long-term plant conservation.

In summary, Figure 12. provides a comprehensive visualization of the conceptual organization and thematic relationships within the literature, illustrating how multiple research domains interact to shape the evolving scientific discourse on plant conservation.

Chapter 5: Discussion

5.1 Overview of the Study

This study sets out to examine the intellectual structure, thematic evolution, and underlying dynamics of long-term plant conservation research through the application of citation network analysis and bibliometric techniques. By systematically analyzing a corpus of one thousand per week reviewed scientific articles retrieved from the Web of Science Core Collection, the research aimed to identify dominant research domains, conceptual relationships, and patterns of knowledge dissemination within the field of plant conservation.

The methodological framework combined VOSviewer based network visualization with supplementary analytical procedures conducted in Python, enabling both quantitative and structural interpretation of scientific literature. Through the construction of keyword co-occurrence networks, cluster mapping, and density visualization, the study provided a comprehensive representation of how plant conservation research is organized, how ideas are interconnected, and how thematic priorities have evolved over time.

The findings contribute to a deeper understanding of conservation science as a complex and multidisciplinary field, shaped by ecological, climatic, technological, and sociopolitical influences. By situating these findings within the framework of Diffusion of Innovations Theory, the study also offers a conceptual lens through which the spread and adoption of conservation knowledge can be interpreted.

5.2 Synthesis of Major Findings

The bibliometric and keyword co-occurrence analyses revealed that long-term plant conservation research constitutes a mature, highly interconnected, and increasingly multidisciplinary field of scientific inquiry. The structure of the literature demonstrates that plant conservation is no longer approached solely as a biological or ecological issue but is increasingly understood as a complex challenge requiring the integration of environmental, technological, governance, and socio-economic perspectives.

The analysis identified a network comprising sixty keywords organized into four major thematic clusters connected through approximately four hundred and eighty links and a total link strength of two thousand four hundred and seventy-five. These indicators demonstrate a substantial degree of conceptual integration among research topics and suggest that contemporary plant conservation research is characterized by strong

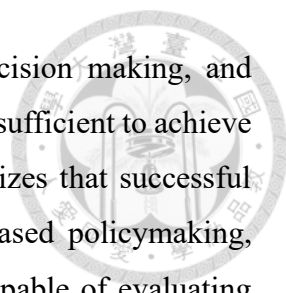
interactions among multiple knowledge domains. Rather than developing independently, key research themes appear to reinforce one another through shared concepts, methodologies, and conservation objectives.

The first major finding concerns the central role of biodiversity conservation within the scientific literature. Keywords associated with biodiversity, conservation, ecosystem services, and restoration occupied dominant positions within the co-occurrence network, indicating that the preservation of plant diversity remains the primary focus of long-term conservation efforts. The findings suggest that biodiversity conservation continues to serve as the conceptual foundation upon which many other conservation strategies and research priorities are built. This centrality reflects the recognition that plant diversity underpins ecosystem functioning, ecological resilience, and the provision of ecosystem services essential for both environmental sustainability and human wellbeing.

A second major finding is the increasing emphasis on ecosystem-based approaches to conservation. The identified thematic clusters demonstrate that conservation research has progressively moved beyond species-level protection toward broader ecosystem-oriented perspectives. Frequent associations among keywords related to ecosystem functioning, ecological communities, restoration, and environmental management indicate a growing recognition that effective conservation requires maintaining ecological processes and interactions rather than focusing exclusively on individual species. This shift reflects a broader understanding that long-term biodiversity preservation depends on the protection of entire ecosystems and the ecological relationships that sustain them.

The analysis also revealed the growing influence of climate change as a defining theme within plant conservation research. Climate-related keywords appeared prominently within the network and formed a distinct thematic domain connected to biodiversity conservation and ecosystem management. This finding suggests that climate change is increasingly viewed not simply as an external environmental pressure but as a fundamental factor shaping conservation priorities, research agendas, and management strategies. The literature indicates a transition from traditional conservation approaches toward adaptive frameworks that seek to enhance ecosystem resilience and accommodate long-term environmental change.

Another important finding concerns the increasing importance of governance, monitoring, and policy implementation within conservation science. The presence of a dedicated



cluster focused on monitoring systems, conservation planning, decision making, and policy frameworks demonstrates that scientific knowledge alone is insufficient to achieve effective conservation outcomes. The literature increasingly recognizes that successful plant conservation depends upon institutional capacity, evidence-based policymaking, stakeholder participation, and long-term monitoring mechanisms capable of evaluating conservation effectiveness over time.

Collectively, these findings reveal several significant challenges confronting long-term plant conservation. Habitat degradation, biodiversity loss, climate change, ecosystem fragmentation, and limitations in conservation governance emerge as recurring concerns throughout the literature. These challenges are frequently interconnected, indicating that conservation problems cannot be addressed through isolated interventions. Instead, the literature emphasizes the need for integrated approaches capable of addressing multiple environmental pressures simultaneously.

At the same time, the findings identify several key enablers that support successful long-term conservation outcomes. These include ecosystem restoration, protected-area management, biodiversity monitoring systems, technological innovation, adaptive management strategies, interdisciplinary collaboration, and the development of effective policy frameworks. The recurring presence of these themes throughout the literature suggests that successful conservation depends not only on understanding ecological problems but also on developing practical mechanisms through which conservation objectives can be implemented and sustained.

The density visualization further revealed that biodiversity conservation, ecosystem services, climate change adaptation, and ecological management represent the principal knowledge hubs within the field. These highly concentrated areas of research indicate where scientific attention has been most strongly directed. Simultaneously, lower density regions within the network suggest the existence of emerging and underexplored research areas, highlighting opportunities for future investigation and interdisciplinary expansion.

Overall, the findings demonstrate that long-term plant conservation research has evolved into an integrated field characterized by strong connections among biodiversity science, ecosystem management, climate adaptation, governance, and technological innovation. The literature increasingly supports the view that long-term conservation success depends upon the simultaneous consideration of ecological, environmental, institutional, and

societal factors. Consequently, effective biodiversity preservation and ecosystem sustainability require coordinated strategies that address both the challenges threatening plant diversity and the enabling conditions necessary for successful conservation implementation.



5.3 Interpretation within the Theoretical Framework

The thematic clusters identified through keyword co-occurrence analysis provide important insight into how scientific knowledge related to long-term plant conservation is organized and how different research domains contribute to the broader objective of biodiversity preservation. Although each cluster represents a distinct area of investigation, the strong interconnections observed within the network indicate that effective conservation depends upon the integration of multiple scientific perspectives rather than isolated disciplinary approaches.

5.3.1 Cluster 1: Biodiversity Conservation and Ecosystem Services

The first thematic cluster represents the conceptual core of the plant conservation literature. Dominated by keywords such as biodiversity, conservation, ecosystem services, restoration, and sustainability, this cluster reflects the primary objective of long-term plant conservation research: the protection and maintenance of biological diversity.

The prominence of biodiversity-related concepts suggests that the preservation of plant diversity remains the central concern of conservation science. However, the cluster also demonstrates that biodiversity is increasingly viewed within the broader context of ecosystem services and ecological sustainability. The frequent association between biodiversity and ecosystem services indicates a growing recognition that plant conservation contributes not only to species preservation but also to the maintenance of essential ecological functions that support human societies.

The findings therefore suggest that modern conservation approaches increasingly emphasize the interconnected relationship between biodiversity protection and ecosystem resilience.

5.3.2 Cluster 2: Species Diversity and Ecosystem Functioning

The second cluster highlights the ecological foundations of conservation science. Keywords within this domain focus on species richness, ecological communities, ecosystem functioning, and biological interactions.

The cluster demonstrates that scientific research increasingly recognizes the importance of ecological complexity in maintaining long-term ecosystem stability. Rather than viewing conservation solely as the protection of individual species, the literature emphasizes the preservation of ecological relationships and processes that sustain biodiversity over time.

This cluster supports the argument that successful conservation requires a systems based perspective capable of addressing interactions among species, habitats, and ecological processes. The emphasis on ecosystem functioning also suggests that conservation outcomes should be evaluated not only through species counts but also through the ability of ecosystems to maintain their ecological integrity and resilience.

5.3.3 Cluster 3: Climate Change and Environmental Dynamics

The third cluster reflects the growing influence of climate change within plant conservation research. The frequent occurrence of climate-related keywords demonstrates that environmental change has become one of the defining challenges confronting long-term biodiversity preservation.

The literature represented within this cluster focuses on the impacts of changing environmental conditions on plant communities, species distributions, ecosystem processes, and conservation effectiveness. The strong connections between climate change and biodiversity-related themes indicate that conservation planning increasingly incorporates considerations of environmental uncertainty and ecological adaptation.

The emergence of this cluster suggests a shift in conservation science from static preservation models toward adaptive management approaches designed to accommodate future environmental change. Consequently, climate resilience has become an essential component of contemporary conservation strategies.

5.3.4 Cluster 4: Governance, Monitoring, and Conservation Management

The fourth cluster represents the applied and institutional dimensions of plant conservation. Keywords associated with monitoring, governance, policy frameworks, decision-making, and management practices indicate a growing emphasis on the implementation and evaluation of conservation actions.

The presence of this cluster demonstrates that scientific knowledge alone is insufficient to achieve successful conservation outcomes. Effective biodiversity preservation requires

governance structures capable of translating scientific findings into practical conservation interventions.

Furthermore, the importance of monitoring-related keywords highlights the need for long-term observation systems that can evaluate conservation effectiveness and support adaptive management. This finding reinforces the view that conservation success depends not only on ecological knowledge but also on institutional capacity, stakeholder engagement, and evidence-based decision-making.

Integrated Interpretation of the Clusters

Although the four clusters represent distinct thematic domains, the network analysis demonstrates that they are highly interconnected. Biodiversity conservation provides the central objective, ecosystem functioning explains the ecological mechanisms supporting conservation, climate change introduces external pressures requiring adaptation, and governance structures provide the means through which conservation actions are implemented.

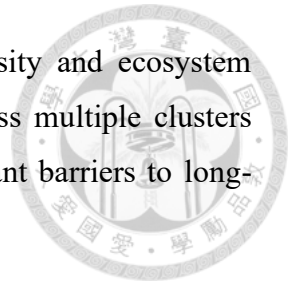
Taken together, the clusters reveal that long-term plant conservation is fundamentally a multidisciplinary endeavor. The literature increasingly supports integrated approaches that combine ecological science, environmental management, climate adaptation, policy development, and stakeholder participation. The strong relationships among clusters suggest that future conservation success will depend upon the ability to coordinate these diverse elements within comprehensive and adaptive conservation frameworks.

5.4 Challenges in Long-Term Plant Conservation

The thematic analysis conducted in this study reveals that long-term plant conservation is confronted by multiple interconnected challenges that threaten biodiversity preservation and ecosystem sustainability. Although the literature demonstrates significant progress in conservation science, the persistence of environmental pressures, governance limitations, and emerging ecological threats continues to complicate conservation efforts worldwide.

One of the most prominent challenges identified within the literature is habitat loss and ecosystem degradation. The continued conversion of natural ecosystems for agricultural expansion, urban development, infrastructure projects, and resource extraction has resulted in the fragmentation and reduction of critical habitats. Habitat degradation not only decreases the availability of suitable environments for plant species but also disrupts

ecological interactions that are essential for maintaining biodiversity and ecosystem functioning. The recurring presence of habitat-related themes across multiple clusters indicates that habitat degradation remains one of the most significant barriers to long-term conservation success.



A second major challenge is the accelerating impact of climate change on plant populations and ecosystems. The increasing frequency of extreme weather events, shifting temperature patterns, altered precipitation regimes, and changing ecological conditions create substantial uncertainty for conservation planning. The prominence of climate-related keywords within the co-occurrence network suggests that climate change is now widely recognized as a fundamental driver of biodiversity loss and ecosystem transformation. Unlike many traditional conservation challenges, climate change operates across broad spatial and temporal scales, requiring adaptive and forward-looking conservation approaches capable of responding to dynamic environmental conditions.

The findings also highlight biodiversity decline as a continuing global concern. The reduction of species richness, genetic diversity, and ecosystem complexity threatens the resilience of ecological systems and undermines their capacity to provide essential ecosystem services. The literature increasingly emphasizes that biodiversity loss is not merely an environmental issue but a challenge with significant implications for food security, water resources, climate regulation, and human well-being. Consequently, reversing biodiversity decline remains a central objective of long-term conservation efforts.

Another challenge emerging from the analysis is ecosystem fragmentation. Fragmented landscapes often isolate plant populations, restrict gene flow, reduce habitat connectivity, and increase vulnerability to environmental disturbances. Fragmentation can also limit the effectiveness of protected areas by preventing species migration and ecological adaptation. The literature suggests that maintaining ecological connectivity has become an increasingly important consideration within conservation planning, particularly in the context of climate change and landscape-scale environmental management.

The thematic clusters further reveal challenges associated with conservation governance and implementation. While scientific knowledge regarding biodiversity conservation continues to expand, translating research findings into effective conservation action remains difficult. Policy limitations, insufficient funding, institutional constraints,

inconsistent management practices, and competing socio-economic priorities frequently hinder conservation implementation. The prominence of governance and management related themes suggests that successful conservation depends not only on scientific understanding but also on the capacity of institutions to implement and sustain effective interventions.

The analysis additionally identifies challenges related to long-term monitoring and data availability. Effective conservation requires continuous assessment of ecological conditions, species populations, and ecosystem responses. However, many regions continue to face limitations in monitoring infrastructure, technical capacity, and long term data collection. These constraints can reduce the ability of conservation practitioners to evaluate management effectiveness, detect emerging threats, and implement adaptive management strategies.

Geographic disparities within conservation research also emerge as a significant concern. The literature indicates that scientific knowledge production is concentrated within certain regions, while many biodiversity-rich areas remain comparatively underrepresented. This imbalance may limit understanding of region-specific conservation challenges and reduce the applicability of existing knowledge to diverse ecological and socio-economic contexts. Expanding research efforts within underrepresented regions is therefore essential for developing more globally inclusive conservation strategies.

Importantly, the challenges identified in this study should not be viewed as independent issues. Habitat degradation, climate change, biodiversity loss, ecosystem fragmentation, governance limitations, and monitoring constraints are closely interconnected and often reinforce one another. The literature consistently demonstrates that conservation problems operate within complex social-ecological systems, where environmental, institutional, and human factors interact in dynamic ways.

Overall, the findings suggest that long-term plant conservation requires a shift from isolated interventions toward integrated conservation strategies capable of addressing multiple challenges simultaneously. The complexity of these challenges underscores the need for interdisciplinary approaches that combine ecological science, environmental management, technological innovation, governance mechanisms, and stakeholder

participation. Only through such integrated approaches can conservation efforts effectively support long-term biodiversity preservation and ecosystem sustainability.

5.5 Implications for Research and Practice

The results of this study have significant implications for both the advancement of scientific research and the practical implementation of conservation strategies.

First, strong interdependence among thematic clusters highlights the necessity of adopting integrated and interdisciplinary approaches to plant conservation. Addressing complex environmental challenges requires the combination of ecological knowledge, climate science, and governance mechanisms. Future research should therefore prioritize cross disciplinary collaboration and the development of comprehensive frameworks that account for multiple dimensions of conservation.

Second, the increasing prominence of climate related research underscores the need to incorporate adaptive and forward-looking strategies into conservation planning. As environmental conditions continue to change, conservation efforts must move beyond static protection models and embrace approaches that enhance resilience and facilitate adaptation.

Third, the presence of governance and policy-oriented themes indicates that the effectiveness of conservation efforts depends not only on scientific knowledge but also on the ability to translate that knowledge into actionable policies. Strengthening the link between research and policy is essential for improving conservation outcomes and ensuring that scientific insights are effectively applied in real world contexts.

Fourth, the emergence of data driven and analytical approaches within the network suggests that technological innovation will play an increasingly important role in conservation science. The integration of advanced tools such as remote sensing, geographic information systems, and machine learning has the potential to improve monitoring, enhance decision making, and optimize resource allocation.

Finally, the findings highlight the existence of geographic and thematic gaps within the literature. Limited representation from certain regions and underexplored topics suggests the need for more inclusive and comprehensive research efforts. Expanding the scope of conservation research to include diverse ecosystems, local knowledge systems, and

underrepresented regions will be critical for achieving global biodiversity conservation goals.



5.6 Enablers of Long-Term Plant Conservation

While the literature identifies numerous challenges that threaten biodiversity preservation and ecosystem sustainability, it also reveals a range of enabling factors that support successful long-term plant conservation outcomes. These enablers represent the mechanisms, strategies, and institutional conditions that enhance conservation effectiveness and improve the capacity of ecosystems and societies to respond to environmental change. The findings suggest that successful conservation is not solely dependent on mitigating threats but also on strengthening the systems and processes that facilitate biodiversity protection and ecological resilience.

One of the most significant enablers identified within the literature is the establishment and effective management of protected areas. Protected areas continue to serve as a cornerstone of global conservation efforts by providing secure habitats for plant species and safeguarding critical ecological processes. The strong presence of conservation related keywords within the network indicates that protected-area management remains a widely recognized and extensively researched strategy for preserving biodiversity. However, the literature also emphasizes that the effectiveness of protected areas depends upon appropriate planning, adequate resources, long-term monitoring, and adaptive management practices.

A second major enabler is ecosystem restoration. Restoration activities have emerged as a central component of contemporary conservation strategies, particularly in response to widespread habitat degradation and biodiversity loss. The prominence of restoration related concepts within the thematic clusters suggests a growing recognition that conservation should not be limited to protecting existing ecosystems but should also include efforts to rehabilitate degraded environments. Restoration initiatives contribute to biodiversity recovery, improve ecosystem functioning, enhance ecological connectivity, and increase resilience to environmental disturbances. As a result, restoration has become an increasingly important tool for achieving long-term conservation objectives.

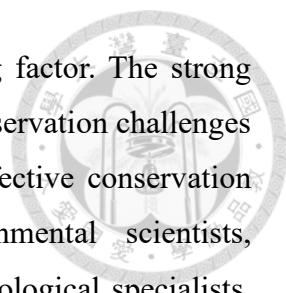
The findings further highlight the importance of ecological monitoring and assessment systems. Long-term monitoring enables conservation practitioners to track ecological change, evaluate management effectiveness, identify emerging threats, and support

evidence-based decision-making. The presence of monitoring-related keywords within the network demonstrates the growing emphasis placed on data-driven conservation approaches. Effective monitoring systems provide the information necessary for adaptive management and ensure that conservation interventions can be adjusted in response to changing environmental conditions.

Technological innovation also emerges as a key enabling factor. Advances in remote sensing, geographic information systems (GIS), environmental modeling, artificial intelligence, and biodiversity informatics have significantly expanded the capacity of researchers and conservation practitioners to monitor ecosystems and analyze environmental change. These technologies improve the efficiency, accuracy, and scale of conservation assessments while facilitating more informed decision-making. The increasing integration of technological tools within conservation research suggests that innovation will continue to play an important role in addressing complex environmental challenges.

Another important enabler identified in the literature is the development of effective governance and policy frameworks. Conservation success depends not only on scientific knowledge but also on the existence of institutional structures capable of implementing and enforcing conservation measures. Policies that support habitat protection, biodiversity management, ecological restoration, and sustainable land-use practices create the conditions necessary for long-term conservation outcomes. The prominence of governance-related themes within the network indicates that conservation is increasingly recognized as both an ecological and institutional challenge requiring coordinated action across multiple levels of governance.

Stakeholder participation and community engagement are also identified as essential components of successful conservation. The literature increasingly emphasizes the importance of involving local communities, indigenous groups, non-governmental organizations, and other stakeholders in conservation planning and implementation. Participatory approaches can improve conservation effectiveness by incorporating local knowledge, enhancing social acceptance, and strengthening long-term stewardship of natural resources. The growing recognition of stakeholder involvement reflects a broader shift toward more inclusive and collaborative conservation models.



Interdisciplinary collaboration emerges as another critical enabling factor. The strong interconnections observed among thematic clusters indicate that conservation challenges cannot be addressed through a single disciplinary perspective. Effective conservation increasingly requires collaboration among ecologists, environmental scientists, policymakers, economists, geographers, social scientists, and technological specialists. Such collaboration facilitates the integration of diverse forms of knowledge and supports the development of comprehensive solutions to complex conservation problems.

The findings additionally suggest that adaptive management plays a central role in enabling long-term conservation success. Given the uncertainty associated with climate change, environmental variability, and socio-economic change, conservation strategies must remain flexible and responsive. Adaptive management provides a structured approach for learning from experience, evaluating outcomes, and modifying interventions based on new information. The increasing prominence of adaptive approaches within the literature reflects a recognition that conservation must be viewed as an ongoing and dynamic process rather than a fixed set of actions.

Collectively, these enabling factors demonstrate that successful long-term plant conservation depends upon the interaction of ecological, technological, institutional, and social mechanisms. Protected-area management, ecosystem restoration, monitoring systems, technological innovation, governance frameworks, stakeholder participation, interdisciplinary collaboration, and adaptive management all contribute to strengthening conservation effectiveness and supporting biodiversity preservation.

Importantly, the literature suggests that no single enabling factor is sufficient on its own. Rather, successful conservation outcomes are most likely to emerge when multiple enabling mechanisms operate together within an integrated conservation framework. The combined application of scientific knowledge, technological tools, effective governance, and stakeholder engagement provides the strongest foundation for addressing conservation challenges and achieving long-term ecosystem sustainability.

5.7 Implications for Biodiversity Conservation and Ecosystem Preservation

The findings of this study provide important insights into the future of biodiversity conservation and ecosystem preservation. By examining the intellectual structure of long-term plant conservation research, the analysis demonstrates that biodiversity protection is increasingly understood as a multidimensional challenge requiring ecological,

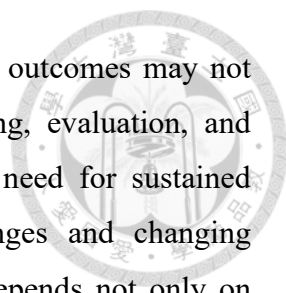
technological, institutional, and societal responses. The identified thematic clusters, conservation challenges, and enabling factors collectively illustrate how contemporary conservation science has evolved toward more integrated and adaptive approaches to environmental management.

One of the most significant implications of the findings is the recognition that biodiversity conservation cannot be achieved through species protection alone. The strong connections among biodiversity, ecosystem services, restoration, ecological resilience, and environmental management indicate that conservation success depends on maintaining the broader ecological systems that support plant diversity. This finding reinforces the growing consensus within conservation science that ecosystem-level approaches are essential for achieving long-term biodiversity outcomes. Protecting individual species without preserving the ecological processes and habitats upon which they depend is unlikely to provide sustainable conservation benefits.

The results also highlight the critical relationship between biodiversity and ecosystem functioning. The literature consistently demonstrates that diverse plant communities contribute to ecosystem stability, productivity, resilience, and the provision of ecosystem services. Consequently, biodiversity preservation should not be viewed solely as an objective of environmental protection but also as a prerequisite for maintaining ecosystem services that support human well-being. The implications extend beyond conservation policy to broader sustainability agendas involving food security, climate regulation, water resource management, and disaster risk reduction.

Another important implication concerns the increasing influence of climate change on conservation priorities. The prominence of climate-related themes throughout the literature indicates that future conservation strategies must account for dynamic environmental conditions rather than assuming ecological stability. Traditional conservation approaches often focused on protecting species and habitats within fixed geographic boundaries. However, the findings suggest that conservation planning must increasingly incorporate adaptive management, ecological connectivity, and climate resilience to ensure that ecosystems remain capable of supporting biodiversity under changing environmental conditions.

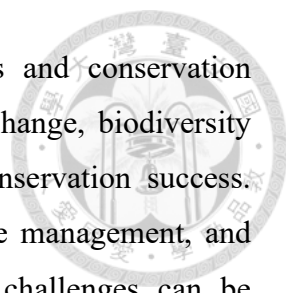
The study further demonstrates that ecosystem preservation requires long-term perspectives that extend beyond short-term conservation interventions. Many ecological



processes operate over extended temporal scales, and conservation outcomes may not become fully apparent for decades. The importance of monitoring, evaluation, and adaptive management identified within the literature reflects the need for sustained conservation efforts capable of responding to emerging challenges and changing ecological conditions. Long-term conservation success therefore depends not only on initial interventions but also on continuous learning, assessment, and adaptation. The findings additionally emphasize the importance of governance and institutional capacity in achieving biodiversity conservation objectives. Scientific knowledge alone cannot guarantee conservation success. Effective implementation requires supportive policy frameworks, adequate financial resources, institutional coordination, and stakeholder engagement. The prominence of governance-related themes within the literature suggests that conservation outcomes are strongly influenced by the ability of institutions to translate scientific evidence into practical action. Consequently, strengthening governance systems should be regarded as a central component of biodiversity conservation strategies.

Another significant implication relates to the role of technological innovation in supporting ecosystem preservation. Advances in remote sensing, environmental monitoring, geographic information systems, artificial intelligence, and ecological modeling have expanded the capacity of researchers and practitioners to monitor biodiversity and evaluate conservation effectiveness. The increasing integration of these technologies within conservation science suggests that future biodiversity management will become increasingly data-driven and evidence-based. Such developments have the potential to improve conservation planning, enhance decision-making, and facilitate more efficient allocation of conservation resources.

The findings also highlight the importance of inclusive and collaborative approaches to conservation. The growing emphasis on stakeholder participation, community engagement, and interdisciplinary collaboration reflects a broader understanding that biodiversity conservation is not solely an ecological challenge but also a social and institutional one. Effective conservation requires cooperation among governments, researchers, local communities, non-governmental organizations, and private-sector stakeholders. Such collaborative approaches can improve conservation legitimacy, strengthen implementation capacity, and enhance long-term sustainability.



Importantly, the study demonstrates that conservation challenges and conservation enablers are closely interconnected. Habitat degradation, climate change, biodiversity loss, and governance limitations create significant barriers to conservation success. However, ecosystem restoration, technological innovation, adaptive management, and effective governance provide mechanisms through which these challenges can be addressed. The literature therefore suggests that conservation outcomes are determined not only by the severity of environmental threats but also by the capacity of institutions and societies to develop effective responses.

Overall, the findings indicate that long-term biodiversity conservation and ecosystem preservation require integrated approaches that combine ecological knowledge, technological innovation, policy support, stakeholder engagement, and adaptive management. The future of plant conservation depends upon the ability to balance environmental protection with social, economic, and institutional considerations while maintaining the ecological processes that sustain biodiversity. Consequently, successful conservation should be viewed as a continuous and collaborative process aimed at strengthening both ecological resilience and societal capacity to respond to environmental change.

5.8 Implications for Research and Practice

The findings of this study have important implications for both the advancement of conservation research and the practical implementation of long-term plant conservation strategies. The bibliometric and keyword co-occurrence analyses demonstrate that contemporary conservation challenges are increasingly complex, requiring integrated approaches that combine ecological science, technological innovation, governance mechanisms, and stakeholder participation. Consequently, future efforts to preserve plant biodiversity and ecosystem integrity must move beyond isolated interventions and adopt more comprehensive and adaptive frameworks.

5.8.1 Implications for Conservation Research

One of the most significant research implications arising from this study is the need for greater interdisciplinary integration within conservation science. The strong connections observed among biodiversity conservation, ecosystem functioning, climate change, restoration ecology, governance, and monitoring indicate that conservation issues cannot be adequately understood through a single disciplinary perspective. Future research

should therefore promote collaboration among ecologists, environmental scientists, climate researchers, policy analysts, economists, geographers, social scientists, and technological specialists. Such collaboration will facilitate a more holistic understanding of conservation challenges and support the development of more effective solutions.

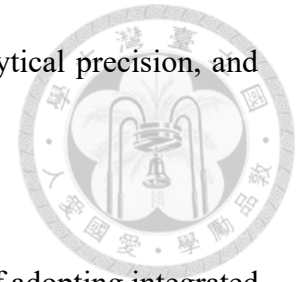
The findings also suggest that future research should place greater emphasis on long-term ecological monitoring and assessment. The prominence of monitoring-related themes within the literature reflects the growing recognition that conservation outcomes can only be effectively evaluated through sustained observation and data collection. Long-term monitoring programs provide essential information regarding species responses, ecosystem changes, conservation effectiveness, and emerging environmental threats. Strengthening these monitoring efforts will improve the scientific basis for adaptive management and evidence-based conservation planning.

Another important implication concerns the need to address geographic and thematic imbalances within the existing literature. The analysis indicates that certain regions and conservation contexts remain underrepresented within scientific research. Expanding research efforts in biodiversity-rich but understudied regions will improve the global applicability of conservation knowledge and contribute to a more comprehensive understanding of conservation challenges across diverse ecological and socio-economic settings.

The growing prominence of climate-related themes further highlights the importance of research focused on climate adaptation and ecosystem resilience. As climate change continues to influence species distributions, ecological processes, and habitat conditions, future research must develop conservation approaches capable of accommodating environmental uncertainty and long-term ecological change. Investigations into adaptive management, climate-resilient ecosystems, ecological connectivity, and assisted restoration may therefore become increasingly important components of conservation science.

In addition, the findings suggest that technological innovation will continue to shape the future direction of conservation research. The increasing use of remote sensing, geographic information systems, environmental modeling, artificial intelligence, and biodiversity informatics demonstrates the growing role of technology in conservation monitoring and decision-making. Future studies should explore how emerging

technologies can improve conservation effectiveness, increase analytical precision, and support more efficient resource allocation.



5.8.2 Implications for Conservation Practice

From a practical perspective, the findings reinforce the importance of adopting integrated conservation strategies that address both ecological and institutional dimensions of biodiversity preservation. Conservation practitioners should recognize that successful outcomes depend not only on protecting species and habitats but also on strengthening governance systems, enhancing stakeholder engagement, and supporting long-term monitoring programs.

The identification of ecosystem restoration as a major enabling factor suggests that restoration initiatives should remain a central component of conservation planning. Restoration programs can contribute to biodiversity recovery, improve ecosystem functioning, strengthen ecological connectivity, and increase resilience to environmental disturbances. Consequently, policymakers and conservation organizations should continue investing in restoration efforts as part of broader sustainability strategies.

The findings also highlight the importance of adaptive management in conservation practice. Given the uncertainty associated with climate change and environmental variability, conservation interventions should remain flexible and responsive to new information. Adaptive management frameworks enable practitioners to evaluate outcomes, learn from experience, and modify strategies as conditions change. This approach increases the likelihood that conservation efforts will remain effective over extended time periods.

Another practical implication concerns the role of policy and governance. The literature demonstrates that scientific knowledge alone cannot guarantee conservation success. Effective implementation requires supportive institutional frameworks, adequate funding, clear policy objectives, and coordination among stakeholders. Governments and conservation agencies should therefore prioritize the development of policies that facilitate evidence-based conservation and encourage collaboration among researchers, practitioners, and local communities.

The study additionally underscores the importance of stakeholder participation in achieving long-term conservation goals. Community involvement, indigenous knowledge

integration, and collaborative governance mechanisms can enhance conservation legitimacy, improve implementation effectiveness, and strengthen local stewardship of natural resources. Conservation initiatives that actively engage stakeholders are often better positioned to achieve sustainable outcomes than those relying solely on top-down management approaches.

5.8.3 Broader Sustainability Implications

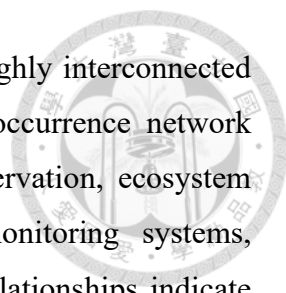
Beyond the immediate context of plant conservation, the findings have broader implications for global sustainability efforts. Biodiversity conservation contributes directly to ecosystem stability, climate regulation, water security, food production, and the maintenance of ecosystem services that support human societies. Consequently, protecting plant diversity is not solely an environmental objective but also a critical component of sustainable development.

The strong connections observed between biodiversity, ecosystem services, climate adaptation, and environmental management suggest that conservation should be viewed as an integral element of broader sustainability strategies. Achieving long-term environmental sustainability will require coordinated efforts that simultaneously address biodiversity loss, climate change, ecosystem degradation, and socio-economic development challenges.

Overall, the findings indicate that future conservation success will depend upon the ability of researchers, practitioners, policymakers, and communities to work collaboratively within integrated and adaptive frameworks. By strengthening the links between scientific knowledge, technological innovation, governance systems, and practical implementation, conservation efforts can better support biodiversity preservation and ecosystem sustainability in an increasingly complex and changing world.

5.9 Chapter Summary

This chapter discussed the findings of the bibliometric and keyword co-occurrence analysis and examined their implications for long-term plant conservation research. Through the interpretation of thematic clusters, conservation challenges, enabling factors, and broader sustainability implications, the chapter provided a comprehensive understanding of how scientific knowledge within the field is structured and how it contributes to biodiversity preservation and ecosystem sustainability.



The analysis demonstrated that long-term plant conservation is a highly interconnected and multidisciplinary field of study. The identified keyword co-occurrence network revealed strong conceptual relationships among biodiversity conservation, ecosystem functioning, climate change adaptation, restoration ecology, monitoring systems, governance frameworks, and environmental management. These relationships indicate that contemporary conservation research increasingly recognizes the need for integrated approaches capable of addressing complex ecological and environmental challenges.

The thematic cluster analysis revealed four major domains that collectively define the intellectual structure of the field. Biodiversity conservation and ecosystem services emerged as the conceptual foundation of conservation research, while species diversity and ecosystem functioning provided the ecological basis for understanding long-term conservation outcomes. Climate change and environmental dynamics highlighted the growing importance of adaptive conservation strategies, whereas governance, monitoring, and conservation management emphasized the institutional and practical dimensions of conservation implementation.

The discussion further identified several significant challenges affecting long-term plant conservation, including habitat degradation, biodiversity loss, climate change, ecosystem fragmentation, governance limitations, and constraints associated with long-term monitoring and data availability. These challenges were shown to be highly interconnected and capable of influencing conservation outcomes across multiple ecological and institutional scales.

At the same time, the analysis highlighted a range of enabling factors that support effective conservation efforts. Protected-area management, ecosystem restoration, biodiversity monitoring, technological innovation, adaptive management, stakeholder participation, interdisciplinary collaboration, and effective governance frameworks emerged as critical mechanisms for enhancing conservation success. The findings suggest that long-term biodiversity preservation depends not only on reducing environmental threats but also on strengthening the institutional, technological, and social conditions that facilitate conservation action.

Overall, the chapter demonstrates that successful long-term plant conservation requires integrated and adaptive approaches that combine ecological knowledge, technological innovation, effective governance, stakeholder engagement, and long-term monitoring.

The findings reinforce the view that biodiversity preservation and ecosystem sustainability are closely linked objectives that can only be achieved through coordinated efforts across scientific, institutional, and societal domains.

The insights generated through this discussion provide the foundation for the final chapter of the thesis, which presents the overall conclusions, recommendations, study limitations, and future research directions arising from the bibliometric analysis of long-term plant conservation literature.

Chapter 6: Conclusion and Recommendations

6.1 Conclusions

This study examined the intellectual structure, thematic organization, and research trends within the field of long-term plant conservation through the application of bibliometric and keyword co-occurrence analysis. Using publications retrieved from the Web of Science Core Collection and analyzed through VOSviewer, the research provided a systematic assessment of the dominant themes, conceptual relationships, conservation challenges, and enabling factors that characterize contemporary plant conservation literature.

The findings demonstrate that long-term plant conservation has evolved into a highly interconnected and multidisciplinary field of scientific inquiry. The keyword cooccurrence network revealed strong relationships among biodiversity conservation, ecosystem functioning, climate change adaptation, ecological restoration, monitoring systems, governance mechanisms, and environmental management. These relationships indicate that conservation science increasingly recognizes the complexity of biodiversity preservation and the need for integrated approaches capable of addressing multiple ecological and societal challenges simultaneously.

The thematic cluster analysis identified four major domains that collectively define the intellectual structure of plant conservation research. Biodiversity conservation and ecosystem services emerged as the conceptual core of the field, emphasizing the central importance of preserving plant diversity and maintaining ecological integrity. Species diversity and ecosystem functioning highlighted the ecological foundations of conservation, while climate change and environmental dynamics reflected the growing influence of environmental change on conservation priorities. Governance, monitoring, and conservation management underscored the importance of institutional capacity, policy frameworks, and evidence-based decision-making in achieving successful conservation outcomes.

The study further revealed that long-term plant conservation is confronted by numerous interconnected challenges, including habitat degradation, biodiversity loss, climate change, ecosystem fragmentation, governance constraints, and limitations in monitoring capacity. These challenges demonstrate that conservation cannot be effectively addressed

through isolated interventions and instead requires coordinated responses across ecological, institutional, and social dimensions.

At the same time, the findings identified several enabling factors that support conservation success. Protected-area management, ecosystem restoration, biodiversity monitoring, technological innovation, adaptive management, stakeholder participation, interdisciplinary collaboration, and effective governance frameworks were consistently identified as critical mechanisms for strengthening conservation outcomes. The literature suggests that these enabling factors are essential for enhancing ecosystem resilience and supporting long-term biodiversity preservation.

Overall, this study contributes to a deeper understanding of the intellectual landscape of long-term plant conservation research. By identifying key themes, challenges, enabling factors, and emerging trends, the research provides valuable insights for researchers, practitioners, and policymakers seeking to strengthen biodiversity conservation and ecosystem sustainability in an increasingly complex environmental context.

6.2 Recommendations

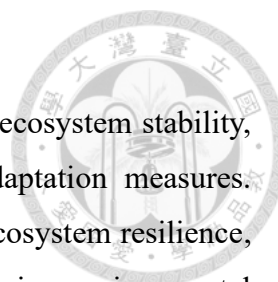
Based on the findings of this study, several recommendations are proposed to strengthen future conservation research and improve the effectiveness of long-term plant conservation initiatives.

6.2.1 Strengthening Interdisciplinary Collaboration

Conservation challenges are increasingly complex and interconnected. Future research and conservation programs should encourage collaboration among ecologists, environmental scientists, climate researchers, policymakers, economists, social scientists, and technological specialists. Such interdisciplinary approaches can facilitate the development of more comprehensive and effective conservation strategies.

6.2.2 Expanding Long-Term Monitoring Programs

Long-term monitoring systems are essential for evaluating conservation effectiveness and detecting ecological change. Governments, research institutions, and conservation organizations should invest in sustained monitoring programs capable of providing reliable data for adaptive management and evidence-based decision-making.



6.2.3 Enhancing Climate-Adaptive Conservation Strategies

Given the growing influence of climate change on biodiversity and ecosystem stability, conservation planning should increasingly incorporate climate adaptation measures. Conservation strategies should emphasize ecological connectivity, ecosystem resilience, and adaptive management approaches capable of responding to changing environmental conditions.

6.2.4 Promoting Ecosystem Restoration Initiatives

The findings demonstrate the importance of restoration activities in supporting biodiversity preservation and ecosystem recovery. Policymakers and conservation practitioners should continue to prioritize ecosystem restoration as a key component of long-term conservation planning.

6.2.5 Strengthening Policy and Governance Frameworks

Effective conservation requires supportive institutional structures and policy environments. Governments should strengthen conservation legislation, improve policy implementation mechanisms, and enhance coordination among stakeholders involved in biodiversity management and ecosystem preservation.

6.2.6 Increasing Stakeholder Participation

Conservation initiatives should actively involve local communities, indigenous groups, non-governmental organizations, and other stakeholders. Participatory approaches can improve conservation legitimacy, strengthen implementation effectiveness, and support long-term environmental stewardship.

6.2.7 Expanding the Use of Technological Innovation

The integration of remote sensing, geographic information systems, environmental modeling, artificial intelligence, and biodiversity informatics should be further encouraged. These technologies can improve conservation monitoring, increase analytical capabilities, and support more effective resource management.

6.3 Study Limitations

Several limitations should be considered when interpreting the findings of this study. First, the analysis was limited to publications indexed within the Web of Science Core Collection database. Although Web of Science is widely recognized as a high-quality source of scientific literature, relevant studies indexed in other databases such as Scopus,

Dimensions, Google Scholar, or regional databases were not included. Consequently, some relevant publications may not be represented within the dataset.

Second, the study focused exclusively on English-language publications. Research published in other languages may contain important perspectives and findings related to plant conservation, particularly in regions with high biodiversity but limited representation in English-language journals.

Third, keyword co-occurrence analysis depends on the quality and consistency of author-provided keywords. Variations in terminology, keyword selection, and indexing practices may influence the structure of the network and the interpretation of thematic relationships. Fourth, the study provides a bibliometric representation of scientific literature rather than a direct assessment of conservation outcomes. While the analysis identifies dominant themes and research trends, it does not evaluate the actual effectiveness of conservation interventions implemented in practice.

Finally, the study represents a snapshot of the literature available at the time of data collection. As conservation science continues to evolve, emerging research themes and new innovations may alter the structure of the field in the future.

6.4 Future Research Directions

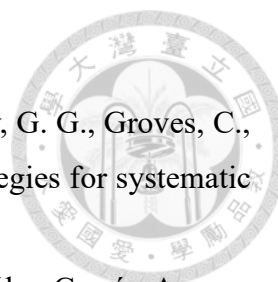
The findings of this study highlight several opportunities for future investigation. First, future bibliometric studies should incorporate multiple databases to improve literature coverage and enhance the comprehensiveness of analysis. Combining Web of Science with databases such as Scopus and Dimensions may provide a broader representation of global conservation research.

Second, greater attention should be given to underrepresented regions and ecosystems. Expanding research coverage in biodiversity-rich regions, particularly within developing countries, would contribute to a more balanced and globally inclusive understanding of conservation challenges and opportunities.

Third, future studies should explore the integration of ecological, social, economic, and governance dimensions of conservation. Such research would provide a more holistic understanding of sustainability and support the development of more effective conservation policies and practices.

Fourth, researchers should consider combining bibliometric methods with qualitative approaches, case studies, and field-based investigations. Mixed-methods research can provide deeper insight into how scientific knowledge influences conservation implementation and environmental outcomes.

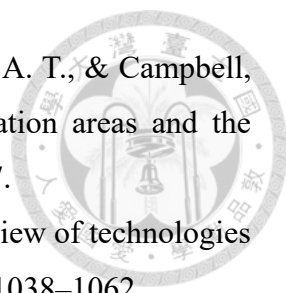
Finally, future research should investigate the relationship between scientific knowledge production and real-world conservation effectiveness. Understanding how research findings are translated into policy, management actions, and biodiversity outcomes remains a critical area for further study.

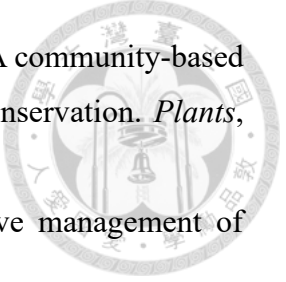


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