Integration of Indigenous Knowledge with Scientific Knowledge for Climate Change Adaptation in Forest Management: A Systematic Review

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Declaration by the candidate

I, Adrita Choudhury Tithi, hereby declare that this thesis entitled “Integration of indigenous knowledge with scientific knowledge for climate change adaptation in forest management: a systematic review” is an authentic record of my research conducted under the supervision of Dr. Kendisha Soekardjo Hintz at the Technical University of Dresden and Dr. Thorsten Treue at the University of Copenhagen. The results embodied in this thesis have not been submitted for any other degree or diploma award.

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Abbreviations

IK	Indigenous Knowledge
SK	Scientific Knowledge
TEK	Traditional Ecological Knowledge
ILK	Indigenous and Local Knowledge
TIK	Traditional Indigenous Knowledge
LEK	Local Ecological Knowledge
TEK	Traditional Environmental Knowledge
IEK	Indigenous Ecological Knowledge
TK	Traditional Knowledge

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Abstract

Indigenous Knowledge (IK) plays a vital role in sustaining forest ecosystems, yet its integration with Scientific Knowledge (SK) in climate-adaptive forest management remains uneven and shaped by structural, political, and epistemic challenges. This study presents a systematic review of 31 peer-reviewed publications and grey literature (2000–2025) to examine how IK contributes to climate-resilient forest management and to identify the broader conditions that enable or constrain its integration with scientific knowledge. Using inductive - deductive thematic analysis, six interlinked dimensions were assessed: the roles of IK, types of integration initiatives, benefits, constraints, governance politics, and policy recommendations. Findings show that IK enhances biodiversity conservation, fire and water regulation, species regeneration, cultural stewardship, and adaptive livelihood systems. Integration practices span a spectrum from informal, community-driven blending to formal co-management, co-produced modelling, and policy-embedded recognition. Successful integration is most evident where Indigenous rights are comparatively more secure, participatory institutions are strong, long-term trust and co-learning guide collaboration, and culturally grounded tools support dialogue across knowledge systems. Conversely, tenure insecurity, bureaucratic fragmentation, colonial legacies, and the dominance of scientific epistemologies often limit meaningful involvement of Indigenous actors and perspectives. Building on these insights, the study proposes a conceptual analytical framework guided by the Two-Eyed Seeing approach, that contributes to identify some key elements for integration. The framework conceptualizes integration as a layered, relational process shaped by constraints, politics, enabling conditions, and integration pathways, ultimately leading to desired outcomes such as climate-adaptive forest management, social equity, and knowledge pluralism. The results underscore the need for forest policy to bridge indigenous perceptions and scientific assessments by recognizing Indigenous authority and stewardship, strengthening collaborative institutions, and supporting respectful, long-term partnerships.

Keywords: Indigenous Knowledge, Scientific Knowledge, Climate Change Adaptation, Forest Management, Knowledge Integration, Two-Eyed Seeing, Integration Pathways

Chapter 1: Introduction

1.1. Background

The increasing urgency of climate change necessitates innovative and effective strategies for adaptation, particularly in forest management, which is crucial for maintaining ecological balance, biodiversity, and community livelihoods. Forests also play a vital role in mitigating climate change by acting as carbon sinks, absorbing billions of metric tons of CO2 annually (UNDP, 2023). As a result of climate change, air temperatures are rising and precipitation patterns are shifting, affecting snowfall as well as its timing, quantity, and interannual rainfall variability (IPCC 2013). Forests are long-lived, widely distributed ecosystems that are heavily and extensively managed. In addition, they are quite sensitive to long-lasting changes of climate change, just like the communities and economies that rely on them. (Keenan, 2015). Climate change is threatening to forests and presents challenges for forest managers as well. Adaptation in forest management due to climate change needs a sufficient understanding of climate change impacts in forests, industries, and human societies; prediction of how these impacts will change over time and integrate the knowledge and information in decision making. Now this requires the integration of multiple knowledge systems and new initiatives in forest management decisions (Keenan, 2015, Bohensky and Maru, 2011). Studies indicate the need for integrating indigenous knowledge into existing scientific knowledge and policies to ensure effective collaboration and implementation of natural resource management (Yanou et al., 2023; Akalibey et al., 2024; Makonnen et al., 2021). Adhikari (2015) highlighted indigenous knowledge of adaptation is based on Indigenous peoples' practical experience of dealing with rapid and harsh changes of climate change in forest ecosystems. For example, in recent years, Indigenous communities in rural Nepal have increasingly relied on Indigenous and Local Knowledge (ILK) to cope with both climatic and non-climatic challenges, as well as to guide adaptive forest management. For many Indigenous and marginalized groups, particularly those in remote regions, ILK remains the primary means of sustaining their lives and livelihoods amid harsh environmental conditions and persistent poverty. Such knowledge and practices support adaptive planning and local resource management by: (a) assessing and utilizing available forest ecosystem resources, (b) strengthening community awareness of climate-related risks, (c) identifying gaps in the adaptive capacities of individuals and institutions, and (d) reducing

adaptation costs through the use of locally available knowledge and resources (Adhikari, 2015). In order to delve deeper into Indigenous knowledge, the different terms used, sometimes simultaneously, in literature need to be explored and elucidated. These different terms - Indigenous Knowledge (IK), Indigenous and Local Knowledge (ILK), Traditional Knowledge (TK), Traditional Indigenous Knowledge (TIK), Traditional Environmental Knowledge (TEK), Indigenous Ecological Knowledge (IEK) and how they can be defined or used interchangeably have been discussed and reflected at length in many studies (e.g., Yanou et al., 2023; Bruchac, 2014; Chitengi Sakapaji, 2022; Bohensky & Maru, 2011; Akalibey et al., 2024; Leal Filho et al., 2022). Akalibey et al (2024) describes Indigenous knowledge (IK) as deep-rooted in the aggregated wisdom of the local communities, and comprising profound understanding of the forest ecosystems, seasonal variations, ecological dynamics, and also the delicate connection between humans and nature. This knowledge and wisdom are well established in culture, traditions, norms, belief systems that are practiced through the traditional practices and shared from one generation to another over time (Akalibey et al., 2024, Dorji et al., 2024) Indigenous knowledge is typically passed down orally and through customs and traditions, both formally and informally (Bruchac, 2014). Yanou et al. (2023), on the other hand, defined the term "Indigenous and Local Knowledge" (ILK) as the understandings, information, expertise, customs, beliefs that are created by communities through their long and deep interactions with their natural environment for a long time. For both indigenous peoples and rural people, local knowledge helps them in their decision making in the regular day to day activities. Studies like Adhikari (2015) have used use indigenous knowledge and indigenous and local knowledge simultaneously. Traditional indigenous knowledge is believed to be a network of knowledge, beliefs and different traditions that conserve, carry, and also contextualize the indigenous relation with their culture and landscape over the years. Usher (2000) classified traditional ecological knowledge (TEK) as knowledge about the environment, the use of the environment, the values about the environment, and the knowledge system itself. Then, when it comes to local ecological knowledge (LEK), in Chitengi Sakapaji (2022), indigenous ecological knowledge (IEK) and local ecological knowledge (LEK) have been used in an interchangeable manner. The terms refer to how indigenous and local people have gained their knowledge through their interaction, communication with their ancestral territory for years. IEK in particular has been defined as a multifaceted body of understanding that has

developed over generations through sustained, intimate relationships with the natural environment (Bhagyanathan and Dhayanithy, 2024).

While some think of knowledge as data, belief systems can be viewed religiously, and tradition can be thought of as practice. When it comes to Indigenous epistemologies, these terms are used in an interchangeable manner (Bruchac, 2014). Indigenous knowledge (IK) covers a much broader area than other terms i.e., IEK, and also reflects more comprehensive worldviews that nurture the indigenous knowledge systems (Bohensky & Maru, 2011). Thus, in this study, the term Indigenous knowledge (IK) has been considered and used in the discussions. On the other hand, Scientific knowledge (SK) is traditionally understood as a form of knowledge developed through systematic observation, logical reasoning, and empirical testing, grounded in transparent procedures and the principle of falsifiability (Popper, 1963). In forestry, this involves the collection of quantitative data on growth rates, disturbance dynamics, soils, and species responses, combined with analytical modelling to support silvicultural decision making (Fortmann & Ballard, 2009). A central aspiration of scientific forestry has been to minimize subjective bias and ensure reproducibility, allowing independent investigators to verify results or challenge them through further experimentation (Fortmann & Ballard, 2009). Yet, even within forestry and conservation science, researchers increasingly recognize that natural systems are too complex, dynamic, and uncertain to be perfectly understood or predicted through controlled hypothesis-testing alone (Ludwig et al., 1993). Scientific knowledge is not purely epistemic but situated within social institutions and historical contexts, and methodological standards are shaped by disciplinary norms and social negotiation (Jasanoff, 2004; Longino, 2002). Jasanoff (2004) demonstrates that science and society are co-produced, meaning that the creation of scientific knowledge involves judgement, collaboration, creativity, and contextual awareness rather than merely formal logic or standardized method. In practice, scientific forestry is therefore not purely deductive; it also synthesizes extensive case-based observations, long-term field experience and adaptive learning, particularly when dealing with climate-driven disturbances or ecosystem transitions (Fortmann & Ballard, 2009; Ludwig et al., 1993). Increasingly, environmental scholarship argues that scientific knowledge remains indispensable but incomplete, and that socially relevant adaptation requires more pluralistic epistemologies that recognize multiple ways of knowing and interpreting ecological change (Ludwig & El-Hani, 2020). Thus, integrating indigenous knowledge (IK) with scientific knowledge (SK) is critical for effective and efficient climate change adaptation in forest

management. Integration is considered to be a process that is established on collaboration based on equity, among the various knowledge holders through empowering the most marginalized or oppressed group (Yanou et al., 2023). Bohensky and Maru (2011) explains how tensions often emerge in the integration of Indigenous Knowledge (IK) and Western science and some studies view IK as inherently scientific, since it develops through empirical observation, experimentation, and systematic practice, while Western science can appear limited in how it frames and defines research questions. Others emphasize that IK is also characterized by wisdom and a strong ethic of respect toward the natural world, which distinguish it from conventional scientific approaches (Berkes, 2007; Akalibey et al., 2024) Bohensky and Maru (2011) discusses highlight how IK holders such as the indigenous North Americans often resist Western philosophy's preoccupation with abstract concepts such as truth, belief, and worldview, focusing instead on practical ways of living and relating to the natural environment. At the same time, much of the apparent incompatibility between these systems arises from portraying either science or IK as uniform, when in reality both are diverse and multifaceted (Bohensky &Maru, 2011). There has been a growing interest in integration of indigenous and science through several lines of argument, for instance, indigenous knowledge fills up gaps and contributes towards valuable information where science lacks (Bohensky & Maru, 2011). However, negative effects of knowledge integration has been also highlighted in several studies, as Ludwig & El-Hani (2020) mentioned about the influential critique regarding how in the process of knowledge integration, hierarchy between the knowledge holders get produced and the marginalized group becomes more marginalized as the TEK holders often have to prove that their knowledge hold up to the values and scientific standards of the academic researchers. As much as that reflects on the difficulties in integration processes, integration also contributes greatly towards resilience and helps a socio ecological system be flexible without falling apart when in contact with changing environment or social contexts (Bohensky & Maru, 2011).

1.2. Why new knowledge integrations are needed

FAO's Global Forest Resources Assessment (2020) documents that the world has continued to lose extensive forest cover and primary forest ecosystems despite decades of scientific forestry, conservation planning, and international policy commitments, with an estimated net loss of 178 million hectares since 1990 and annual deforestation still averaging around 10 million hectares

between 2015 and 2020 (FAO, 2020). This suggests that dominant Western science-based forest management regimes have not adequately secured long-term forest resilience or halted deforestation trends. At the same time, climate-induced disturbances—including drought, heat waves, intensified wildfires, insect outbreaks, invasive pathogens, and severe weather events are increasing in severity and frequency in many forest regions (Dale et al., 2001; Seidl et al., 2017). Recent global syntheses show that compound climate stresses are producing mortality events and ecosystem failures in forests previously considered resilient, raising concerns about the limits of predictive and adaptive capacity within conventional silvicultural systems (Trumbore et al., 2015; Hartmann et al., 2022). Thus, while Western scientific forestry has been crucial in identifying and explaining the risks associated with forest loss and climate change, the dominant management approaches derived from it, often standardized, technocratic, and geared toward control and prediction, have not consistently secured long-term ecological resilience on the ground. As a result, there is growing recognition across research and policy communities that more adaptive and socially grounded approaches are needed, and that plural knowledge systems, including Indigenous ways of knowing, have an important role to play in strengthening forest governance under climate uncertainty (Kimmerer, 2013; Tengö et al., 2014).Moreover, Indigenous knowledge has always had a significant contribution in forest management, for example, the indigenous knowledge of Bulang people in China and their traditional practice of “Sacred Tree Worshiping” has contributed to protecting and conserving trees for a long time now (Su et al., 2020). The following table exemplifies a few more of the elements and practices of indigenous people to manage their forest sustainably for thousands of years while adapting to changes like climate change.

Element	Description	Example Practices	Reference
Cultural Burning	Controlled burns to manage undergrowth and promote biodiversity	Intentional fire practices by Indigenous peoples	(Christensen, 2022)
Ethnobotanical Knowledge	Understanding plant species for ecological balance	Use of native plants for restoration	(Theilade et al., 2007)

Knowledge of medicinal plants and herbs	Having a strong understanding of the medicinal plants and herbs	Use of medicinal plants for a healthier community	(Godwin et al., 2018)

Table 1: Some examples of different forms of Indigenous Knowledge in Forest Management

1.3. Rationale

Indigenous peoples, due to their indigenous knowledge, which is both intergenerational and community-based, were the first to notice the early signs of climate change. Now as climate change has intensified more than ever, their knowledge offers climate solutions which will help to enhance adaptation strategies and build resilience greatly (UNDP, 2024). Indigenous peoples are distinct groups of social and cultural people with deep ties to their ancestors' time with the natural resources where they live. Their connection with their land and the resources is quite intricately linked with their existence, culture, livelihoods and also their physical and spiritual wellbeing (Leal Filho et al., 2022). Though there has been a growing interest in integrating indigenous and scientific knowledge, the process often causes more marginalization of the already marginalized IK holders (Bohensky & Maru, 2011). Moreover, the documentation of such integration initiatives also remains fragmented and deficient (Yanou et al., 2023). However, the integration of indigenous knowledge is highly significant at this point as it can fill up the gaps that depending on only scientific knowledge would not, and also make the adaptation strategies in forest management more efficient, effective, context-specific and practical. Furthermore, as Bohensky and Maru (2011) highlights how several studies have argued that integration of indigenous knowledge would also be a step towards recognition, which would ultimately contribute greatly towards social justice for indigenous people, their sovereignty, autonomy, and their identity.

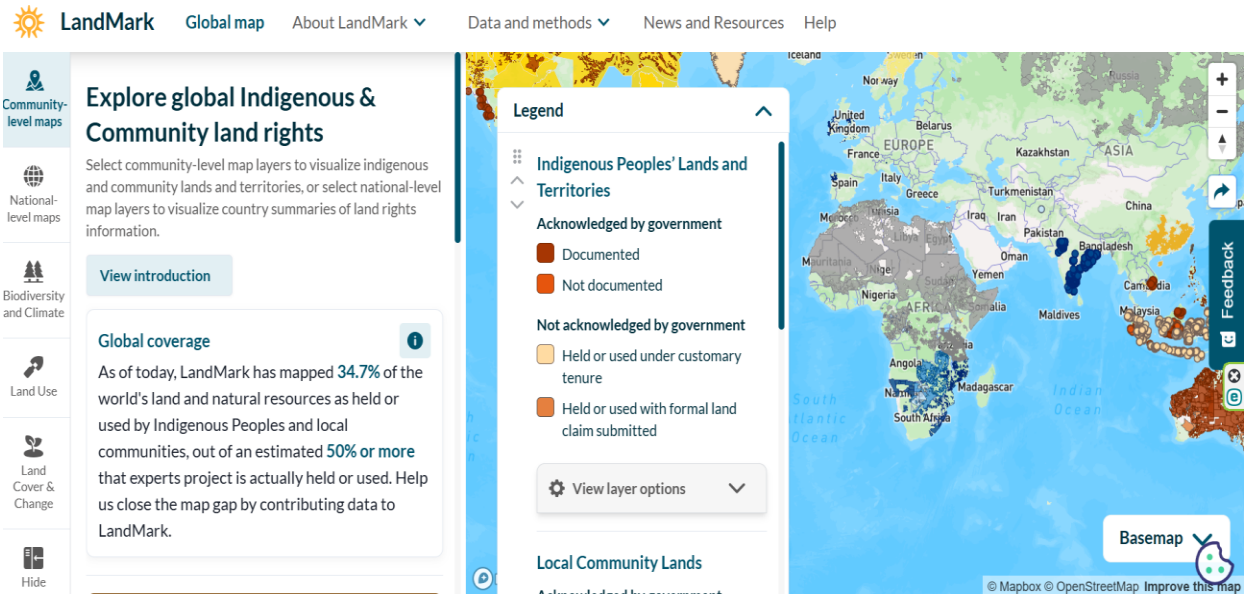

Figure 1: A screen shot of Global Platform of Indigenous & Community Lands Platform

LandMark is a platform of local, regional, and international organizations that support Indigenous and local communities and their land rights globally. It is the first online global interactive platform that shows different aspects of indigenous communities like how much of the world's land and natural resources are occupied by Indigenous Peoples and local communities, out of an estimated 50% or more that experts project occupy (LandMark, 2025). Research like this could contribute to enriching platforms through adding the aspects of indigenous knowledge integration level in different parts of the world which would help strengthen the Indigenous communities around the world.

Systematic reviews have become increasingly significant and popular as professionals read them to keep updated on their field, they are also often utilized as a starting point for further research or guiding principles (Moher et al., 2009). One significant justification for systematic reviews is nicely pointed out by Petticrew and Roberts (2006) that single studies that are conducted in isolation can often be misleading, in the sense that while one study can conclude positively regarding a research topic, another can also point out negatives. Thus, systematic reviews provide an overview of all the studies. On the other hand, in addition to helping to answer questions about what works and what does not, systematic literature reviews offer a way to make sense of vast amounts of information and answer many other kinds of inquiries. It is a technique for outlining

areas of uncertainty and determining where fresh research is required yet little or no pertinent work has been done. Systematic reviews also highlight areas with a high prevalence of false certainty. As in some areas, it is believed that a lot is known, but there is not much solid evidence to back up the claims (Petticrew & Roberts, 2006).

This systematic review aims to explore the state of art of the integration of IK in forest management for climate change adaptation and provide an analytical framework for integration of IK with SK in forest management for efficient climate change adaptation. It also aims to contribute to filling gaps and establishing research agenda for this field. Finally through these findings, the review seeks to deliver insights that can enhance climate change adaptation efforts in forest management and contribute to more informed decision making.

1.4. Objectives

Overall Objective:

To document and assess how Indigenous Knowledge is currently used and integrated with Scientific Knowledge in forest management strategies for climate change adaptation, and to identify key elements that can inform an analytical framework to guide the integration of Indigenous and Scientific Knowledge for climate change adaptation in forest management practices.

Objective 1 – Documenting how indigenous knowledge is used to create climate change-adapted forest management strategies.

Objective 2 – Identifying potentials and constraints related to the integration of indigenous and scientific knowledge in forest management strategies to promote efficient and socially just climate change adaptation in forestry development.

1.5. Research Questions

1. In what ways is Indigenous Knowledge applied and integrated in forest management strategies for efficient climate change adaptation?

2. What key elements should a framework include to effectively guide the integration of Indigenous and Scientific Knowledge for climate change adaptation in forest management practices?

Chapter 2: Conceptual Framework

This conceptual framework is designed to guide a systematic review and synthesis process (Phase 1) and the development of an analytical model (Phase 2) to promote the effective integration of Indigenous Knowledge (IK) and Scientific Knowledge (SK) in forest management for climate change adaptation.

It is motivated by the Theory of Change framework which is perceived like a road map which will guide how different inputs and activities in the different phases can lead to expected outputs and outcomes (THEORY of CHANGE, MONITORING, and EVALUATION a TOOLKIT for DEVELOPING a CULTURE of EVALUATION and LEARNING 6 2.0, n.d.).

In this study, the conceptual framework is structured into two complementary phases – phase 1 and phase 2, following the objectives 1 and 2. This study aims to show complex integration of indigenous knowledge (IK) and scientific knowledge in the context of climate change adaptation within forest management.

The first phase - Diagnostic and Documenting - works as the foundation of the review, identifying the types of integration, the specific roles IK plays in forest management strategies, enabling conditions and constraints, all drawn from a systematic review of literature.

Phase 1

Phase 1 of the framework is about identifying how these two knowledge systems are currently integrated (or not) in literature or practice. The existence and characteristics of IK and SK are getting analyzed. So:

- If a paper only presents IK, it has shown a gap or lack of integration with SK but can contribute to the roles of IK in forest management, benefits, and constraints.

- If both IK and SK are involved, it has been examined how they are brought together, who participates, and what outcomes result.

In this way, IK and SK serve as the core variables under investigation in the systematic review.

The second phase – contributing towards Analytical Framework Development, which builds on the constrains and potentials such as enabling conditions, recommendations, etc. through both deductive and exploratory/ inductive coding done. Through the development of this analytical framework, the study aims to contribute towards identifying the key elements needed to design practical and context-sensitive model for integrating Indigenous knowledge with scientific knowledge in climate change–adapted forest management.

Phase 2

1. Inputs:

- Evidence from systematic review (Phase 1): roles of IK, integration approaches, benefits, constraints.

2. Guiding Lens - Two-Eyed Seeing (Etuaptmumk):

- One eye values the strengths of Indigenous Knowledge. The other eye values the strengths of Scientific Knowledge. Together they guide balanced integration (Bartlett et al., 2012).

3. Core Elements of Integration Framework:

- **Integration Pathways:** recognition, parallel use, institutional integration, co-production.
- **Enabling Conditions:** institutional support, participatory governance, equity, trust-building, policy inclusion.
- **Barriers/Constraints:** power imbalances, lack of recognition, epistemological differences, policy/legal gaps.
- **Other Key Elements Identified**

After mapping different cases, integration models, and outcomes, the proposed framework aims to guide how IK and SK would be combined more effectively. The model:

- Reflects the unique values and strengths of IK and SK
- Identifies conditions under which each can meaningfully contribute
- Provides steps or pathways for bringing the two into conversation and collaboration

This framework illustrates how evidence gathered in Phase 1 (systematic review of roles, approaches, benefits, and constraints) feeds into the development of an analytical framework in Phase 2. At the core lies the Two-Eyed Seeing approach, which provides the guiding lens for balancing the strengths of Indigenous Knowledge and Scientific Knowledge without subordinating one to the other. The Two-Eyed Seeing framework emphasizes the importance of blending scientific knowledge with local practices and strategies to create ecosystem management policies that benefit all stakeholders. This approach ensures that sustainable forest management (SFM) policies are not only inclusive but also embraced by local communities, who are more likely to support their implementation when their perspectives are considered. Such recognition fosters genuine ownership, enabling Indigenous knowledge to complement scientific approaches and collectively advance sustainable environmental management (Akalibey et al., 2024). Through this lens, four dimensions are considered: integration pathways (ranging from recognition to co-production), role of indigenous knowledge in forest management, enabling conditions (such as institutional support, participatory governance, etc.) and barriers/ constraints.

Output and outcome

Together, these components inform the construction of possible actionable strategies that contribute to the desired output of the final analytical framework, that contributes towards identifying key elements for integration. Ultimately leading to the desired outcome of climate-adaptive forest management.

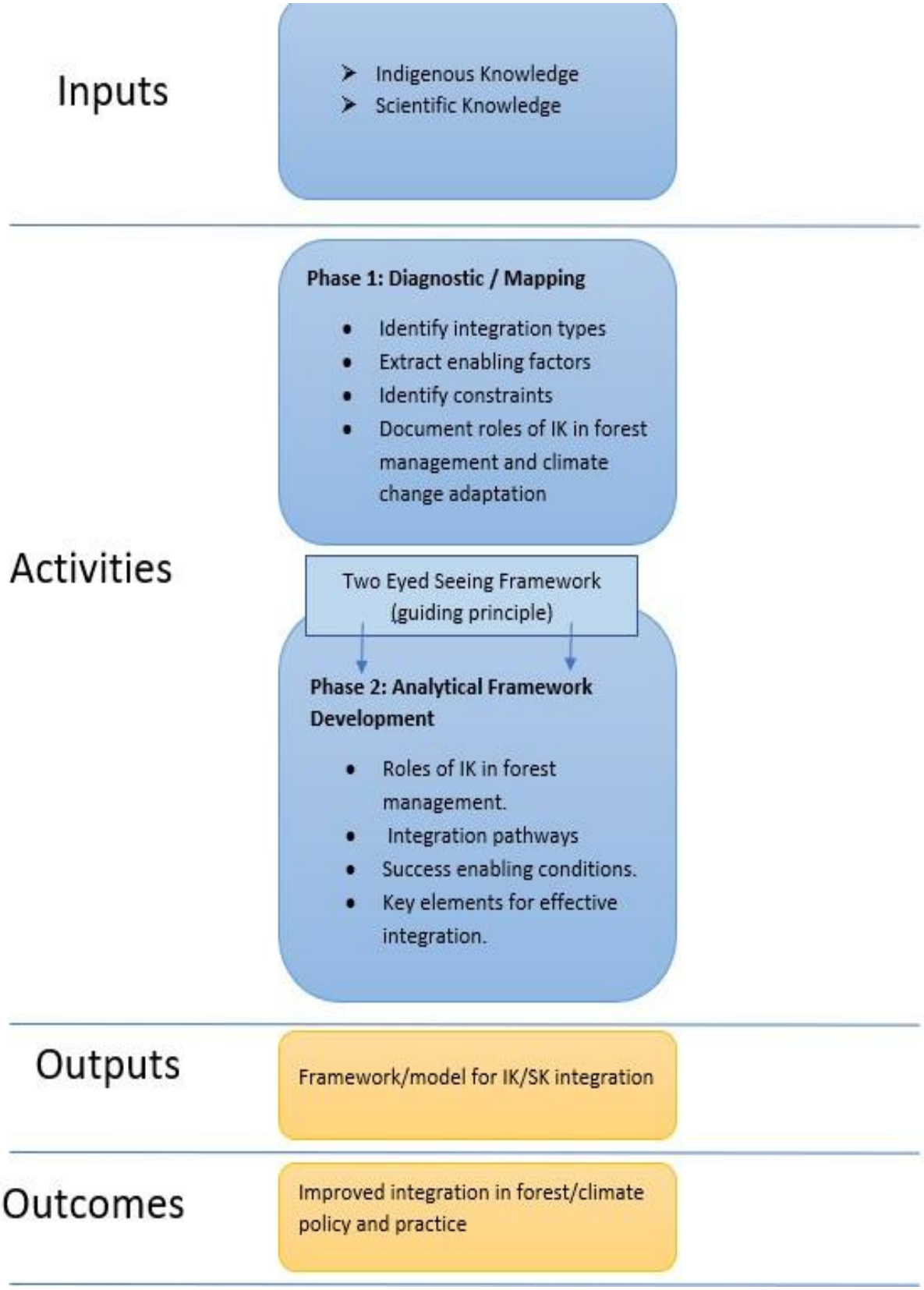

Figure 2: Conceptual Framework

Chapter 3: Methodology

3.1. Data collection:

Research Design

This study employs the systematic review methodology to identify, evaluate, and synthesize peer-reviewed and grey literature on the integration of Indigenous Knowledge (IK) and Scientific Knowledge (SK) in forest management for better climate change adaptation. The approach will follow the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (Moher et al., 2009), ensuring transparency, replicability, and rigor.

Search strategy: This study, following Petricrew and Roberts (2006) and Hintz et al (2021), has used the systematic review approach to investigate the mentioned objectives. A comprehensive literature search has been conducted across two major academic databases Scopus, Web of Science, complemented by grey literature. The search includes studies published between 2000 and 2025, The publication period from 2000 to 2025 has been purposively selected to capture contemporary, policy-relevant, and methodologically explicit studies on Indigenous - Scientific Knowledge integration. These two databases have been chosen to ensure quality and due to limitation of time. The search has been conducted in a thematic approach as all studies covered the themes required and some only focused on a few. To account for diverse terminology associated with Indigenous Knowledge, the search strategy (query) has been a combination of key terms on integration of IK and SK to address climate change adaptation in forest management, with the main themes such as indigenous knowledge which also includes other synonymous and related terms such as indigenous and local knowledge, traditional knowledge, etc. scientific knowledge, integration, climate change adaptation, and forest management. The complexities and sensitivities associated with terminologies such indigenous knowledge; integration is being acknowledged in this study.

Search strings have combined keywords and Boolean operators, for example:

("Indigenous Knowledge" OR "Traditional Knowledge" OR "Local Knowledge") AND ("Scientific Knowledge" OR "Western Science") AND ("forest management" OR "forestry") AND ("climate change" OR "adaptation").

Grey Literature Selectivity

In this systematic review, the primary literature search was restricted to peer-reviewed journal databases (e.g., Scopus, Web of Science) to ensure rigor, replicability, and methodological transparency in line with PRISMA standards. Peer-reviewed sources provide consistency in quality control and reduce the risk of including unverified or anecdotal information. However, in fields such as Indigenous Knowledge and forest governance, many important insights are reported in non-indexed outlets, including NGO reports, government publications, and collaborative project documents which are often not accessible through academic databases. To avoid excluding these valuable contributions, grey literature was included only through manual, targeted selection (e.g., reference chaining, expert recommendations, etc.).

Screening and Selection

The searches in the two databases yielded 549 papers and these papers have been screened for selection, the screening of all identified records has proceeded in three stages:

1. Title screening for relevance

2. Abstract screening against inclusion criteria

3. Full-text review for final eligibility

In order to select the eligible papers, the inclusion criteria has been applied:

- Peer-reviewed journal articles, reviews.
- Studies explicitly discussing integration of IK and SK in forest management and/or climate adaptation.

- Studies providing empirical evidence, frameworks, case studies, or policy analyses.
- Publications in English.

Through screening in the title screening phase, at first duplicates have been removed, then abstracts have been screened, and finally, the full texts have been screened against the inclusion for final eligibility. The systematic review checklist according to Moher et al., 2009 has been followed throughout the screening and the selection process which resulted in 31 papers being selected finally. Among these papers, twenty-six were journal articles, two were review papers, one book chapter, one conference paper and one report.

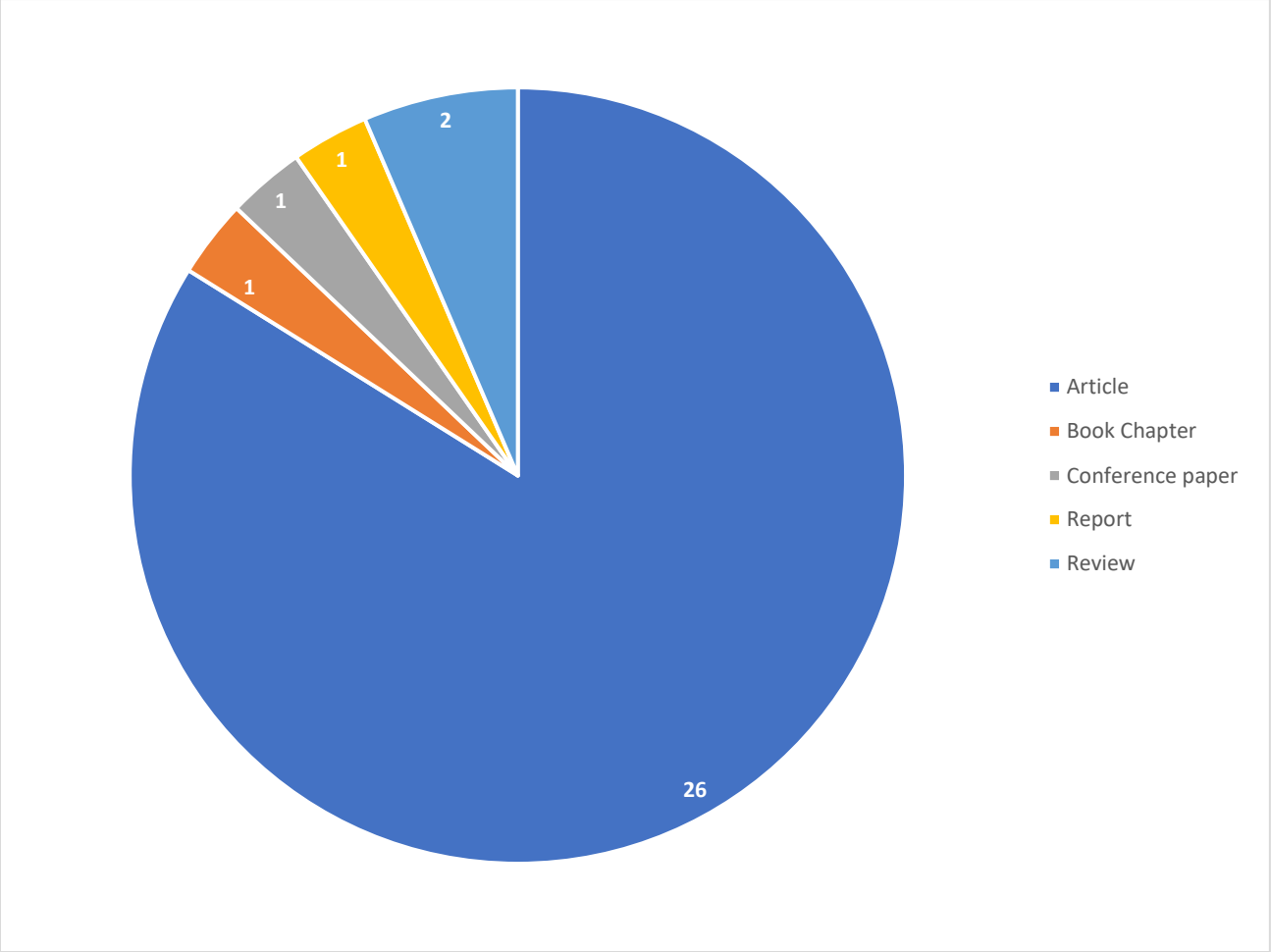

Figure 3: Different types of documents reviewed

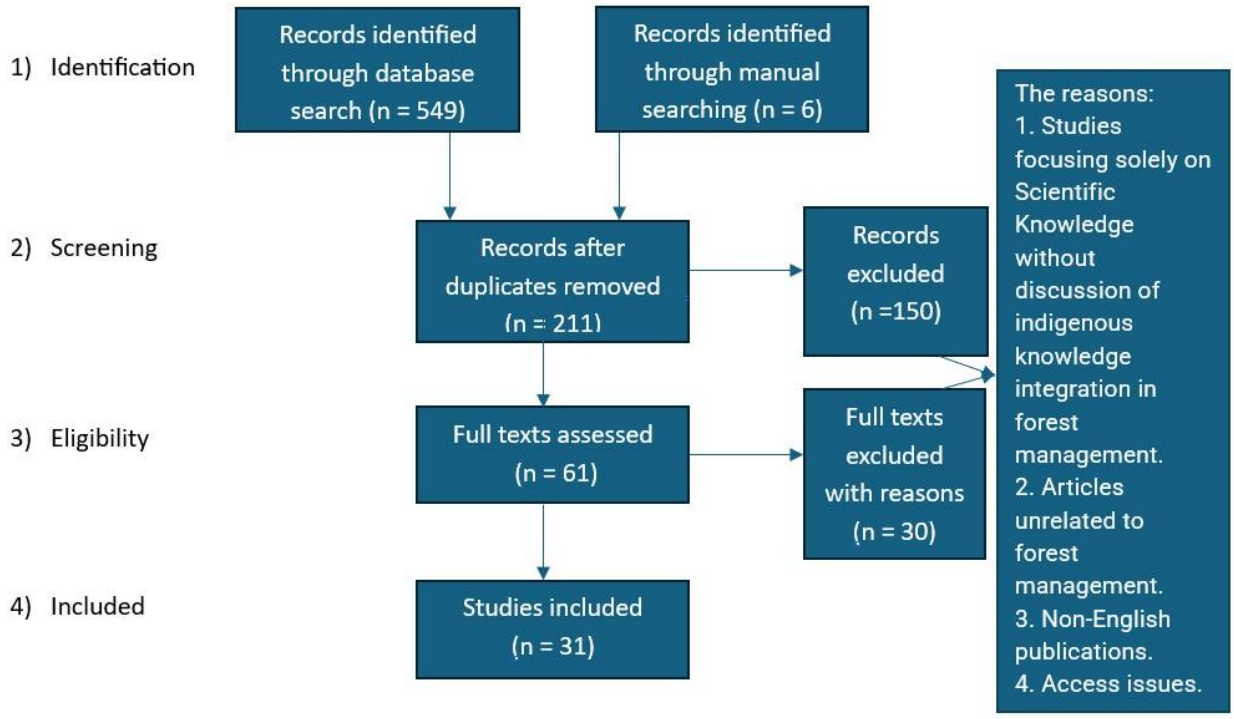

Figure 4: A PRISMA flow diagram to illustrate the number of studies identified, screened, included, and excluded.

3.2. Data Analysis

Data Extraction

Data were extracted into a standardized Excel sheet, guided by the objectives. The extraction categories reflect the variables appropriate to each objective:

For Objective 1 (Documenting IK contributions):

- Role of Indigenous Knowledge
- Benefits of integration
- Integration initiatives

For Objective 2 (Identifying potentials and constraints for integration):

- Constraints and challenges (legal barriers, epistemological differences, institutional fragmentation, lack of recognition, power asymmetries, etc.)
- Governance Politics (colonial histories, governance systems, land rights, power dynamics, etc.)
- Recommendations (policy reforms, co-governance structures, methods for equitable integration, etc.)

The analysis has adopted a qualitative content analysis with thematic analysis, deductive and inductive coding approach, to ensure the research is exploratory to new themes and concepts from the extracted literature. Because the review is exploratory and interpretive, the approach was inductive, meaning that themes emerged directly from the data and were not generated through a layered coding hierarchy. Codes and themes have been treated as interchangeable, and separate coding levels have not been developed. Thematic analysis followed Braun and Clarke's (2006) iterative steps familiarization, theme generation, review, refinement, and final synthesis adapted to an inductive, theme-focused approach. Each paper has been read closely to identify meaningful segments, which have immediately been grouped into thematic categories aligned with the seven variables mentioned above. Furthermore, descriptive statistics and simple visualizations has been used where appropriate to summarize patterns.

Degree of Collaboration Analysis for Primary Initiatives

The "type of integration" required deeper analysis especially the primary initiatives often involve detailed co-production, formalized participation, and institutional partnerships. To assess the depth of collaboration, the study applied the Degree of Collaboration Framework developed adopted from the Yanou et al. (2023). The framework comprises seven collaboration levels: Ignorance, Information, Consultation, Setting-up collaboration, Co-design, Co-management, Dissemination.

Each primary initiative has been examined to determine its position on this continuum, based on evidence of:

- Level of engagement,

- Shared authority or decision-making power,
- Co-development or co-analysis of tools,
- Participatory planning or scenario-building,
- Joint governance structures,
- Or co-led outputs and activities.

This analysis clarified not only what integration looked like across initiatives but also the depth, quality, intensity of IK - SK integration.

Categorization of Collaboration Levels (Based on Yanou et al., 2023)

To support meaningful comparison across initiatives, the seven collaboration levels in the Degree of Collaboration were grouped into high, medium, and low collaboration categories by Yanou et al. (2023). High collaboration includes co-design, co-management, and jointly authored or co-led dissemination activities. These levels reflect deep, substantive engagement characterized by shared decision-making, formalized partnerships and recognition of Indigenous authority. Medium collaboration, comprising consultation and the setting-up of collaboration, represents forms in which Indigenous actors participate in discussions, validation processes, or participatory tools, but without full authority-sharing. Engagement is meaningful but not yet institutionalized, and Indigenous priorities may inform but do not determine final outcomes. Low collaboration, which includes information and ignorance levels, reflects minimal or symbolic engagement. These cases involve one-way communication, limited recognition of Indigenous knowledge, and little to no participation in planning or decision-making. Categorizing collaboration in this way allows the study to assess the depth of IK – SK integration and provide a foundation for developing the integration pathways in the analytical framework.

In addition to assessing collaboration levels, the analysis of primary integration initiatives also included two further dimensions extracted from the Degree of Collaboration table: enabling conditions and integration pathways/mechanisms. These have been analyzed inductively alongside the collaboration levels because they offered crucial explanatory insights into how and why certain integration processes achieved higher or lower degrees of collaboration. Enabling conditions refer

to the structural, relational, institutional, cultural, and methodological factors that supported collaboration within each initiative, for example, trust - building processes, long-term partnerships, legal recognition, Indigenous-led institutions, skilled facilitation, capacity-building, or multi-stakeholder platforms. Integration pathways or mechanisms describe the operational modes through which IK and scientific knowledge were brought together, such as co-production of modelling tools, dialogue-based hybridization of agroforestry and market systems, participatory scenario building, etc. These two dimensions have been analyzed thematically in parallel with collaboration levels because they reveal the practical processes and conditions that distinguished high-collaboration cases from medium or low ones. Most importantly, all the variables are essential for Objective 2, as they illuminate the structural and relational conditions under which IK–SK integration becomes effective, equitable, and socially legitimate. These insights later feed into the construction of the analytical framework for integration, which has been synthesized based on constraints, potentials, enabling factors, pathways, and outcomes.

Chapter 4: Results

4.1. Geographical distribution, temporal distribution, and knowledge terms in the reviewed studies

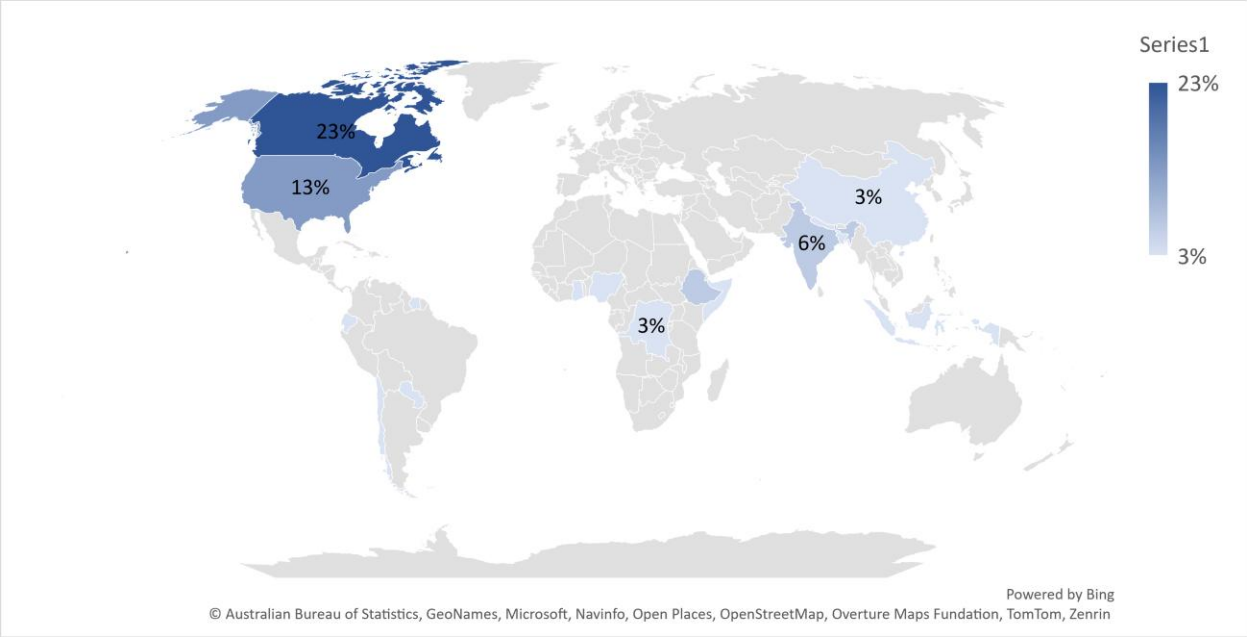

Figure 5: Geographic Distribution of Reviewed Study Sites (N = 31)

4.1.1. Geographic Distribution of Reviewed Study Sites

This map illustrates the geographic distribution of the study areas represented in the papers reviewed for the thesis. The reviewed literature spans multiple world regions, with the highest concentration of studies (23%) originating from North America (Canada), followed by Africa, Asia, and parts of South America. The shading intensity represents the number of reviewed studies originating from each country, with darker shades indicating locations from which a larger share of the papers was conducted. This pattern reveals an uneven geographic distribution in the literature, showing where research on Indigenous knowledge and forest management has been more extensively documented. In turn, it helps identify regions where empirical evidence is well established and regions where research remains comparatively limited. However, the knowledge synthesized here is dominated by cases from the west, which may suggest that the knowledge may be western-centric.

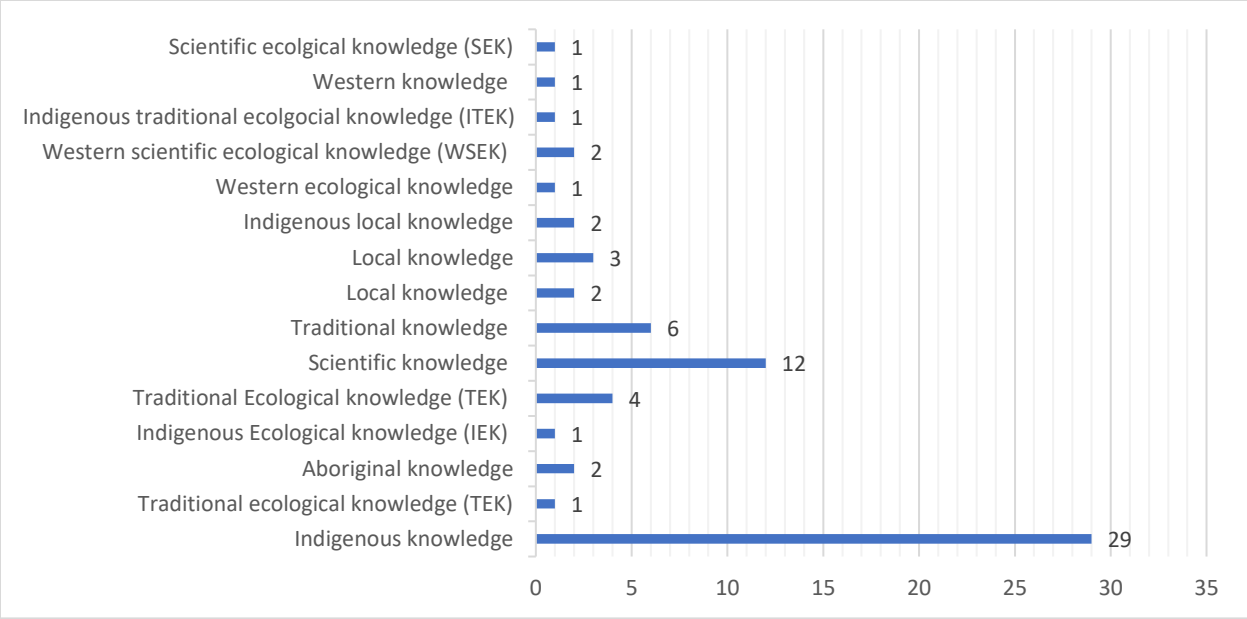

Figure 6: The most common knowledge terms used in the studies (N=31)

4.1.2. Use of Knowledge Terminology in the Reviewed Studies

Figure 6 shows the frequency of different knowledge-related terms used across the reviewed literature. The term "Indigenous knowledge" is by far the most commonly used, indicating a strong preference for broad and inclusive terminology when referring to Indigenous knowledge systems. This suggests that many studies adopt a holistic framing that goes beyond purely ecological knowledge to include cultural, governance, and relational dimensions.

"Scientific knowledge" is the second most frequently used term, reflecting the central focus of the literature on the relationship and interaction between Indigenous and scientific knowledge systems. More specific terms such as "traditional knowledge" and "Traditional Ecological Knowledge (TEK)" appear less often, indicating a more limited or discipline-specific use.

Other terms including "local knowledge," "Indigenous ecological knowledge," "Aboriginal knowledge," and variations of Western or scientific ecological knowledge are used infrequently. This uneven distribution suggests both a lack of terminological consistency and a tendency for scientific knowledge to remain implicit, while Indigenous knowledge is more explicitly named and categorized. Also, quite a few studies use different terms such as "Indigenous Knowledge", "Traditional and Ecological Knowledge" interchangeably. Overall, as the figure highlights that

the literature mostly frames integration through the broad concepts of Indigenous knowledge and scientific knowledge, with less emphasis on finer-grained or alternative terminologies.

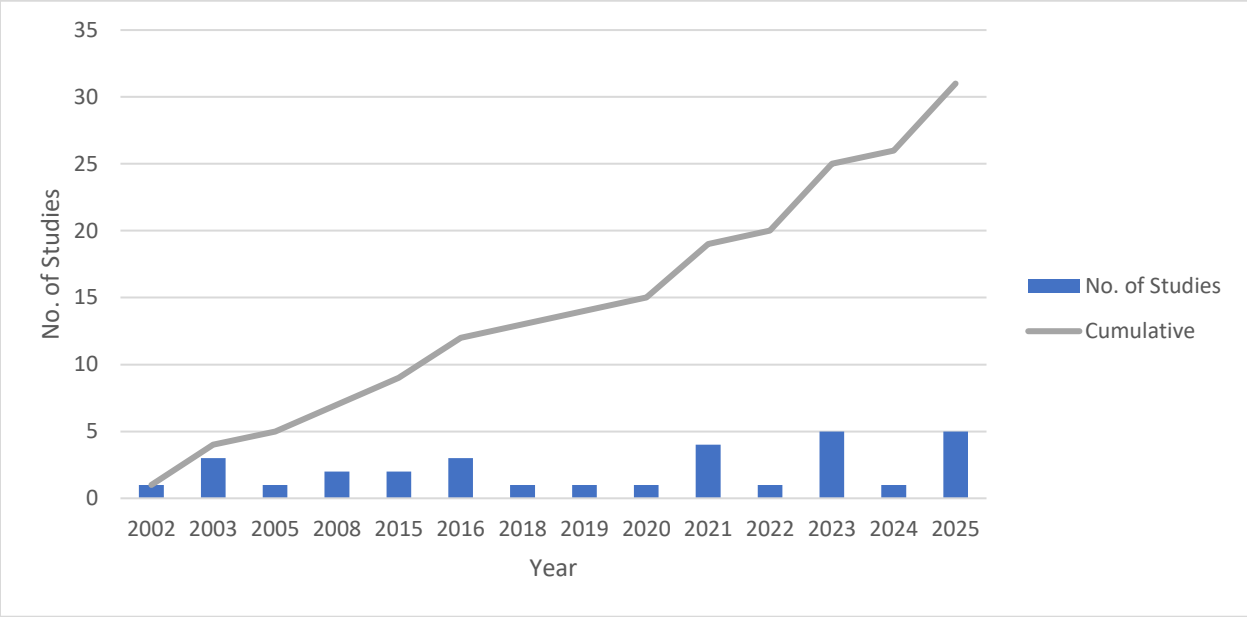

Figure 7: Temporal Distribution of Reviewed Studies

Figure 7 presents the temporal distribution of the studies included in this review, illustrating how research on Indigenous and scientific knowledge integration in forest management has evolved over time. The distribution shows a clear concentration of publications in recent years, with the majority of studies (approximately three-quarters) published within the last decade. While a small number of studies appeared in the early 2000s, research output increases markedly after 2015 and accelerates further after 2020.

This recent concentration of studies suggests that integration of Indigenous and scientific knowledge has become a more prominent research focus, likely driven by increasing recognition of climate change impacts, biodiversity loss, indigenous knowledge and the need for more inclusive and adaptive forest management approaches. Overall, the figure highlights a clear upward trend in research output over time, demonstrating that scholarly engagement with knowledge integration in forest management is both relatively recent and rapidly expanding.

4.2. Thematic Analysis of Roles of IK, Integration Pathways, Benefits, Constraints, Politics & Recommendations

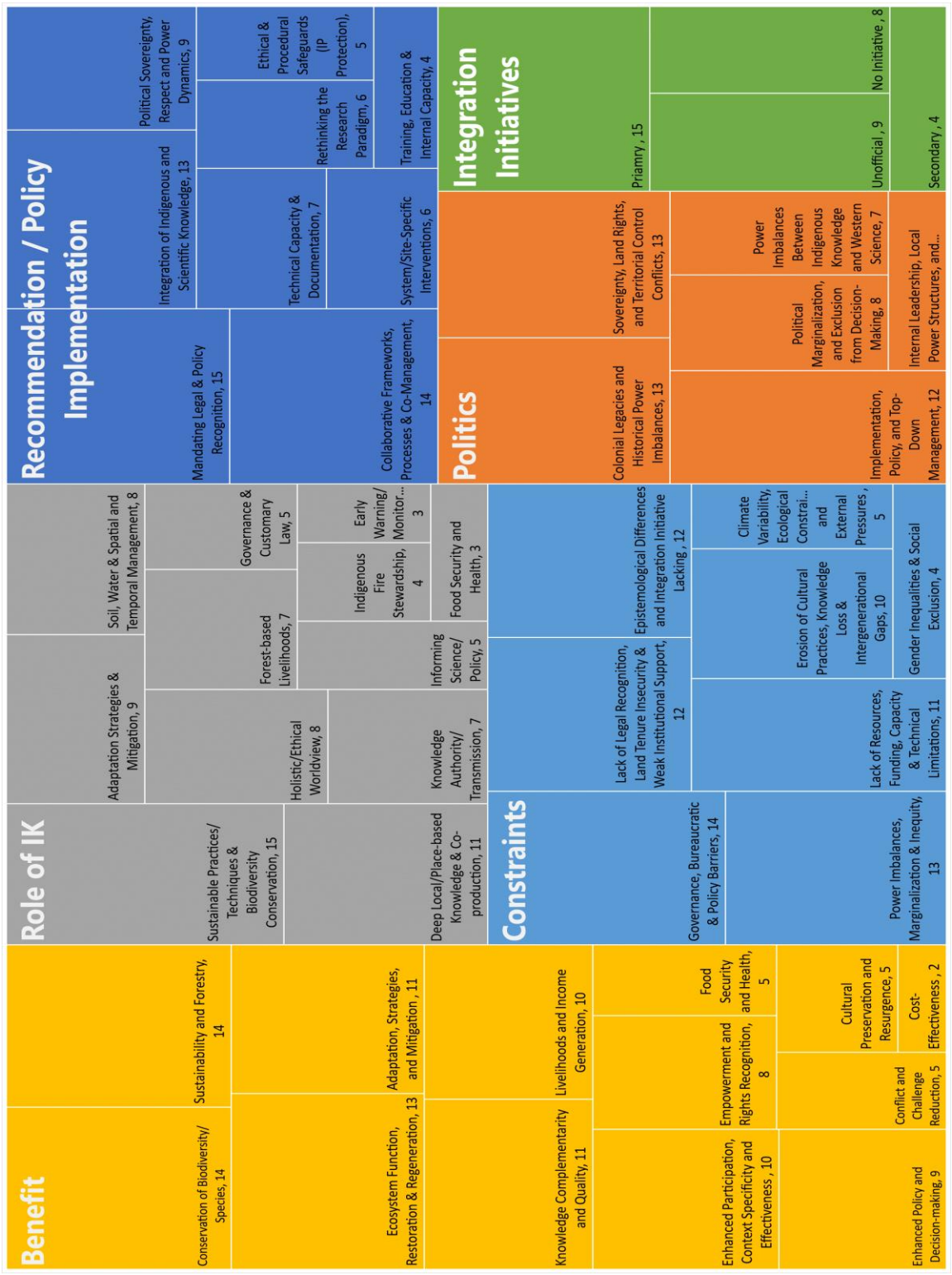

Figure 8: Tree map diagram showing the different variables and themes identified both through deductive and inductive analysis

Before moving into the detailed presentation of findings of thematic analysis, the tree map diagram offers a clear, visual snapshot of the thematic landscape that emerged from the review. It brings together all six variables explored in this study - the role of Indigenous Knowledge, benefits, constraints, politics, recommendations, and the different forms of integration and displays the themes identified within each of them. The size of each segment reflects how frequently a theme appeared across the literature, giving an immediate sense of which issues received the most attention. In many ways, this visual acts as a roadmap for the results that follow, it shows the breadth of insights generated through the analysis and helps orient the reader to the structure of the chapter, where each variable and its themes are explored in greater depth. Overall, the diagram aims to provide a helpful starting point for the chapter by showing how the different themes fit together and how they are distributed across the study.

4.3. Documenting how indigenous knowledge is used to create climate change-adapted forest management strategies

4.3.1. Roles of Indigenous Knowledge

1. Sustainable Practices, Techniques and Biodiversity conservation (n = 16)

One of the major findings of the analysis is the sustainable practices and techniques, showing how Indigenous communities have developed intricate methods for managing species, harvesting resources, and maintaining ecological balance. IK functions as an applied ecological management system; knowledge that is lived, practiced, and repeatedly refined through generations of interaction with forests. This theme captures the practical, time-tested application of knowledge on the land and forest ecosystems. IK constitutes the empirical foundation for effective resource stewardship over time, and this is evident in most of the reviewed studies such as the Menominee Nation's long history of sustained timber production (Nasr-Azadani et al., 2023), the selective harvesting of Araucaria cones among the Pewenche (Herrmann, 2005), the maintenance of

ecological integrity across generations in Ghanaian landscapes (Sraku-Lartey, 2014), the use of sophisticated agroforestry systems that embody minimal external inputs for example, Kichwa chakra (Coq-Huelva et al., 2018). Specific conservation techniques like selective harvesting (Filho et al., 2025) illustrate that these practices are far from accidental. Instead, they reflect systems of experimentation, monitoring, and adjustment that parallel scientific ecological management. The reviewed studies also demonstrate how IK ultimately contributes greatly towards biodiversity protection/conservation actions such as the widespread practice of designating sacred groves (Bhagyanathan & Dayanidhi, 2025) or through implementing protective taboos (Negi et al., 2021). In Paraguay, Indigenous agro-ecological and forest management practices actively sustain biodiversity while maintaining local food sovereignty (Apgar et al., 2016). These practices serve as culturally enforced preservation strategies, ensuring long-term protection of unique ecosystems and species integrity (Su et al., 2020).

2. Soil, Water, and Spatial – Temporal Management (n = 9)

Quit a few studies show how Indigenous Knowledge provides an integrated ecological management system that regulates soil, water, and resource use through a combination of biophysical techniques and place-based temporal planning. Communities actively prevent erosion, maintain soil fertility, and protect hydrological systems through practices such as constructing stone terraces and cultural dams (Mekonnen et al., 2021). Agro-ecological cultivation strategies sustain long-term soil health and productivity with minimal external inputs (Ite, 2025; Sraku-Lartey, 2014), while sacred grove conservation enhances stormwater regulation and watershed security (Bhagyanathan & Dhayanithy, 2025). These practices show that IK-based ecological designs function as adaptive, low-impact strategies for sustaining productive landscapes under climatic vulnerability pressure.

This stewardship is inseparable from Indigenous spatial and temporal management, where landscape- level planning, seasonal rhythms, and cultural zoning create ecologically coherent management systems. Seasonal calendars guide planting and harvesting cycles with remarkable precision (Budiman & Oue, 2025), grounded in long-term observations of climate, soil conditions, and ecological thresholds. Sacred forest patches and culturally defined zones for resource use and nature-based solutions (NbS) reinforce spatial boundaries and ensure that forest, water, and

agricultural activities are coordinated across scales (Bhagyanathan & Dhayanithy, 2025). Rather than being compartmentalized interventions, these temporal and spatial logics operate as part of the same ecological governance system that maintains soil stability, hydrological balance, and biological productivity over generations.

Taken together, Integrated Soil, Water, and Spatial -Temporal Management demonstrates how IK functions as a deeply embedded ecological science, where geomorphology, water flows, seasonal timing, and culturally driven land-use zoning are interdependent and continuously adjusted through lived experience.

3. Governance and Customary law (n=5).

The findings demonstrate that Indigenous Knowledge persists not only because it is effective, but because it is reinforced by governance systems that uphold communal responsibility, regulate access, and maintain community-based decision making that enhances accountability and legitimacy. Governance and customary law form the backbone of these systems. The Somali *Xeer* system of customary regulations, for instance, provides a coherent structure through which communities resolve disputes, allocate rights, and restrict destructive practices (Ibrahim, 2023). In other settings, moral norms and public accountability function as powerful regulatory tools, discouraging unsustainable behavior without the need for formal sanctions (Su et al., 2020). Leadership roles, such as those of the Cree tallymen (Cyr et al., 2022), demonstrate how authority in IK systems is rooted in experience, trust, and responsibility.

4. Informing Scientific and Policy Decision-Making (n =5)

According to the studies reviewed, the governance dimension intertwines with the capacity of IK to Inform Scientific and Policy Decision-Making. IK offers critical context for interpreting scientific data (Yazzie et al., 2019) and is invaluable in grounding landscape decision-making (Best et al., 2021) by providing the necessary local reality check for abstract modeling tools, helping to develop culturally appropriate policies and ensuring that models used for land management or climate adaptation genuinely reflect lived landscape realities. Scientific models

and policy frameworks often lack the fine-grained, place-specific understanding that IK provides. Participatory processes that integrate IK have also been shown to increase the cultural relevance of sustainability criteria and strengthen the legitimacy of management decisions (Karjala & Dewhurst, 2003; Best et al., 2021). In this way, IK becomes not only a local governance tool but also a necessary partner for meaningful policy development.

5. Adaptation and Mitigation Strategies (n =10)

The role of IK in adaptation capacity directly addresses the core thesis objective and perhaps the most urgent theme emerging from the review by providing the means for communities and landscapes to cope with present and future climate variability. Adaptation Strategies grounded in IK appear in many forms, from drought-resilient silvopastoral systems in high-altitude regions (Balehegn et al., 2014) to multi-layered agroforestry that integrates crops, livestock, and trees in ways that stabilize local livelihoods under climate variability (Mekonnen et al., 2021). These systems are not merely coping mechanisms; they represent long-term adaptive designs rooted in a deep understanding of climate - ecosystem dynamics. In Nigeria, for instance, Farmer Managed Natural Regeneration restored millions of hectares of degraded land and dramatically improved food security through IK-guided regeneration practices (Filho et al., 2025). This theme captures IK's most powerful climate function: field-tested, locally effective and cost-effective adaptation strategies against environmental shocks (Balehegn et al., 2014, Mekonnen et al., 2021). Beyond adaptation, Indigenous practices also extensively contribute towards climate change mitigation, since many approaches that prevent deforestation, promote natural regeneration, and sustain soil carbon stocks directly contribute to global carbon sequestration and long-term ecosystem integrity (Adhikari, 2015; Filho et al., 2025). In this sense, IK simultaneously supports local livelihoods and contributes to broader environmental objectives, linking daily land-use decisions to climate resilience at multiple scales.

6. Early Warning/Monitoring system (n = 4)

Few reviewed studies highlight how IK acts as an indispensable early warning/monitoring system providing long-term landscape perspectives that serve as an early warning signal for ecological

decline (Souther et al., 2023). This knowledge includes a deep understanding of local climate patterns, which guides local communities in predicting and responding effectively to changes (Mekonnen et al., 2021). Communities draw on multigenerational experience to observe climatic shifts, identify ecological thresholds, and anticipate extreme events (Souther et al., 2023; Budiman & Oue, 2025).

7. **Indigenous Fire Stewardship** (**n =4**)

IK provides critical, active solutions for climate-related hazards, through Indigenous fire stewardship. This includes cultural burning documented among Native American nations (Hessburg et al., 2021) and prescribed fire, which is shown to intentionally shape forest composition (Souther et al., 2023, Nasr-Azadani et al., 2023) and build landscape resistance against extreme, unmanaged wildfires (Hessburg et al., 2021). Across these examples, IK emerges as both a form of resilience and a proactive strategy for survival.

8. Holistic/ Ethical Worldview (**n =6**)

Some reviewed studies discuss how the enduring sustainability of IK is fundamentally rooted in its ethical and spiritual worldview, which differentiates management from purely commercial models and ensures intergenerational responsibility. Indigenous worldviews situate humans within an interconnected web of relationships in which forests, water, animals, and ancestors are active participants rather than resources to be extracted (Bhagyanathan & Dhayanithy, 2025; Su et al., 2020; Best et al., 2021).This holistic/ ethical worldview is rooted in principles of reciprocity, respect, and spiritual connection and appears in many forms: in the Andean principle of *Sumak Kawsay* (Coq-Huelva et al., 2017), in the Cree emphasis on respectful dialogue with all beings (Bussey et al., 2016), and in the recognition that forest health is inseparable from community well-being (Coq-Huelva et al., 2017).

9. Deep Place-Based Knowledge and Co-Production (n = 10)

Findings highlight how IK provides deep local/place-based knowledge that is rich from long-term interaction with landscapes over lifetimes and across generations (Bélisle et al., 2025), and the intimate first-hand experience (O'Flaherty et al., 2008) of local experts. IK provides intricate ecological and biological information that is often challenging to obtain using standard quantitative research methods (Scholastica Akalibey et al., 2024). This deep ecological familiarity offers a foundation for interpreting ecosystem dynamics and refining land-use decisions through lived experience.

This knowledge also facilitates co-production and co-construction, where Indigenous communities and researchers actively collaborate to blend IK with new agricultural tools (Apgar et al., 2016) and co-produce knowledge for sustainability planning (Nasr-Azadani et al., 2023). Co-production seems to result in hybrid ecological solutions that are more effective and culturally acceptable than externally designed interventions. Rather than competing with scientific knowledge, IK consistently complements and enriches it, strengthening monitoring accuracy, supporting adaptive learning, and legitimizing joint land management decisions.

10. Forest-Based Livelihoods (n=7)

Reviewed studies highlight the role of IK systems in providing the necessary resources and economic stability for communities to remain viable and resilient, explicitly linking human well-being directly to forest health (Su et al., 2020; Adhikari, 2015). IK systems sustain forest-based livelihoods and are structured around practices that conserve biodiversity and maintain forest productivity across generations (Sraku-Lartey, 2014; Herrmann, 2005). This also strengthens social bonds, for example, communal harvesting events (Herrmann, 2005) and provides essential community resources (Sraku-Lartey, 2014, Negi et al., 2021).

11. Knowledge Authority/Transmission (n=4)

Findings reveal that this enduring worldview is protected through knowledge authority/transmission. IK is recognized as a cumulative body of knowledge inherited passed down

through generations (Cheveau et al., 2008, Bussey et al., 2016). This knowledge authority and transmission process is formalized, with authority often resting with elders whose authority comes from lifelong experience and proven wisdom (O'Flaherty et al., 2008, Negi et al., 2021), ensuring the continuous, localized transfer and refinement of adaptive knowledge. Knowledge is passed on through oral traditions, observation, ceremonial practice, and learning-by-doing (Negi et al., 2021). This intergenerational continuity ensures that IK remains a living, adaptive heritage that evolves with people and landscapes. In many ways, this cultural foundation explains why IK systems are able to maintain coherence across centuries despite external pressures.

12. Food Security and Health (n = 4)

Few reviewed studies mention IK systems as critical sources of food security and health, providing essential resources like medicinal plants and wild edibles (Negi et al., 2021, Sraku-Lartey, 2014) which often form the basis for healthcare in rural communities. This relationship between IK and sustenance underscores its role as a social safety net that remains especially crucial under climate stress.

Figure 9: Pie-chart showing different themes and frequencies of Role of Indigenous Knowledge, identified through thematic analysis (N = 31).

4.3.2. Benefit

1. Conservation of Biodiversity/Species (n = 14)

Majority of the findings highlight how integrating IK into forest and ecosystem management consistently produces strong benefits for biodiversity conservation. Across fourteen studies, IK-based practices such as sacred groves, customary governance, and species-specific stewardship provide proven mechanisms for protecting species and maintaining ecological diversity. Sacred groves function as IK-driven Nature-based Solutions (NbS), preserving undisturbed forest patches that shelter rare, threatened, and vulnerable species (Bhagyanathan & Dhayanithy, 2025). By placing cultural restrictions on disturbance, indigenous communities conserve in situ refugia that scientific management alone often fails to maintain.

Customary regulations and governance also contribute directly to species protection. The Somali *Xeer* regulations safeguard frankincense trees by preventing overexploitation and regulating access (Ibrahim, 2023). Ethnobotanical knowledge, seed banks, mixed land-use practices, and taboos embedded within IK support sustainable forest management and biodiversity conservation (Scholastica Akalibey et al., 2024). Sacred forests similarly protect endemic and medicinal species (Negi et al., 2021).

IK integration further benefits species-level conservation for example, in the case of The Mapuche Pewenche maintain a "unique system of Araucaria use," including harvesting protocols and nursery cultivation that support long-term regeneration of *Araucaria araucana* (Herrmann, 2005). Indigenous fire stewardship maintains culturally valued species and habitats (Hessburg et al., 2021). Customary taboos act as "de facto ecological regulations," contributing to species protection and higher abundance in areas where traditional norms remain strong (Kasoki et al., 2025). Together, these examples show that IK enhances biodiversity outcomes by embedding conservation directly into daily practice.

2. Ecosystem Function, Restoration, and Regeneration (n = 13)

Findings highlight how integrating IK improves ecological function by sustaining hydrological cycles, soil fertility, ecosystem resilience, and habitat quality. For example, riparian sacred groves help regulate stormwater run-off, reduce flash flooding, and ensure water availability during dry seasons (Bhagyanathan & Dhayanithy, 2025). Community rules such as "only planting but not cutting" help maintain forest structure and wildlife habitat, thus preserving ecological integrity (Su et al., 2020).

Locally evolved silvopastoral systems demonstrate how protocols for managing *Ficus thonningii* create a "climate-resilient silvopastoral system" that supports year-round fodder production and nutrient cycling (Balehegn et al., 2014). Another example of IK benefits is how spatial, temporal, and functional IK-based management helps reduce forest degradation and maintain ecosystems as carbon sinks and sources of clean water and food (Budiman & Oue, 2025).

Multiple studies show how integrated agroforestry systems, terraces, and crop - tree combinations maintain soil fertility, control erosion, and support hydrological balance (Mekonnen et al., 2021; Filho et al., 2025). IK also guides biodiversity friendly harvesting and regenerative interactions, improving ecological outcomes (Scholastica Akalibey et al., 2024; Herrmann, 2005). Collectively, these examples demonstrate how IK integration strengthens ecosystem function in ways that conventional management alone possibly does not. These ecological benefits extend directly into forest regeneration and restoration, highlighting IK's critical role in sustaining ecological renewal. IK integration directly benefits forest regeneration by guiding restoration practices and enabling early ecological intervention. For instance, the Mapuche Pewenche has cultivated *Araucaria* seedlings in nurseries and restored logged areas, combining in situ and ex situ strategies that support ecological renewal and community self-development (Herrmann, 2005). Another case is where agro-ecological practices in Paraguay have conserved and restored forest diversity, with communities producing evidence of ongoing restoration initiatives (Apgar et al., 2016). IK-based wisdom, including culturally grounded forest sayings and ecological observations, guides restoration and conservation decisions (Scholastica Akalibey et al., 2024). Traditional Ecological Knowledge (TEK) has been used to identify species decline early and inspire targeted conservation interventions before irreversible loss, such as the case of Emory oak (Souther et al., 2023).

3. Adaptation Strategies, and Mitigation (n = 11)

Multiple reviewed studies show IK integration significantly enhances climate adaptation and mitigation strategies. Sacred groves serve as NbS that buffer communities against floods and droughts (Bhagyanathan & Dhayanithy, 2025). Silvopastoral system grounded in IK has been observed to enable communities to "adapt to climate change, while benefiting from the various economic and environmental qualities of the species," rehabilitating degraded landscapes and maintaining livestock during drought (Balehegn et al., 2014). These systems also offer mitigation benefits through carbon sequestration.

Indigenous knowledge systems possess qualities such as local specificity, practicality, and constant evolution that make them especially effective for sustainable forest management and climate change adaptation (Adhikari, 2015). TEK's or IK's long-term ecological memory contributes to climate resilience, informing adaptive decision-making and safeguarding carbon sinks (Bussey et al., 2016; Filho et al., 2025). Integrated farming systems help maintain productivity under climate variability (Mekonnen et al., 2021). Blended strategies enhance resilience and resource conservation (Rahman & Alam, 2016; Kasoki et al., 2025). These benefits demonstrate that IK enhances both adaptation and mitigation capacities in forested landscapes.

4. Food Security and Health (n = 5)

Reviewed studies discus the role of IK integration in strengthening food and health security by sustaining access to nutritious foods and essential medicines. As found in one study, Indigenous foods significantly enhance nutritional wellbeing, while forest-derived medicines remain essential for healthcare, used by 80% of the African population (Sraku-Lartey, 2014). Another study shows sustainably managed forests provide water and food security, especially under climate stress (Budiman & Oue, 2025). Farmer-Managed Natural Regeneration has restored over 5 million hectares of degraded land in Niger, increasing crop yields, soil moisture, and drought resilience (Filho et al., 2025). While IK-based forest management in Lawachara has decreased forest dependence while strengthening food security (Rahman & Alam, 2016). Indigenous fire stewardship practices have been found to support food and medicinal resource availability by maintaining culturally important species (Hessburg et al., 2021).

5. Livelihoods and Income Generation (n = 10)

Multiple reviewed papers show that IK sustains and enhances livelihoods. In one study, traditional agroforestry systems have been found to produce cocoa for international markets while slowing deforestation (Coq-Huelva et al., 2017). IK-based practices have been found to sustain forest-dependent livelihoods over generations (Sraku-Lartey, 2014), and harvesting of wild edibles and medicinal plants based on IK, also provides critical income sources (Negi et al., 2021). In another study, small farmers in montane forests are found to rely on IK for agro-ecological management, acting as conservationists rather than agents of forest loss (Ite, 2025). On the other hand, Aboriginal forestry programs build economic self-sufficiency by creating partnerships, joint ventures, and training opportunities grounded in TEK (Parsons & Prest, 2003). IK-based management in Lawachara improved forest quality, tourism, alternative income, and community participation (Rahman & Alam, 2016). Few studies show that climate-resilient systems such as integrated farming and silvopastoral strategies sustain incomes under environmental stress (Mekonnen et al., 2021; Balehegn et al., 2014). Participatory governance aligned with Indigenous values also enhances economic opportunities (Teitelbaum et al., 2023).

6. Cost-Effectiveness (n = 2)

Findings show IK integration yields cost-effective solutions because it relies on locally available knowledge and resources rather than expensive external technologies. For example, IK-driven development is “both cost-effective and sustainable” because it relies on accessible local knowledge and resources rather than expensive external technologies (Sraku-Lartey, 2014). Indigenous strategies have been described as “generally cost-effective, participatory and sustainable” compared with large-scale technological interventions (Balehegn et al., 2014).

7. Empowerment and Rights Recognition (n = 8)

Across several studies, it is consistently shown that integrating IK enhances social justice, autonomy, and the recognition of Indigenous rights. As highlighted in one study, co-constructed knowledge better supports the wellbeing of marginalized groups and contributes to ongoing

political struggles for rights (Apgar et al., 2016). Integration of IK also promotes cultural preservation and recognition of Indigenous rights (Scholastica Akalibey et al., 2024).

IK strengthens autonomy through decision-making power, as seen in governance arrangements in the study where forest planning authority shifted to Indigenous governments (Cyr et al., 2022). TEK integration has also fostered territorial rights recognition and community empowerment (Cheveau et al., 2008). Another study found that IK contributes to both rights protection and ecological resilience (Kasoki et al., 2025).

8. Enhanced Policy and Decision-Making (n = 9)

Multiple cases demonstrate how IK integration improves policy relevance and decision quality. As seen in study combining Indigenous expertise with modeling has produced unique perspectives for conservation and policy improvement (Bélisle et al., 2025). Co-design and co-management approaches has also enhanced ecological and social outcomes (Nasr-Azadani et al., 2023; Bussey et al., 2016). Another study shows how locally based indigenous sustainability criteria provide more appropriate guidance for forest planning and increase community trust, ownership, and collaboration (Karjala & Dewhurst, 2003). It is also clear from multiple studies how recognition of IK strengthens policy legitimacy and supports more effective management systems (Scholastica Akalibey et al., 2024; Souther et al., 2023). IK-based governance has been found to contribute to decisions that are culturally appropriate, context-specific, and ecologically grounded (Kasoki et al., 2025).

9. Conflict and Challenge Reduction (n = 5)

Findings highlight that IK integration reduces conflict by improving trust, addressing competing land-use narratives, and supporting collaborative governance. It has been found in one study that co-construction processes challenge dominant narratives and help communities confront environmental degradation (Apgar et al., 2016). Another study shows how participatory tools enhance understanding of trade-offs and increase buy-in, reducing conflict (Best et al., 2021). Recognizing TEK mitigates disputes between commercial forestry and Indigenous rights (Cheveau

et al., 2008). Autonomous forest governance reduces tensions and enhances cooperation (Cyr et al., 2022). Participation aligned with local knowledge transforms development practices and reduces conflict potential (Teitelbaum et al., 2023).

10. Knowledge Complementarity and Quality (n = 11)

Across the reviewed studies, it is consistently shown that integrating IK and scientific knowledge provide complementary strengths to each other, integrating both results in more grounded and effective conservation and management strategies (Bélisle et al., 2025). As heighted in one study, rapid TEK integration improves ecological outcomes and addresses historical injustices (Souther et al., 2023). IK's applied, and adaptive qualities enhance SFM and CCA (Adhikari, 2015). Long-term TEK records offer insights unattainable through short-term scientific data (Bussey et al., 2016). As found in one study, integrated knowledge frameworks create self-improving forest management systems (Natcher & Hickey, 2002). Furthermore, interweaving IK and scientific approaches prevents maladaptation (Mekonnen et al., 2021). These examples show that IK integration would enhance the depth, quality, and legitimacy of knowledge systems.

11. Enhanced Participation, Context Specificity, and Effectiveness (n = 10)

Reviewed studies highlight how IK strengthens participatory and context-specific forest governance. Multiple studies have shown co-design workshops and visualization tools improve accessibility and participatory engagement (Bélisle et al., 2025; Nasr-Azadani et al., 2023). Interactive tools like 3D modeling and scenario planning increase participation among disadvantaged or low-literate members and support social learning (Best et al., 2021). Moreover, it has been found that locally grounded participation transforms conventional approaches to development (Teitelbaum et al., 2023). Integrated frameworks improve learning, transparency, and adaptive management (Natcher & Hickey, 2002). Participatory management incorporating IK produces ecological and social benefits, such as improved forest condition and increased community ownership (Rahman & Alam, 2016).

12. Cultural Preservation and Resurgence (n = 5)

IK integration strengthens cultural continuity, identity, and resurgence. As seen in one study, Aboriginal forestry initiatives have revived traditional worldviews and provided spaces for cultural teachings across generations (Parsons & Prest, 2003). IK integration supports cultural preservation and recognition of Indigenous identities (Scholastica Akalibey et al., 2024). Culturally based management preserves customary stewardship and strengthens spiritual relationships with the land (O'Flaherty et al., 2008). Indigenous fire stewardship sustains longstanding cultural responsibilities and practices (Hessburg et al., 2021). Another study shows collaborative work on Indigenous landscape values strengthens community cohesion and understanding (Bélisle et al., 2025).

13. Sustainability and Forestry (n = 14)

Across multiples reviewed studies, Indigenous Knowledge emerges as a foundational driver of long-term sustainability within forest landscapes. Customary governance systems such as *Xeer* provide community-embedded mechanisms that regulate resource extraction and ensure the continued availability of key forest species, promoting sustainable use grounded in social responsibility (Ibrahim, 2023). IK-based food systems and forest-dependent livelihoods are likewise described as inherently sustainable, drawing on local species, seasonality, and low-impact harvesting practices that maintain ecological balance across generations (Sraku-Lartey, 2014). Everyday rules such as "only planting but not cutting" and broader cultural norms actively sustain forest structure, wildlife habitat, and ecological function (Su et al., 2020). Spatial and temporal IK-centered management supports forests as providers of clean water, carbon storage, and other ecosystem services, illustrating how sustainability is embedded within Indigenous understandings of forest function (Budiman & Oue, 2025). IK-informed wisdom and local ecological principles underpin sustainable harvesting practices, resource rotation, and forest regeneration (Scholastica Akalibey et al., 2024), while Mapuche Pewenche techniques for *Araucaria* stewardship exemplify sustainable use that protects both ecological integrity and cultural continuity (Herrmann, 2005). Sustainable collection of medicinal plants and wild edibles likewise demonstrates how IK structures long-term forest–livelihood relationships (Negi et al., 2021). At a governance level, TEK integration strengthens sustainable forestry by enhancing community empowerment and

ensuring that land-use decisions align with Indigenous values (Cheveau et al., 2008). Culturally grounded stewardship systems embed sustainability within everyday practice, reinforcing long-term responsibility to place (O'Flaherty et al., 2008). Integrated crop-tree-livestock systems offer sustainable production models that improve soil health, reduce erosion, and maintain yields (Mekonnen et al., 2021), while large-scale landscape transformations such as those achieved through Farmer-Managed Natural Regeneration demonstrate how IK can restore fertility, increase productivity, and build large-scale ecological resilience (Filho et al., 2025). Aboriginal forestry partnerships rooted in TEK provide models for sustainability that blend cultural priorities, ecological insight, and economic opportunity (Parsons & Prest, 2003). Locally based sustainability criteria derived from Indigenous values inform forest planning, creating context-appropriate frameworks that enhance both ecological integrity and community ownership (Karjala & Dewhurst, 2003). Together, these studies reveal that sustainability is not an add - on to Indigenous Knowledge systems; it is a deeply rooted orientation that shapes how forests are understood, used, governed, and cared for across generations.

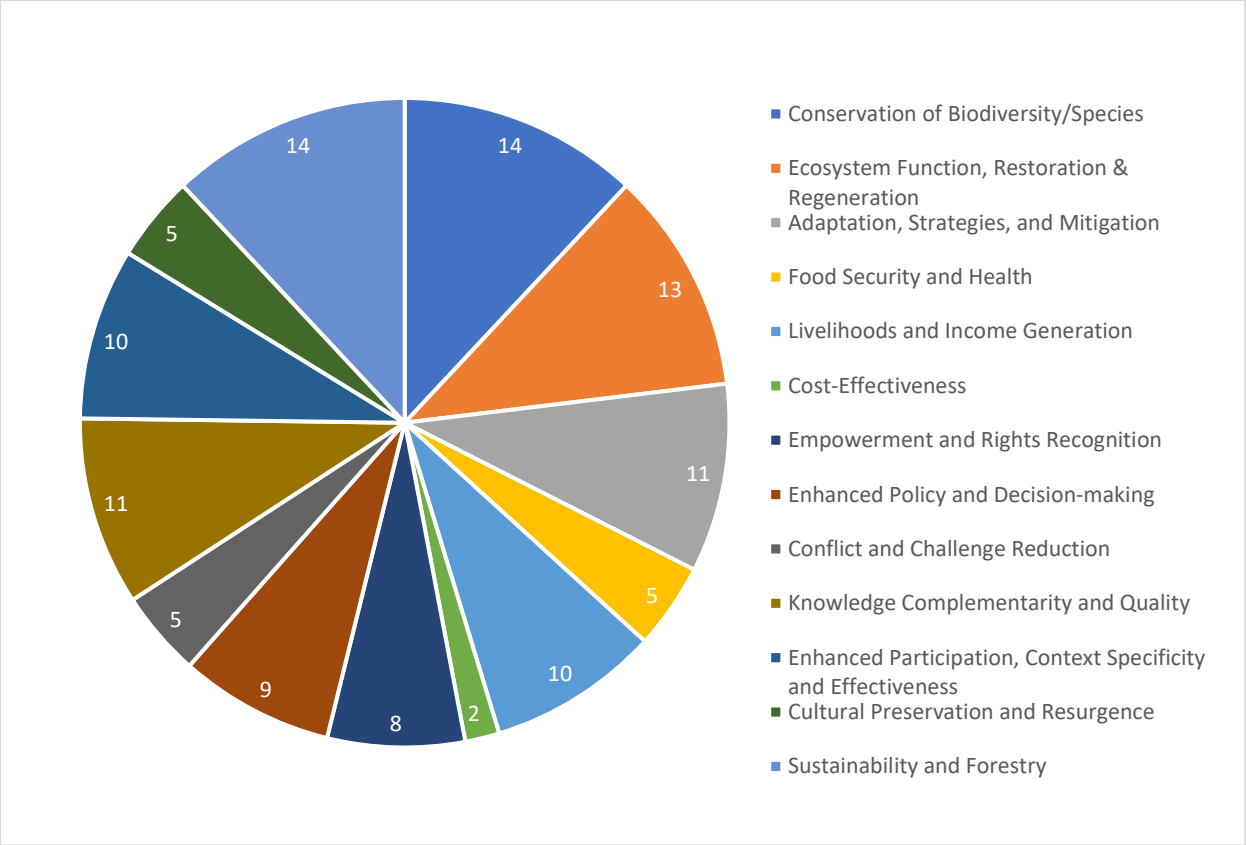

Figure 10: Pie-chart showing different themes and frequencies of Benefit, identified through thematic analysis (N = 31)

4.3.3. Type of Integration

1. Primary Integration Initiatives (n = 15)

Primary integration initiatives represent active, formally acknowledged, and often authority-supported integration efforts. These initiatives typically involve substantial detail, originate from collaborative research or co-management programs, and are grounded in primary data where Indigenous peoples and external institutions work together directly.

Primary integration initiatives reveal the most deliberate and institutionally supported blending of Indigenous Knowledge (IK) and Western scientific or administrative systems. Across fifteen studies, integration is constructed as a formalized and intentional process, supported by recognized authorities such as governments, forest agencies, universities, and co-management boards. These efforts operate through co-designed modelling frameworks, cross-scale governance structures, hybrid economic systems, and participatory platforms that explicitly incorporate IK into decision-making.

In some cases, integration is structured into scientific modelling itself. One such example involves the co-production of forest landscape simulations where Indigenous landscape values, abundance, access, and relational qualities are embedded into LANDIS-II models and a Bayesian network. Interviews, workshops, elicitation sessions, and validation processes with Indigenous land-use experts ensure that simulations directly reflect Indigenous priorities, and the results are returned through story maps, booklets, and open-access data. (Bélisle et al., 2025). Similarly, Diné kinship principles guide the application and interpretation of the Climate-Forest Vegetation Simulator (C-FVS). Rather than treating C-FVS as neutral, the study explicitly uses Diné concepts of respect, reciprocity, and responsibility to define objectives and interpret model outputs (Yazzie et al., 2019). These examples illustrate how Western scientific tools become reoriented around Indigenous worldviews through direct collaboration.

Integration is also enacted through hybrid management and livelihood systems that merge Indigenous value frameworks with modern economic or administrative tools. In one case, the Kallari association's cocoa agroforestry represents a practical integration of Sumak Kawsay (SK) and Indigenous management principles with modern business practices such as quality control,

branding, and global market access. Convention Theory is used to understand how Indigenous and Western rationalities are held in dialogue, with SK presented both as an Indigenous worldview and as a logically framed set of guiding principles (Coq-Huelva et al., 2017). Another initiative demonstrates "Aboriginal forestry" as an explicit model that brings together traditional knowledge systems and Western Scientific sustainable forest management. Integration is operationalized through forest management planning, Traditional Land Use and Occupancy Studies, cultural transmission, training, and joint ventures under programs such as the First Nations Forestry Program, which create socio-economic opportunities while embedding Indigenous values into management (Parsons & Prest, 2003).

Participatory and visualization tools provide additional pathways for such integration. Three-dimensional visualization technologies allow Menominee community members and students to explore sustainability concepts by linking TEK with Western systems thinking. 3D visualization tools and systems-thinking frameworks to integrate Menominee TEK with Western "Systems Thinking competency." Cognitive mapping, place-based scenarios, and surveys help younger generations and students see sustainability as touching all facets of life and enable them to integrate cultural values with Western sustainability concepts (Nasr-Azadani et al., 2023). Multi-actor landscape governance processes incorporate participatory 3D modelling, scenario planning, and interactive games to help community members link local ecological knowledge with broader land-use governance agendas and decision making (Best et al., 2021). Primary integration here is centered on tools and processes designed from the start to weave IK and scientific/technical knowledge together.

A major cluster of primary initiatives involves formal co-management or shared governance structures that institutionalize integration. In Nepal, there has been formal recognition and integration of the Shingi Nawa system into Sagarmatha National Park's buffer zone management, and community forestry user groups (CFUGs) where forest users "integrate, synergize, and complement" Indigenous practices with modern rules and technologies, including alternative energy initiatives (Adhikari, 2015). In northern Ontario, the Whitefeather Forest Initiative and Community-based Land-Use Planning (C-LUP) is where Pikangikum First Nation leads planning processes under provincial frameworks. Cross-scale links between community institutions and provincial agencies are designed to embed Pikangikum knowledge, mapping, and land-use

strategies into forest licensing and operations (O'Flaherty et al., 2008). Then comes the Adapted Forestry Regime, under the *Paix des Braves* agreement between the Cree Nation and Québec. The AFR includes joint institutions such as the Cree-Québec Forestry Board and community-level Joint Working Groups, as well as trapline-based decision structures led by Cree tallymen. These mechanisms ensure Cree participation and IK influence throughout planning and operations (Cyr et al., 2022) Another study highlights community forest tenures, First Nations Woodland Licenses, Local Forest Management Corporations, and forest certification systems (e.g., FSC, PEFC) that embed commitments to Indigenous rights and participation, including principles such as Free, Prior and Informed Consent (FPIC) embedding IK in provincial forestry systems (Teitelbaum et al., 2023).

Criteria-and-indicator frameworks co-developed with communities (Karjala & Dewhurst, 2003) and scenario-based learning processes are adapted to incorporate Indigenous values, place-based knowledge, and community-defined forest criteria. Workshops, field trips, mapping, and focus groups translate local values into operational indicators of sustainable management (Natcher & Hickey, 2002). In Lawachara National Park, where formal co-management arrangements (e.g., Nishorgo, IPAC, CREL, co-management committees in Lawachara National Park) create structured spaces for Indigenous representatives to participate in decision-making, blending local practices with modern management and climate-adaptation tools. Indigenous representation has become possible through co-management bodies that ensures sustained engagement in planning and management activities (Rahman & Alam, 2016).

Across these cases, primary integration initiatives are characterized by explicit, planned, and often legally or institutionally anchored efforts to integrate IK and Western/scientific approaches, involving structured participatory processes, governance reforms, hybrid management models, and co-produced knowledge.

2. Secondary Integration Initiatives (n = 4)

Secondary integration initiatives are characterized by their limited detail and reliance on secondary data, with Indigenous Knowledge (IK) appearing primarily as contextual information or as part of policy or conceptual frameworks rather than through actively documented collaborative processes.

In these four cases, integration is described at the level of legal recognition, administrative directives, or theoretical pathways, but with little insight into how these frameworks translate into implementation on the ground. One example involves Indonesia's constitutional recognition of customary forests, which formally acknowledges systems such as *hutan adat, nagari*, *tana' ulen*, and *pasang ri Kajang* (Budiman & Oue, 2025). While this represents a significant legal development, the study provides limited description of how these reforms shape concrete IK–SK collaboration in forest management.

Similarly, Indigenous knowledge is referenced within U.S. federal land management through mandates, orders, and directives that recognize TEK as a valid input to restoration and adaptation programs (Souther et al., 2023). These policy instruments are described broadly, but the study does not document specific co-produced processes or Indigenous decision-making roles. Conceptual pathways for potential integration also appear, such as using Indigenous rules as planning frameworks, incorporating Indigenous land-use values into mapping, or aligning zoning frameworks with traditional land-use patterns (Cheveau et al., 2008). These remain theoretical models within the reviewed study, without detailed accounts of applied integration. Finally, some conservation and development contexts reference Indigenous agricultural or forest practices as supportive elements (Rahman & Alam, 2016), but they are not documented as part of a structured integration initiative.

Together, the secondary initiatives illustrate how IK may be recognized or mentioned at policy, conceptual, or discursive levels, while the operational details of integration remain unclear or undocumented in the studied literature.

3. Unofficial Integration Initiatives (n = 9)

Unofficial integration initiatives are community-led, lack formal or legal authority acknowledgement, and are documented through primary data but with limited detail. These initiatives show how integration occurs informally in daily practice, driven by local needs and relationships rather than institutional mandates. One example shows how customary tenure rules and Indigenous agro-ecological knowledge intersect to shape patterns of land clearing and forest retention in communities surrounding a protected area. Even without a formal integration

framework, decisions about who may clear land and which trees should be retained operate jointly to influence forest outcomes (Ite, 2025). Similarly, farmers managing *Ficus thonningii* develop climate-resilient silvopastoral systems by blending longstanding Indigenous protocols with adaptive management strategies as needs change, producing a hybrid system without external authority involvement (Balehegn et al., 2014).

In some contexts, integration arises through informal collaborations between Indigenous resource managers and state agencies. For instance, joint prescribed burns, informal coordination, and on-the-job exchanges between the Leech Lake Division of Resource Management and the U.S. Forest Service create practical spaces where TEK interacts with agency knowledge despite the absence of a formal co-management agreement (Bussey et al., 2016).

Indigenous systems themselves may also selectively incorporate external knowledge. Sacred groves and forests in Uttarakhand and Sikkim continue to operate under customary norms but interact with modern conservation frameworks through recognition, tourism, or local scientific engagement (Negi et al., 2021). Mapuche Pewenche stewardship of Araucaria incorporates certain Western ecological techniques such as nursery propagation while maintaining Indigenous management principles (Herrmann, 2005).

Some unofficial initiatives overlap with more formal contexts yet remain primarily community-driven. In Indonesia, for instance, villages recognized under customary forest law adopt different strategies: some relying solely on IK, others informally blending IK with modern knowledge for climate adaptation and forest management (Budiman & Oue, 2025). Likewise, community-led restoration efforts, such as those triggered by Indigenous observations of species decline in oak populations, later intersect with scientific organizations but originate as grassroots initiatives (Souther et al., 2023).

Everyday agricultural practices in Lawachara National Park reveal another form of unofficial integration. Households combine Indigenous cultivation knowledge with selective use of modern inputs like hybrid seeds or chemical fertilizers to enhance productivity and ecological resilience (Rahman & Alam, 2016).

Across all these examples, unofficial integration initiatives demonstrate that so much integration happens outside formal institutions. They show IK interacting with SK through lived practice,

adaptive experimentation, and community-led innovation forms of integration that are grounded in primary data but lack the formal authorization or detailed documentation characteristic of primary initiatives.

Across the three themes - Primary, Secondary, and Unofficial Integration Initiatives, the "integration" variable captures a spectrum:

- From explicit, institutionally designed co-management and co-production (primary),
- Through supportive legal, policy, and conceptual frameworks that recognize or facilitate IK (secondary),
- To everyday, practice-based blending and informal collaborations (unofficial).

Many reviewed studies span multiple themes (e.g., Budiman & Oue, 2025, Souther et al., 2023, Bussey et al., 2016, Rahman & Alam, 2016), showing that integration is not a single event but a layered process that can move from unofficial practice to secondary recognition and, in some contexts, into primary, formalized regimes.

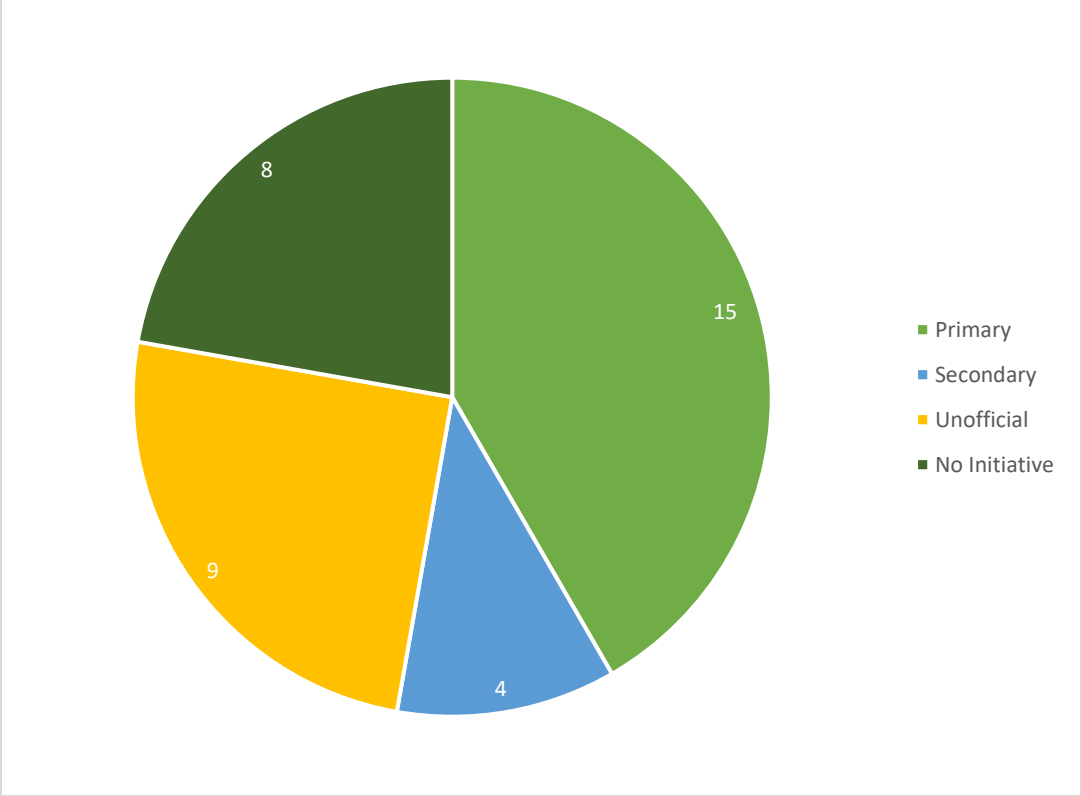

Figure 11: Pie-chart showing different themes and frequencies of Integration, identified through thematic analysis (N = 31)

4.4. Identifying constraints and potentials related to the integration of IK and SK

This study has considered the constraints, the governance politics and potentials to be shaping the ultimate current and future state regarding the integration of the knowledge systems in the forest management strategies for socially just and efficient climate change adaptation. In this study, potentials refer to the plausible future directions of Indigenous - Scientific Knowledge integration indicated by existing evidence. Accordingly, recommendations and policy implications represent envisioned pathways for advancing integration, the degree of collaboration observed in primary initiatives reflects how far integration can progress in practice, and enabling conditions capture the contextual factors that make deeper collaboration and integration possible. Together, these elements define the conditions and trajectories that shape what integration could become.

4.4.1. Constraints

1. Lack of Legal Recognition, Land Tenure Insecurity & Weak Institutional Support (n = 12)

Across the dataset, one of the most pervasive constraints relates to the to the legal and institutional marginalization. Several studies show that IK-based management lacks formal legal backing, making community protections "purely cultural practices with little or no legal support" (Bhagyanathan & Dhayanithy, 2025; Apgar et al., 2016; Best et al., 2021). Land tenure insecurity is a consistent barrier, communities face expansion of agro-industrial frontiers (Apgar et al., 2016), unresolved rights to ancestral territories (Herrmann, 2005), and forest management regimes where customary institutions have "no formal form" (Budiman & Oue, 2025).

Legal frameworks often fail to recognize Indigenous authority. In many regions, the absence of laws governing IK leads to risks of misappropriation and exploitation (Sraku-Lartey, 2014). Similarly, national forestry and conservation policies either marginalize or outright ignore the role of Indigenous peoples in mitigation and adaptation (Scholastica Akalibey et al., 2024). Land claims remain unsettled in places like British Columbia, complicating participation in planning

processes and undermining community authority (Karjala & Dewhurst, 2003). Complex and overlapping legislation creates "moral and legal clashes" that impede Aboriginal land use (Parsons & Prest, 2003). Globally, these institutional weaknesses reinforce dependency, limit decision-making power, and create vulnerability to external development pressures (Filho et al., 2025, Teitelbaum et al., 2023). Taken together, the absence of secure land rights and legal recognition structurally limits the viability and influence of Indigenous Knowledge systems.

2. Erosion of Cultural Practices, Knowledge Loss & Intergenerational Gaps (n = 10)

Several reviewed studies point towards the erosion of cultural practices and the gradual loss of intergenerational knowledge transmission. Several studies describe IK as being "rapidly on the decline" due to cultural homogenization, real-estate encroachment, and weakening customary norms (Bhagyanathan & Dhayanithy, 2025). The failure to pass on ecological practices to younger generations is highlighted explicitly, with participants acknowledging that they are "not actively passing on these practices to their own children" (Ibrahim, 2023). Some studies emphasize that TEK is disappearing because it is primarily oral and therefore vulnerable when elders pass away without mechanisms for documentation (Cheveau et al., 2008, Sraku-Lartey, 2014). In some communities, modernization, religious shifts, and youth rejection of traditional practices further accelerate this erosion, such as the view that certain IK practices are "evil spirit" activities (Mekonnen et al., 2021) or the decline in ceremonial obligations among converted Pentecostal Pewenche (Herrmann, 2005). This erosion is not simply cultural, it poses profound ecological consequences. As cultural knowledge diminishes, so too does the transmission of ecological stewardship practices that have shaped sustainable land relations for generations.

3. Power Imbalances, Marginalization & Inequity (n = 13)

Power asymmetries between state and community, industry and Indigenous peoples, Western science and Indigenous knowledge, constitute one of the strongest themes. These imbalances manifest in discriminatory enforcement of customary penalties (Ibrahim, 2023), unequal authority in planning processes (Cyr et al., 2022), and marginalization through corruption, extractive development, and agro-industrial expansion (Apgar et al., 2016). Concerns about the appropriation

or sanitization of Indigenous knowledge surface repeatedly, where TEK is removed from its cultural context or treated as secondary to scientific evidence (Cheveau et al., 2008, Souther et al., 2023). In some cases, participation processes themselves intensify inequity: bureaucratic structures and centralized planning marginalize the voices and priorities of Indigenous communities (Best et al., 2021, O'Flaherty et al., 2008, Teitelbaum et al., 2023). Large-scale industrial forestry continues to dominate decision-making, leaving Indigenous communities with limited real influence (Teitelbaum et al., 2023). Power imbalances also appear internally, for example when dominant community factions overshadow alternative knowledge holders or marginalized groups (Natcher & Hickey, 2002). These studies collectively show that the integration of IK is not occurring on equitable terms that often. Instead, knowledge is often filtered, subordinated, or selectively taken, reflecting deeper histories of colonial governance and ongoing structures of exclusion.

4. Epistemological Differences & Lack of Effective Integration Mechanisms (n = 12)

Findings show epistemological divides between Indigenous knowledge systems and Scientific knowledge systems as a central constraint. Several studies describe difficulties in bridging fundamentally different worldviews, values, and assumptions, for example, the tension between holistic Indigenous cosmologies and reductionist scientific frameworks (Bussey et al., 2016). Differences in conceptualizing landscape, species, and stewardship complicate collaborative work, as shown in the divergent understandings of woodland caribou conservation (O'Flaherty et al., 2008) or the challenge of integrating Indigenous categories into modelling tools (Bélisle et al., 2025). Visual modeling and technical platforms may be intimidating or inaccessible for elders (Nasr-Azadani et al., 2023), while the scientific process itself often excludes or devalues spiritual or qualitative knowledge (Souther et al., 2023). Some studies express concern that integration may devolve into extracting IK as "data," rather than building relationships of reciprocity and co-production (Bussey et al., 2016, Cheveau et al., 2008). Where processes fail, it is often because "proper synergy" or meaningful partnership was absent (Adhikari, 2015).

5. Lack of Resources, Funding, Capacity & Technical Limitations (n = 11)

Across several studies, it is consistently shown that technical and resource constraints are widespread and multifaceted. Studies describe limitations in funding, capacity, or scientific data, such as missing ecological information, lack of modeling capability, or inability to simulate extreme disturbances (Yazzie et al., 2019). Communities face practical challenges in maintaining IK-based practices because of technical barriers such as difficulties propagating key species (Balehegn et al., 2014) or insufficient resources for participatory projects (Best et al., 2021). Government agencies similarly face constraints, from limited budgets to personnel shortages (Hessburg et al., 2021). Training gaps, lack of professional expertise, and limited institutional capacity also hinder collaborative work, particularly in Aboriginal forestry (Parsons & Prest, 2003). Meanwhile, local communities struggle with low access to climate-specific weather and advisory services (Mekonnen et al., 2021). These resource limitations weaken not only the practice of IK but also the possibility of building equitable, sustained partnerships with scientific and governmental institutions.

6. Governance, Bureaucratic & Policy Barriers (n = 13)

Reviewed studies highlight a dense web of bureaucratic fragmentation, contradictory policies, and entrenched governance practices forms a major constraint. It has been shown how knowledge co-production becomes entangled in “organizational and administrative mazes” (Cyr et al., 2022), or how participatory initiatives stall for decades due to procedural delays (Cyr et al., 2022). Forest governance in many regions prioritizes economic extraction over cultural or ecological values (Budiman & Oue, 2025, Teitelbaum et al., 2023), reinforcing policies that marginalize Indigenous perspectives. Regulatory frameworks often fail to recognize customary institutions, making it difficult for communities to enforce rules or respond to violations (Budiman & Oue, 2025). Policy bias toward industrial forestry, ecosystem management paradigms misaligned with Indigenous values, and governmental reluctance to devolve meaningful authority all constrain community involvement (Teitelbaum et al., 2023, Parsons & Prest, 2003). Even global climate agreements neglect to fully acknowledge Indigenous knowledge (Scholastica Akalibey et al., 2024). These findings illustrate how governance structures often undermine IK not through direct opposition,

but through institutional inertia, top-down decision-making, and policy designs that center industrial priorities over Indigenous sovereignty.

7. Gender Inequities & Social Exclusion (n = 4)

Gendered exclusions surface in several studies, particularly regarding access to knowledge, participation in decision-making, and inclusion in forest-based practices. In some communities, women are explicitly prohibited from engaging in certain livelihood activities, including frankincense harvesting, inheritance, or proximity to culturally important species (Ibrahim, 2023). Participation in mapping or planning exercises may be limited by gendered labour roles that restrict women's availability (Best et al., 2021). In other cases, cultural norms and institutional biases undermine women's influence in policy processes (Negi et al., 2021) or frame their ecological knowledge as backward or unscientific (Mekonnen et al., 2021). Overall, it has been discussed that gendered exclusion weakens the completeness and continuity of IK systems, as women's knowledge often critical for food systems, medicinal practices, and land stewardship remains undervalued.

8. Climate Variability, Ecological Constraints & External Pressures (n = 5)

Finally, ecological and climatic pressures further complicate the practice and transmission of IK. Studies describe unpredictable weather conditions, shifting species phenology, and declining biotic indicators (Mekonnen et al., 2021). Climate change challenges the reliability of traditional knowledge-based forecasting and resource management (Yazzie et al., 2019), while biophysical disturbances such as fungal disease in agroforestry systems undermine productivity and Indigenous livelihoods (Coq-Huelva et al., 2017). Communities also face external pressures such as illegal logging, agricultural expansion, and wildlife hunting (Rahman & Alam, 2016), as well as governance systems that marginalize Indigenous adaptive strategies (Filho et al., 2025). These findings underscore that IK is not only challenged by social and political structures but also by rapidly changing ecological contexts that test its adaptive capacity.

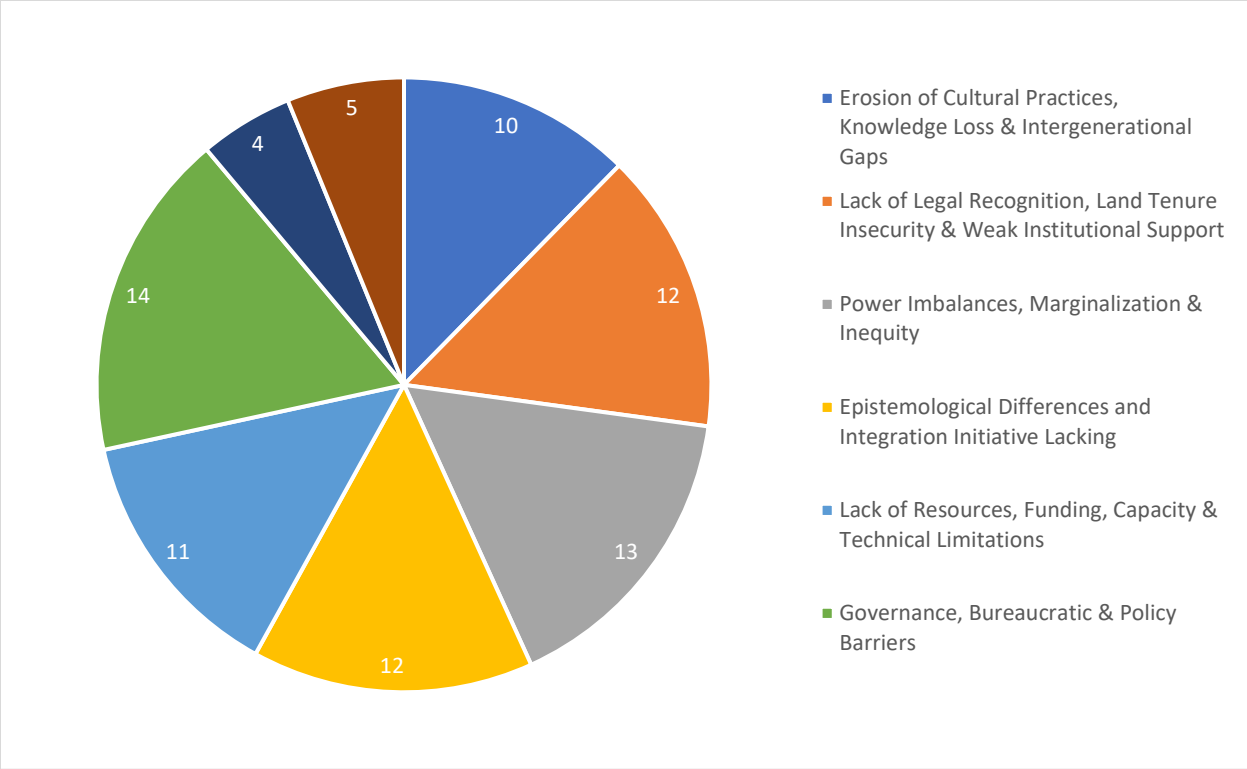

Figure 12: Pie-chart showing different themes and frequencies of Constraints, identified through thematic analysis (N = 31)

4.5. Governance Politics

1. Colonial Legacies and Historical Power Imbalances (n = 13)

Across many reviewed studies, participants describe political environments still deeply shaped by colonial histories. These legacies manifest through disrupted cultural structures, altered governance systems, and persistent inequalities that continue to shape Indigenous and state relations (Apgar et al., 2016; Best et al., 2021; Nasr-Azadani et al., 2023) For instance, colonial reforms and agricultural interventions created mismatches between local practices and state-imposed systems, reinforcing Indigenous marginalization (Coq-Huelva et al., 2017). In other cases, longstanding political pressures led to attempts to erase Indigenous sovereignty, such as federal termination policies that threatened the identity and authority of communities like the Menominee (Nasr-Azadani et al., 2023). These imbalances persist in the present, where political marginalization and external economic or governance priorities continue to override Indigenous

voices (Ite, 2025; Apgar et al., 2016). Broader geopolitical processes ranging from globalization to the imposition of foreign governance structures have also deeply reshaped Indigenous territories and authority (Filho et al., 2025). In several regions, Indigenous nations find themselves in ongoing struggles with government institutions, courts, and industrial actors, often navigating systems where sovereignty must be continuously defended or negotiated (O'Flaherty et al., 2008; Cyr et al., 2022; Teitelbaum et al., 2023). The cumulative effect is a power imbalance that restricts how IK can influence policy and decision-making processes, even when political recognition is formally sought (Parsons & Prest, 2003; Herrmann, 2005).

2. Political Marginalization and Exclusion from Decision-Making (n = 8)

A recurring theme across the dataset is the exclusion of Indigenous communities from decision-making processes that directly affect their lands and knowledge systems. In scientific and policy contexts, Indigenous priorities are often overshadowed by technical models or institutional norms, leaving communities without meaningful representation in shaping conservation or management strategies (Bélisle et al., 2025; Ite, 2025). Political exclusion is also evident where national or international policy frameworks acknowledge IK in principle but fail to implement such commitments in practice. Communities remain structurally sidelined, with their rights and voices diminished by bureaucratic inertia or competing political agendas (Apgar et al., 2016; Su et al., 2020). In other cases, Indigenous claims receive symbolic recognition, but genuine participation in policy development is limited, as seen in both local governance and global climate negotiations (Best et al., 2021; Scholastica Akalibey et al., 2024; Adhikari, 2015). This marginalization restricts communities' ability to assert their knowledge systems and influence political agendas that impact their livelihoods.

3. Sovereignty, Land Rights, and Territorial Control Conflicts (n = 13)

Land and territorial control form one of the most politically charged dimensions of IK governance among the reviewed studies. Many accounts highlight the absence of formal recognition for customary institutions, which leaves communities vulnerable when newcomers violate traditional rules but cannot be held accountable under state law (Budiman & Oue, 2025). In other settings,

the establishment of state-managed reserves or conservation areas has resulted in large-scale loss of Indigenous land and diminished local autonomy, creating profound tensions around sovereignty (Su et al., 2020; Herrmann, 2005). Political conflicts are also visible in contexts where state or provincial authorities retain overriding control over decisions, even when Indigenous governance systems advocate different priorities or spatial scales of concern (Cheveau et al., 2008; O'Flaherty et al., 2008). Broader colonial structures continue to condition how land rights are recognized, contested, or denied, leading to persistent struggles for territorial recognition and political authority (Filho et al., 2025; Cyr et al., 2022; Teitelbaum et al., 2023). These issues are further complicated by multilayered governance systems, where federal, provincial, and local entities impose overlapping regulations that clash with Indigenous territorial claims (Parsons & Prest, 2003; Karjala & Dewhurst, 2003; Natcher & Hickey, 2002). Collectively, these dynamics position sovereignty and land rights as central political battlegrounds shaping the future of Indigenous Knowledge.

4. Policy Dynamics, Implementation, and Top-Down Management (n = 12)

Findings reveal that many political challenges arise not from the absence of policy, but from how policy is implemented or imposed. Cases describe how top - down governance structures override local decision-making, resulting in management systems that fail to reflect Indigenous priorities (Apgar et al., 2016; Budiman & Oue, 2025). In Ghana, despite national programs that claim to support IK, scientific research often proceeds without incorporating Indigenous perspectives, and the absence of legal frameworks hinders effective policy execution (Sraku-Lartey, 2014). Bureaucratic processes frequently delay or derail political initiatives, especially when multiple agencies or regulatory frameworks are involved (Souther et al., 2023; Cyr et al., 2022). Even when policies aim to decentralize authority, the reality on the ground often remains centralized, with governments retaining final decision-making power and Indigenous groups receiving limited influence (Hessburg et al., 2021; Teitelbaum et al., 2023). In some contexts, outdated or exclusionary frameworks persist, creating institutional conflict and reducing opportunities for meaningful community participation (Adhikari, 2015; Karjala & Dewhurst, 2003; Kasoki et al., 2025). The result is a pattern of political processes that nominally engage Indigenous groups but ultimately reinforce hierarchical governance.

5. Power Imbalances (Frequency: 7)

The findings highlight that political relationship between IK and SK is full of asymmetries that extend beyond epistemology into governance and policy. Scientific models and management systems often guide action, while Indigenous insights are treated as supplementary or symbolic (Bélisle et al., 2025; Coq-Huelva et al., 2017). In collaborative arrangements, the political authority to approve projects often lies with state agencies, even when Indigenous experts warn that proposed interventions are misguided (Bussey et al., 2016; Cyr et al., 2022). These dynamics reinforce longstanding hierarchies where scientific knowledge is positioned as the default decision-making framework, and IK as subordinate. This political imbalance is also seen in conservation and forestry settings where Indigenous governance structures or practices are overlooked or dismissed, despite their historical effectiveness (Adhikari, 2015; Filho et al., 2025; Natcher & Hickey, 2002). The power relations embedded in these interactions shape whose knowledge counts and whose authority prevails in determining environmental futures.

6. Internal Leadership, Local Power Structures, and Community Politics (n = 4)

The reviewed studies reveal political dynamics are not only external. Some political barriers arise from internal governance structures that influence how IK is managed within communities. Customary leadership such as clan heads or village chiefs may hold significant authority and shape how rules are enforced, creating situations where justice or decision-making becomes unevenly distributed (Ibrahim, 2023; Su et al., 2020). In some settings, internal political influences such as dominance by powerful clan. In other contexts, longstanding local political systems are undergoing change, with traditional structures weakening under modern pressures, thereby reducing their capacity to protect communal interests (Ite, 2025). Meanwhile, localized leadership arrangements—such as community-level leasing systems also illustrate the political organization of resource management, reflecting both autonomy and internal hierarchies (Rahman & Alam, 2016). These internal political dimensions demonstrate that IK governance is shaped by complex relationships within communities as well as by external forces.

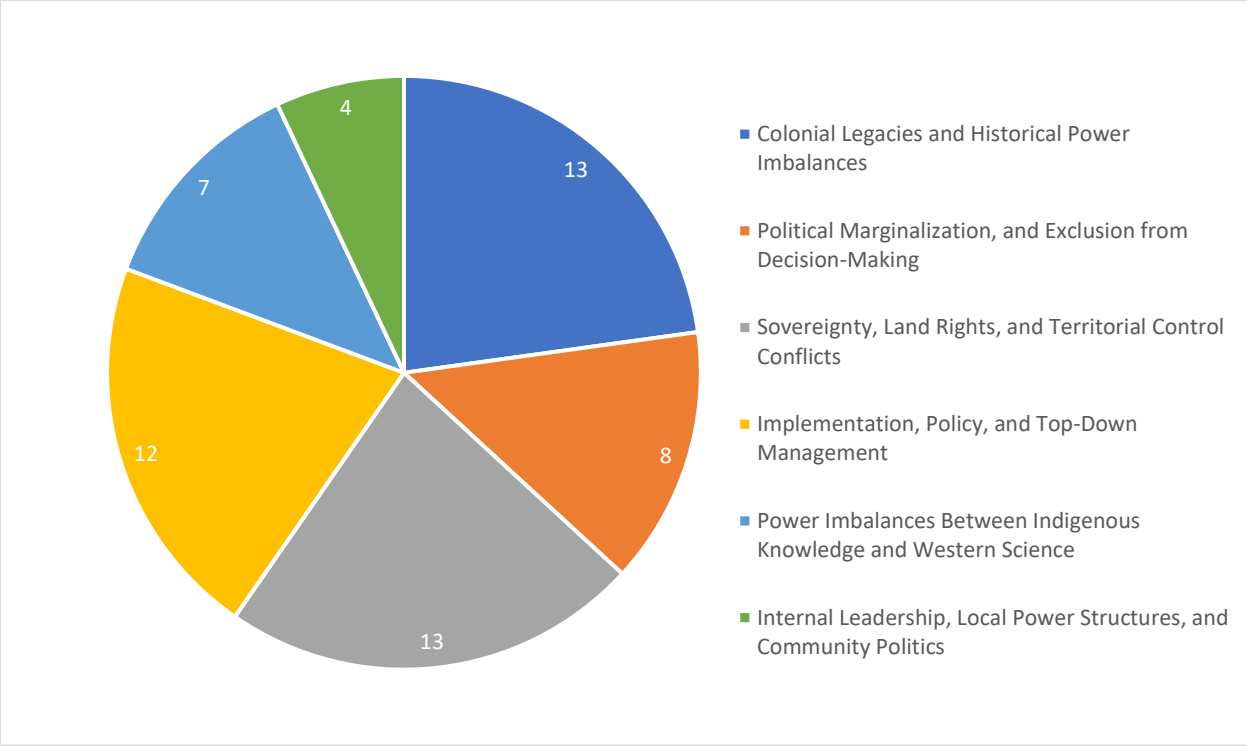

Figure 13: Pie-chart showing different themes and frequencies of Politics, identified through thematic analysis (N = 31)

4.6. Recommendations/ Policy Implications

1. Mandating Legal & Policy Recognition (n = 15)

Legal and policy recognition emerged as the most frequently cited recommendation among the reviewed papers, reflecting widespread concern that Indigenous knowledge continues to lack legal and institutional protection. Several studies emphasize the need for legal backing to protect sacred groves (Bhagyanathan & Dhayanithy, 2025) or to preserve and legitimize customary forest management systems (Budiman & Oue, 2025). Others call for IK to be "protected by law and integrated into formal science," requiring databases, metadata standards, and procedures for storage and preservation (Sraku-Lartey, 2014). Many authors highlight that meaningful recognition must extend beyond symbolic inclusion. For example, policy frameworks are urged to incorporate IK in biodiversity conservation and adapt it into national and international policy processes (Apgar et al., 2016, Sraku-Lartey, 2014, Scholastica Akalibey et al., 2024). At broader

scales, studies note that international agreements and environmental policies must treat Indigenous participation as equal to that of other major stakeholders (Scholastica Akalibey et al., 2024). The need for "firm political decisions" that mandate Indigenous participation in forest governance is repeatedly stressed (Cheveau et al., 2008, Filho et al., 2025, Cyr et al., 2022). Altogether, this theme points to the necessity of institutionalizing Indigenous rights and knowledge systems within the policy architecture itself.

2. Integration of Indigenous and Scientific Knowledge (n = 13)

A major body of recommendations among the findings, emphasizes the need to consciously integrate Indigenous and scientific knowledge systems as complementary rather than competing frameworks. Across several studies, Indigenous communities and researchers call for "combining TEK and scientific knowledge" to enhance conservation outcomes (e.g., Ibrahim, 2023, Bélisle et al., 2025). This integration is not framed merely as methodological enrichment, but as a necessary step toward sustainable resource management whether for frankincense conservation (Ibrahim, 2023), climate-change adaptation strategies (Yazzie et al., 2019), or silvopastoral systems that merge ecological tradition with climate mitigation (Balehegn et al., 2014). Many authors stress that both knowledge systems "are complementary and have to mutually enrich, rather than replace each other" (Herrmann, 2005). Others argue that bridging them requires careful co-design, such as developing models "in line with Indigenous priorities and values" (Bélisle et al., 2025), or employing hybrid approaches that allow community-led processes alongside provincial conservation goals (O'Flaherty et al., 2008). This theme underscores that knowledge integration is not only technical, but deeply relational, requiring respect, reciprocity, and recognition of Indigenous epistemologies (Mekonnen et al., 2021; Rahman & Alam, 2016; Kasoki et al., 2025).

3. Collaborative Frameworks, Processes & Co-Management (n = 14)

Many recommendations across the dataset advocate for developing or strengthening collaborative mechanisms that bring Indigenous communities and external agencies together as equal partners. These recommendations highlight co-management as a practical and ethical requirement (Su et al., 2020; Teitelbaum et al., 2023; Kasoki et al., 2025). Studies call for "egalitarian dialogue" between

Indigenous and Western conventions to counteract subalternity (Coq-Huelva et al., 2017) and for participatory frameworks that involve "diverse landscape actors with different values and interests" (Best et al., 2021). Effective collaboration is described as dependent on respectful, cross-cultural dialogue (O'Flaherty et al., 2008), shared training and joint monitoring programs (Bussey et al., 2016), and processes ensuring the involvement of knowledge holders in decision-making (Filho et al., 2025). In some cases, it is recommended that collaborations proceed without demanding cultural convergence but instead agree on shared outcomes (O'Flaherty et al., 2008). This theme reinforces that successful policy implementation relies on governance models that are relational, participatory, and capable of adapting to community-specific contexts.

4. Technical Capacity & Documentation (n = 7)

A smaller but significant cluster of recommendations addresses the technical requirements needed to support the long-term sustainability of Indigenous knowledge systems. These include formal guidelines on identifying and disseminating IK, creating user-friendly databases with proper metadata standards (Sraku-Lartey, 2014), documenting knowledge through participatory approaches (Negi et al., 2021), and integrating scientific knowledge in technical domains such as nursery management, soil analysis, or climate adaptation (Adhikari, 2015; Cheveau et al., 2008). Several studies highlight the need for supportive institutions and technical backstopping to sustain resilient Indigenous forestry practices (Adhikari, 2015). Others emphasize process-oriented tools such as PBRs, scenario planning, and participatory geo-information tools (Filho et al., 2025; Best et al., 2021). Together, these recommendations reflect the infrastructural and methodological foundations required for robust knowledge integration.

5. Ethical & Procedural Safeguards (IP Protection) (n = 5)

Ethical considerations and the protection of Indigenous intellectual property appear in studies that caution against extractive or inequitable uses of knowledge. Recommendations emphasize safeguarding sensitive information, setting rules for disclosure and attribution, and ensuring knowledge-gathering follows community-led protocols (Sraku-Lartey, 2014; Souther et al., 2023). Power imbalances and historical exploitation are identified as structural risks that must be

addressed through ethical guidelines and legal safeguards (Bussey et al., 2016; Filho et al., 2025). This theme highlights that policy implementation must protect not only the knowledge itself but the autonomy and dignity of its holders.

6. Training, Education & Internal Capacity (n = 4)

Several recommendations focus on building internal capacity within Indigenous communities and strengthening cross-cultural competencies among external actors. For example, training in communication, negotiation, and forest management systems is recommended for Indigenous youth (Parsons & Prest, 2003). Basic education in Indigenous worldviews and ways of knowing is encouraged for external agencies (Bussey et al., 2016). Some studies also advocate for building local leadership capacity and creating spaces for youth, women, and elders in forest management boards (Natcher & Hickey, 2002). This theme underscores that knowledge integration depends on empowered individuals capable of navigating and transforming governance systems.

7. System/Site-Specific Interventions (n = 6)

A number of recommendations endorse highly localized or ecosystem-specific actions. These include protecting sacred groves through tailored legal interventions (Bhagyanathan & Dhayanithy, 2025), adopting silvopastoral systems involving Indigenous tree species in sub-Saharan Africa (Balehegn et al., 2014), and designing village-level forest regulations based on customary knowledge (Budiman & Oue, 2025). Other examples emphasize the need to incorporate Indigenous fire stewardship or species-specific ecological knowledge into forest management (Hessburg et al., 2021; Ite, 2025). These recommendations show that place-based interventions are essential and cannot be generalized without attention to unique cultural and ecological contexts.

8. Rethinking the Research Paradigm (n = 6)

A recurring theme in several reviewed studies is the critique of existing research paradigms and the call to reconfigure knowledge production itself. Several studies recommend learning from resource users rather than imposing generalized assumptions (Ite, 2025; Apgar et al., 2016). Others

argue for instrumental and normative co-construction approaches that support meaningful change (Apgar et al., 2016).

Some authors urge moving beyond theoretical endorsement of TEK toward developing practical processes for documentation that involve local communities (Cheveau et al., 2008). Calls for new methodological approaches such as participatory tools, community-led validation processes, and cross-cultural evaluation frameworks signal a shift toward more grounded, relationship-based research practices (Best et al., 2021; Rahman & Alam, 2016). This theme highlights a fundamental epistemic realignment required in forestry research and policy development.

9. Political Sovereignty, Respect & Power Dynamics (n = 9)

Finally, several studies situate recommendations within broader struggles over sovereignty, recognition, and power. Some emphasize the need to address unequal sovereignties that shape collaborative processes (Cyr et al., 2022). Others stress that co-management can only succeed if Indigenous approaches are respected and not subordinated to Western Scientific frameworks (Bélisle et al., 2025; Su et al., 2020). Recommendations call for respecting community authority, enhancing the role of traditional leaders, and balancing power between different knowledge systems (Budiman & Oue, 2025; Herrmann, 2005). Several studies highlight that inclusive governance requires legitimacy, transparency, and careful attention to existing power structures, particularly when integrating TEK into formal systems (Souther et al., 2023; Filho et al., 2025). This theme underscores that meaningful policy implementation is inseparable from the political realities Indigenous communities navigate.

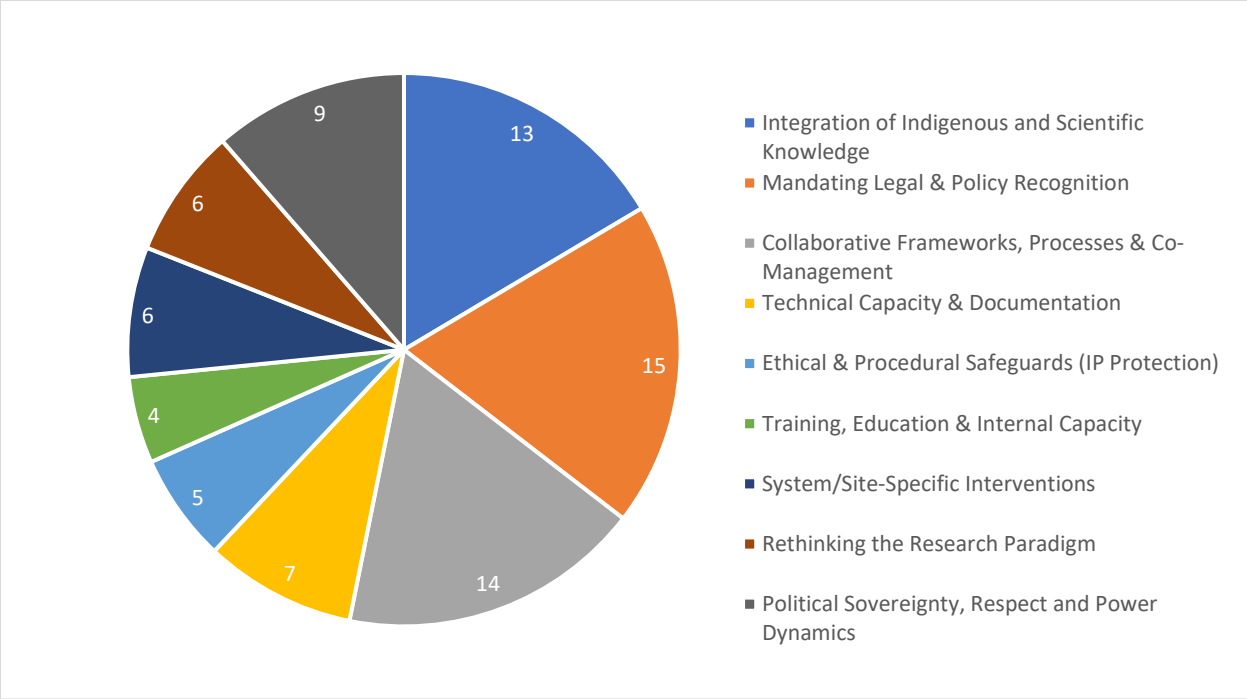

Figure 14: Pie-chart showing different themes and frequencies of Recommendation/Policy Implementation, identified through thematic analysis (N = 31)

4.7. Degree of Collaboration of Primary Initiatives

ID	Degree of Collaboration	Reasoning (Yanou et al.)	Enabling Conditions	Integration Pathway / Mechanism
Bélisle et al., 2025	High (Co-design & Co-management)	Co-developed models; iterative workshops; shared decision-making; joint dissemination.	Trust-building, ethical protocols, training, prior partnership.	Co-production of modelling tools and scenarios through joint workshops and shared interpretation.
Best et al., 2021	High (Co-design & Co-management)	Joint production of spatial models; multi-actor scenario creation; negotiated outcomes.	Skilled facilitation, multi-stakeholder participation.	Participatory geo-information tools enabling shared spatial knowledge and future scenarios.

Apgar et al., 2016	High (Co-design + Dissemination)	Community-driven assessments; co-constructed resilience analysis; collective policy output.	NGO alliances, activist groups, multi-country platform.	Co-produced resilience assessment leading to jointly generated policy recommendations.
Yazzie et al., 2019	High (Co-design)	Indigenous values define objectives; co-interpretation of model outputs; IK frames science.	Cultural grounding (K'é), agency partnerships.	IK-guided framing of scientific models, aligning simulations with Indigenous worldviews.
Karjala & Dewhurst, 2003	High (Co-design)	Community values define C&I; scenario planning jointly developed; strong co-design.	University–community partnership, local steering.	Co-developed planning tools (C&I + scenarios) reflecting Indigenous values.
Natcher & Hickey, 2002	High (Co-design)	Community-defined criteria; sustainability matrix jointly adapted; continuous engagement.	Dedicated local research coordinator, extended fieldwork.	Value-driven co-design of sustainability criteria and evaluation systems.
Adhikari, 2015	High (Co-management)	Formal recognition of Indigenous institutions; joint rule-making; shared governance.	Legal recognition, existing Indigenous systems.	Institutional co-management through integration of customary systems into formal governance.
O'Flaherty et al., 2008	High (Co-management)	Shared authority under C-LUP; elders as decision-makers; hybrid planning structure.	Enabling policy, cross-scale mechanisms.	Cross-scale co-management combining First Nation leadership with provincial planning.
Cyr et al., 2022	High (Co-management)	Joint boards, equal representation, authority of tallymen; collaborative directives.	Treaty framework, institutional power-sharing.	Formalized co-management structures combining state and Indigenous decision-making.
Teitelbaum et al., 2023	Medium - High (Setting-up - Co-design)	Tenure reforms, certification systems, hybrid arrangements; not full shared authority.	Certification policies, Indigenous leadership, provincial frameworks.	Hybrid governance mechanisms via certification standards, community tenures, and shared planning.
Coq-Huelva et al., 2017	Medium–High (Setting-up - Co-design)	Hybrid agroforestry + market practices; egalitarian	Indigenous cooperative, market access, technical agency support.	Dialogue-based hybridization of Indigenous agroforestry with

		dialogue; partial shared design.		modern value-chain practices.
Parsons & Prest, 2003	Medium–High (Setting-up - Co-design)	Joint ventures, TEK integration into forest plans, training and co-learning; partial authority.	Federal programs, NAFA, capacity-building.	Co-designed forestry model blending TEK with Western management practices.
Nasr-Azadani et al., 2023	Medium (Consultative + Setting-up)	Indigenous knowledge informs design but no shared authority; consultative engagement.	Community–university collaboration, visualization tools.	Consultative incorporation of TEK into visualization and systems-thinking tools.
Bussey et al., 2016	Medium (Consultative + Setting-up)	Knowledge exchange, joint activities (e.g., prescribed burns), but not shared governance.	Professional exchanges, long-term relationships.	Consultative knowledge exchange through collaborative training and field operations.
Rahman & Alam, 2016	Medium (Consultative)	Indigenous representatives involved, but limited authority; participation without shared power.	CMC structure, NGO facilitation.	Consultative participation in forest management committees.

Table 2: Degree of Collaboration Among Primary Integration Initiatives

The primary integration initiatives demonstrate a consistently high level of collaboration between Indigenous knowledge holders and external institutions, aligning closely with the upper end of the collaboration continuum proposed by Yanou et al. (2023), where co-design, co-management, and joint dissemination represent the most equitable and participatory forms of knowledge integration. By examining the details of each initiative such as the activities, participants, integration details, it becomes evident that primary initiatives not only employ higher degrees of collaboration than secondary and unofficial initiatives but also operationalize integration through structured, detailed, and culturally grounded processes.

Across most cases, co-design emerges as the dominant mode of collaboration, expressed through shared modelling, participatory scenario development, and joint construction of conceptual and

spatial tools. In the initiative combining Indigenous landscape values with LANDIS-II simulations (Bélisle et al., 2025), collaboration unfolds through workshops, expert elicitation, joint model refinement, and shared dissemination materials, reflecting a full alignment with the co-design and co-production stages that Yanou et al. identify as markers of equitable knowledge integration. The inclusion of training sessions and pre-validation of modelling materials by Indigenous community researchers further exemplifies a multi-directional flow of knowledge, suggesting a shift from extractive engagement toward reciprocal co-learning.

Similarly, the Diné-guided modelling initiative (Yazzie et al., 2019) in USA demonstrates deep co-design: the scientific tool (C-FVS) is reframed and interpreted through Diné relational ethics of K'é, with joint field visits, consultations, and collaborative interpretation sessions. This reorientation of modelling around Indigenous cosmology and obligations mirrors the decolonial-responsive form of integration discussed by Yanou et al., wherein Indigenous epistemologies actively shape the analytical structure of scientific tools rather than being retrofitted onto them.

Co-management is most visible in initiatives embedded within formal governance frameworks, such as the integration of the Shingi Nawa institution into Sagarmatha National Park management (Adhikari, 2015), the Whitefeather Forest Initiative and its Community-based Land-Use Planning system (O'Flaherty et al., 2008), and the Adapted Forestry Regime under the Paix des Braves treaty (Cyr et al., 2022). In these cases, shared authority is institutionalized through formal bodies buffer zone committees, cross-scale planning mechanisms, joint working groups, and or through examples such as tallyman-led trapline governance in Canada, that is a consultation process is based on traditional Cree family where a senior family member recognized for his knowledge and experience shares governance control of hunting grounds (traplines) with the state. These structures correspond to the highest rungs of the collaboration ladder described by Yanou et al., where power is redistributed and Indigenous actors exercise sustained authority across multiple planning and implementation stages. The Cree-Québec Forestry Board (Cyr et al., 2022), with equal representation from Cree and state authorities, further exemplifies co-management grounded in negotiated power-sharing rather than symbolic participation.

Other initiatives occupy intermediate positions, where collaboration moves beyond consultation but stops short of fully shared authority. In the hybrid agroforestry and value-chain work of the Kallari Association (Coq-Huelva et al., 2017), for instance, Indigenous management philosophies

are in dialogue with Western market and technical knowledge through egalitarian exchanges, but institutional authority remains partially differentiated. This aligns with the "setting-up - co-design" category, where partnership structures are emerging but not yet consolidated into shared governance. Similarly, visualization-based systems-thinking tools in the Menominee context (Nasr-Azadani et al., 2023) employ consultative and dialogic learning but do not embed IK holders in positions of equal decision-making, situating these initiatives at the medium level of collaboration.

A small number of initiatives display a mixed collaboration profile. The multi-tool participatory governance initiative in Suriname (Best et al., 2021) involves deeply interactive engagement through P3DM, simulation games, and scenario planning yet authority resides primarily within facilitation teams rather than indigenous communities. The result is a high degree of co-design in knowledge production but not full co-management of governance outcomes. Likewise, certification- and tenure-based hybrid arrangements (Teitelbaum et al., 2023, Parsons & Prest, 2003) demonstrate significant progress toward shared planning through co-learning and joint decision-making but remain limited by external regulatory structures.

An important pattern across the primary initiatives is the emphasis on joint dissemination, an element Yanou et al. identify as a high-collaboration indicator. Several studies including Bélisle et al., 2025, Apgar et al., 2016, and Karjala & Dewhurst, 2003 produced shared materials, community-approved story maps, or co-authored policy recommendations, signalling that communities remained engaged through the final stages of knowledge translation.

Overall, the degree of collaboration across primary initiatives is consistently higher than what Yanou et al. observe in much of the Southern African knowledge-integration literature. Primary initiatives in this dataset frequently reach the upper tiers: co-design, co-production, and co-management. This pattern underscores those primary initiatives, by definition, involve not merely the presence of Indigenous knowledge but its active incorporation through partnerships, negotiated power-sharing, and culturally grounded methodological frameworks. Across the primary integration initiatives, several enabling conditions emerge as crucial determinants of whether projects achieved co-design, co-production, or co-management, the highest rungs of collaboration described by Yanou et al. (2023) These enabling conditions, visible across the detailed initiatives,

reveal why certain cases reached deep forms of partnership while others plateaued at medium–high or consultative levels.

Chapter 5: Discussion

5.1. The Roles of Indigenous Knowledge: in the Ecological and Governance System

The results demonstrate that IK functions simultaneously as an ecological science, a livelihood system, and a governance structure. Themes such as sustainable practices, biodiversity conservation, soil and water stewardship, and spatial - temporal management (e.g., Nasr-Azadani et al., 2023; Herrmann, 2005; Mekonnen et al., 2021; Bhagyanathan & Dhayanithy, 2025) corroborate long-standing literature describing IK as a cumulative body of adaptive ecological knowledge developed through repeated experimentation and observation (Berkes, 2018; Mekonen, 2017; Hosen et al., 2020). IK's emphasis on reciprocity, stewardship, and multi-generational responsibility aligns closely with the concept of "kincentric ecology" described by Salmón (2000), where humans and non-human beings are understood as part of an interconnected moral and ecological community.

The reviewed studies further show that IK-based management often achieves ecological outcomes comparable to or superior to scientific forestry interventions. This is consistent with research demonstrating that Indigenous-managed lands frequently exhibit equal or higher biodiversity than state-protected areas (Schuster et al., 2019). Such empirical patterns reinforce the argument that IK represents not simply "local knowledge" but a comprehensive environmental governance system.

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knowledge developed through repeated experimentation and observation (Berkes, 2018; Mekonen, 2017; Hosen et al., 2020). The depth of empirical evidence in the reviewed studies strengthens this interpretation: IK does not manifest as isolated techniques, but rather as a coherent ecological system capable of sustaining soil fertility, regulating hydrological flows, preventing forest degradation, supporting forest-based livelihoods, and enhancing long-term adaptive capacity without intensive external inputs. Much of this ecological precision arises because IK is rooted in lived experience — knowledge is continuously tested on the land through selective harvesting, agroforestry design, spatial zoning, fire stewardship, and long-term observation of ecological thresholds. IK's emphasis on reciprocity, stewardship, and multi-generational responsibility aligns closely with the concept of "kincentric ecology" described by Salmón (2000), where humans and non-human beings are understood as part of an interconnected moral and ecological community.

The reviewed studies further show that IK-based management often achieves ecological outcomes comparable to or superior to scientific forestry interventions. Across diverse landscapes, IK supports biodiversity maintenance, soil carbon storage, natural regeneration, and culturally embedded conservation strategies such as sacred groves, rotational harvesting, and community-led enforcement. These patterns directly correspond with findings from the broader literature demonstrating that Indigenous-managed lands often exhibit equal or higher biodiversity than state-protected areas (Schuster et al., 2019). The results illustrate why this occurs: IK systems embed ecological science within land-use norms, customary law, seasonal planning, leadership roles, and community accountability, thereby ensuring that ecological stewardship is both technically sound and socially enforced. Such empirical patterns reinforce the argument that IK represents not simply "local knowledge" but a comprehensive environmental governance system. In IK-based landscapes, ecological function, livelihood security, and cultural continuity are inseparable; governance, science, and lived practice converge into a single adaptive framework rather than being compartmentalized domains. This integrated quality is what makes IK systems enduring, context-sensitive, and capable of shaping resilient forest futures.

5.2. Benefits of Knowledge Integration: Complementarity, Ecosystem Function, and Social Wellbeing

The benefits identified in the results conservation outcomes, forest regeneration, food security, climate adaptation, cost-effectiveness, cultural resurgence, and stronger governance highlight the profound potential of IK-SK integration. These findings align with studies that emphasize complementarity between the two systems, where IK provides fine-grained ecological indicators and long-term environmental memory, while SK contributes modelling, monitoring technologies, and institutional support (Tengö et al., 2014; Lyver et al., 2018).

For instance, participatory modelling initiatives (e.g., Bélisle et al., 2025; Yazzie et al., 2019) demonstrate how community knowledge can refine scientific assessments, leading to more effective and context-appropriate climate adaptation strategies. Such hybrid approaches echo findings by Raymond et al. (2010), who show that co-produced knowledge enhances both scientific robustness and social acceptance.

Moreover, several reviewed studies highlight how integration contributes to cultural revitalization, community empowerment, and improved livelihoods, benefits widely documented in participatory forestry and co-management scholarship (Okedele et al., 2024).

5.3. Persistent Constraints: Structural Inequities, Epistemological Gaps, and Institutional Barriers

Despite the benefits, the results also reveal persistent constraints that hinder meaningful integration. These include erosion of cultural practices (Bhagyanathan & Dhayanithy, 2025; Apgar et al., 2016), lack of legal recognition (Budiman & Oue, 2025; Herrmann, 2005), power imbalances (Cyr et al., 2022; Apgar et al., 2016), epistemological differences (Bussey et al., 2016; Bélisle et al., 2025), technical limitations (Best et al., 2021; Apgar et al., 2016), and bureaucratic barriers (Parsons & Prest, 2003; Teitelbaum et al., 2023). All of these constraints are widely recognized in knowledge co-production literature, where integration efforts often struggle not

because of technical incompatibility, but because of socio-political conditions that prevent Indigenous communities from engaging as equal partners. Many IK systems operate within historical contexts of dispossession, marginalization, and policy exclusion, which means that even when IK is scientifically valuable, it is not necessarily institutionally recognized or politically supported.

These constraints reflect well-documented challenges in knowledge co-production. Scholars such as Nadasdy (1999) argue that integration efforts often become mechanisms for assimilating IK into Western frameworks, stripping it of cultural context and political meaning. The evidence in the review particularly concerns about IK being reduced to "data" (Bussey et al., 2016; Cheveau et al., 2008) supports this critique and resonates with institutional critiques in the broader literature. In many of the reviewed examples, IK is invited into planning spaces only after scientific priorities have been set, creating conditions where Indigenous contributions are treated as supplementary ecological detail rather than as a governance system with its own norms, authority, and decision-making processes.

Similarly, the findings that colonial legacies and marginalization continue to shape forest governance (Coq-Huelva et al., 2017; Cyr et al., 2022; Ite, 2025) align with literature emphasizing that power inequalities remain a fundamental barrier to equitable IK–SK collaboration (Whyte, 2017; Smith, 2012). Structural inequities persist in decision-making, where technical expertise, regulatory authority, and bureaucratic legitimacy are typically vested in state actors or scientific institutions rather than Indigenous governance systems. Under such conditions, IK cannot easily determine policy priorities, resource-use norms, or territorial rights. Instead, integration is often filtered through technocratic logic, diluting cultural meaning and community authority.

The institutional fragmentation, conflicting policies, and technocratic decision-making highlighted in the results mirror the observations of Armitage et al. (2011), who show that bureaucratic systems often do not have the flexibility needed to support authentic co-management. Even integration efforts that are genuinely well-intentioned can end up being shaped by external timelines, data requirements, and procedural rules that Indigenous communities have little ability to shape. The empirical cases in this review make this point clear that successful integration is not just a matter of bringing different knowledge systems together, it also depends on shifting authority, ensuring

meaningful participation, securing legal recognition, and creating institutional arrangements that can genuinely accommodate Indigenous governance principles.

5.4. Governance Political Dimensions: Colonial Continuities, Sovereignty, and Decision-Making Power

The results show that politics is not a background factor but a core determinant shaping whether integration is meaningful or extractive. Themes of colonial legacies, political marginalization, and sovereignty conflicts reflect broader scholarly consensus that Indigenous peoples' forest management struggles are deeply political (Simpson, 2014; Bélisle et al., 2025). These struggles show up in many everyday forms, including disputes over land ownership, exclusion from decision-making processes, weak legal protections, and the ongoing tendency to favor outside economic interests over Indigenous governance and knowledge systems. In these situations, politics determines not only who gets a seat at the table, but also whose knowledge is treated as legitimate, whose measurements are taken seriously, and whose understanding of forest conditions becomes embedded in policy and practice (Simpson, 2014; Wyatt, 2008).

For example, the political exclusion of Indigenous communities from forestry decision-making (Bélisle et al., 2025; Best et al., 2021; Su et al., 2020) echoes Wyatt's (2008) findings that forest governance often structurally sidelines Indigenous perspectives despite legal recognition. Even when formal recognition exists, bureaucratic mandates and scientific procedures frequently dominate operational decision-making, relegating IK to advisory or consultative roles. As the reviewed evidence shows, exclusion is not always overt, it may occur through procedural norms, technical standards, professional hierarchies, or legislative ambiguities. In each case, IK's governance capacity is weakened not because the knowledge lacks ecological value, but because the political structure limits the authority to act on it.

The results also highlight sovereignty disputes and unresolved land claims (Karjala & Dewhurst, 2003; Cyr et al., 2022), consistent with research showing that land rights are the strongest predictor of sustainable forest governance (Walker et al., 2020). When Indigenous tenure is insecure, IK is

vulnerable to extraction, co-optation, or selective appropriation. Conversely, When Indigenous communities have real authority over their lands, they are far more likely to maintain ecological health, uphold conservation practices, and develop adaptive land-use approaches that help both people and ecosystems stay resilient over time. The evidence from the review shows that knowledge integration cannot succeed through technical collaboration alone. For integration to be meaningful, it must also deal with deeper political issues such as sovereignty, decision-making power, land and territorial rights, and the broader conditions that determine whether Indigenous knowledge holders have the authority to act on what they know (Walker et al., 2020, Wyatt, 2008). Overall, the political analysis confirms that integration is impossible without addressing structural sovereignty, decision-making power, and politics. IK - SK complementarity is therefore not only a knowledge question but a governance and justice question, requiring policies that recognize IK not merely as a set of observations, but as a legitimate system of environmental authority.

5.5. Recommendations identified for integrating Indigenous Knowledge in forest management climate adaptation

The recommendations identified in this review reflect a clear shift toward institutional, and epistemological transformation in climate adaptation practice. Rather than offering isolated technical measures, the literature proposes integrated recommendations that reframe how Indigenous Knowledge (IK) is recognized and applied. A key set of recommendations in the reviewed papers focus on strengthening legal and policy recognition of Indigenous rights, lands, and governance systems, including recognition of customary law, Indigenous land tenure, co-management arrangements, Indigenous-led planning, and Free, Prior and Informed Consent (FPIC). These align with rights-based approaches that position Indigenous peoples as rights-holders and central decision-makers in climate governance (Morgera & Nakamura, 2022; Tauli-Corpuz et al., 2020). A second group emphasizes institutional reform and power-sharing, such as devolving authority to Indigenous institutions, restructuring state agencies to embed Indigenous participation, and establishing joint decision-making bodies. These recommendations are well grounded in co-management and collaborative governance research which identifies equitable

power-sharing as fundamental to durable and legitimate partnerships (Berkes, 2009; Armitage et al., 2011). The reviewed literature also highlights methodological and procedural innovation, including participatory mapping, scenario planning, co-produced modelling, culturally grounded indicators, and the integration of IK into monitoring and evaluation. These approaches aim to accommodate multiple knowledge systems without subsuming IK within predefined scientific frameworks, this is consistent with calls for genuine knowledge co-production (Tengö et al., 2017; Yanou et al., 2025). Another recurring theme concerns capacity-building and mutual learning, including training for Indigenous youth, support for Indigenous-led research, and the development of cross-cultural competencies among scientists and practitioners. These recommendations reflect co-learning principles central to Two-Eyed Seeing and related approaches that emphasize reciprocal learning while maintaining the integrity of distinct knowledge systems (Bartlett et al., 2012). Finally, several recommendations situate climate adaptation within broader political, historical, and ethical contexts, calling for recognition of colonial legacies, support for Indigenous self-determination, and framing adaptation as a matter of justice rather than solely technical risk management (Whyte, 2020; Ford et al., 2016). Overall, the recommendations point toward a holistic and transformative vision of IK integration in climate adaptation in forest management, grounded in rights-based governance, institutional reform, methodological pluralism, and ethical engagement.

5.6. Integration Initiatives in Climate-Adapted Forest Management

The results reveal that Indigenous - scientific knowledge integration occurs through a layered spectrum of initiatives ranging from highly formalized, institutionally supported collaborations to informal, community-led practices embedded in everyday land-use decisions. This spectrum has been captured through primary, secondary, and unofficial integration initiatives in the results.

5.6.1. Primary Integration Initiatives: Formal, Co-Designed, and Institutionally Anchored Integration

Primary initiatives represent the most deliberate and institutionally supported forms of integration. These cases demonstrate how IK and scientific knowledge become intertwined through co-production frameworks, co-management institutions, hybrid governance systems, and participatory modelling processes. Such integration reflects what Armitage et al. (2011) describe as "deliberate co-production," where knowledge is jointly generated, validated, and mobilized by Indigenous communities and scientific or governmental institutions.

A central feature of these primary initiatives is the reorientation of scientific tools around Indigenous worldviews. The co-production of LANDIS-II forest simulations informed directly by Indigenous landscape values (Bélisle et al., 2025), or the use of Diné kinship principles to guide the interpretation of the Climate–Forest Vegetation Simulator (Yazzie et al., 2019), exemplifies how scientific models can be reshaped through Indigenous ethics of reciprocity, respect, and relationality. Similar transformations are reported in global literature where Indigenous peoples reinterpret scientific outputs through local ontologies resulting in more culturally grounded, socially legitimate ecological modelling based on first-hand experience (Johnson et al., 2015; Bohensky & Maru, 2011).

Primary initiatives also highlight the role of hybrid livelihood systems and institutional platforms. The Kallari Association's (indigenous farmers association) blending of Sumak Kawsay (indigenous ways and views of life) with modern market systems (Coq-Huelva et al., 2017) echoes studies in Latin America where Indigenous economies combine intrinsic values and principles to create resilient forest-based livelihoods (Cronkleton et al., 2008, Bray et al., 2005). Likewise, "Aboriginal forestry" models (Parsons & Prest, 2003) align with long-standing findings that culturally rooted forestry programs can enhance both ecological outcomes and Indigenous sovereignty (Natcher & Hickey, 2002; Wyatt, 2008; McGregor, 2011).

The review further reveals that many primary initiatives involve formal co-management and shared governance institutions (O'Flaherty et al., 2008; Cyr et al., 2022; Adhikari, 2015). These findings reflect broader evidence that co-management when rights are respected and Indigenous authority is meaningful provides a robust platform for integrating IK into forest planning,

monitoring, and climate adaptation (Berkes, 2009; Stevenson, 2006). For example, the Adapted Forestry Regime under Paix des Braves (Cyr et al., 2022) mirrors similar Indigenous - state agreements in Canada and Australia where trapline systems, clan structures, or customary tenure form the decision-making core of forest co-governance (McDonald & Figueiredo, 2022; Natcher et al., 2005).

Finally, initiatives which explore the use of participatory modelling, scenario planning, 3D visualization, and criteria-and-indicators frameworks (Nasr-Azadani et al., 2023; Best et al., 2021; Karjala & Dewhurst, 2003; Natcher & Hickey, 2002) shows how integration is facilitated through tools that create intercultural learning spaces. These align with Tengö et al.'s (2014) "multiple evidence base" approach, where visual and relational tools enable IK and SK to contribute on equal footing without collapsing one into the other.

Together, the primary initiatives demonstrate that formal, authority-recognized integration is possible when supported by trust, respect, Indigenous leadership, and institutional flexibility, reinforcing global evidence that integration is most effective under conditions of shared authority and long-term partnership (Diver, 2016, 2007; Kearney et al., 2019).

5.6.2. Secondary Integration Initiatives: Policy, Legal, and Conceptual Enablement

The secondary integration initiatives identified in this review illustrate a form of IK - SK interaction that is present in discourse but under-documented in practice. Unlike primary initiatives where integration is anchored in participatory processes, co-management, or co-produced modelling, secondary initiatives describe broader institutional or conceptual developments that acknowledge Indigenous Knowledge without providing detailed evidence of how such recognition translates into collaborative forest governance.

The case of Indonesia's customary forest recognition (Budiman & Oue, 2025) captures this pattern clearly. The study highlights major legal shifts such as constitutional court rulings and policy reforms but does not present empirical material showing how these reforms shape everyday decision-making or create spaces for collaborative integration with scientific or state forest

agencies. This absence of operational detail does not imply that integration is ineffective; rather, it reflects the limited depth of documentation available in the reviewed study. Many authors have noted that legal reforms often provide an important foundation for future collaboration, but their practical implications depend on context-specific implementation processes that are not always captured in secondary literature (Larson & Dahal, 2012; Sikor & Lund, 2009). A similar pattern appears in studies describing federal directives that recognize TEK within U.S. land management (Souther et al., 2023). These directives signal institutional openness to Indigenous knowledge, yet the study does not outline concrete examples of co-produced actions, collaborative planning, or Indigenous authority within restoration programs. This gap aligns with broader critiques that policy-level commitments to Indigenous inclusion often precede, or even outpace their implementation in day-to-day forest governance (Moyo, 2022; Martin et al., 2025). Conceptual pathways presented in Cheveau et al. (2008) such as using Indigenous rules to inform planning frameworks or aligning zonation structures with Indigenous land-use patterns further demonstrate how IK is positioned within theoretical models of adaptive governance. These models highlight potential future directions for integration but the study does not document the institutional or relational processes needed to operationalize them. The distinction between conceptual potential and applied practice is important, as it shapes how these initiatives should be interpreted within a systematic review. Finally, the examples in Rahman & Alam, 2016, where Indigenous practices are referenced within broader conservation or livelihood strategies, underscore the limited degree of integration described. Here, IK is acknowledged but not structurally embedded in governance processes or decision-making systems. Taken together, secondary integration initiatives in this review represent policy recognition, conceptual modelling, or institutional statements of support, rather than fully documented, collaborative integration. Their value lies in illustrating institutional shifts toward acknowledging IK, but they provide little empirical insight into how integration unfolds in practice. This cautions against overinterpreting these examples as indicative of operational integration and positions them instead as background conditions or conceptual openings within the broader landscape of IK - SK relations.

5.6.3. Unofficial Integration Initiatives: Everyday, Community-Led, and Practice-Based Integration

Unofficial initiatives highlight that much integration happens organically, outside formal structures. These cases illustrate a form of "everyday co-production" (Sundberg, 2013), grounded in relationships, adaptive experimentation, and pragmatic decision-making rather than in policy or formal agreements.

Examples include hybrid agro-ecological practices such as community-devised silvopastoral systems (Balehegn et al., 2014), informal collaborations between Indigenous resource officers and state agencies (Bussey et al., 2016), and everyday forest decisions shaped jointly by customary tenure and scientific concepts of restoration (Ite, 2025). These processes align with findings by Chaudhary et al. (2025) and Long & Zhou (2001), who show that Indigenous communities continually adapt their knowledge through selective incorporation of external techniques, climate information, and market tools. Unofficial integration is also evident in sacred grove management (Negi et al., 2021), Mapuche nursery propagation of Araucaria (Herrmann, 2005), and community-triggered restoration initiatives based on Indigenous ecological observations (Souther et al., 2023). Such situations exemplify how IK systems actively evolve, integrating scientific insights where meaningful while retaining core relational principles.

These initiatives echo global patterns where Indigenous–scientific integration develops through interpersonal trust, repeated interaction, and shared land stewardship, even in the absence of formal authority. They remind us that integration is not only a bureaucratic or institutional process but also a lived, situated practice that develops from necessity, environmental change, and cross-cultural encounters (Nightingale, 2011; Cleaver, 2017).

5.7. Analytical Framework

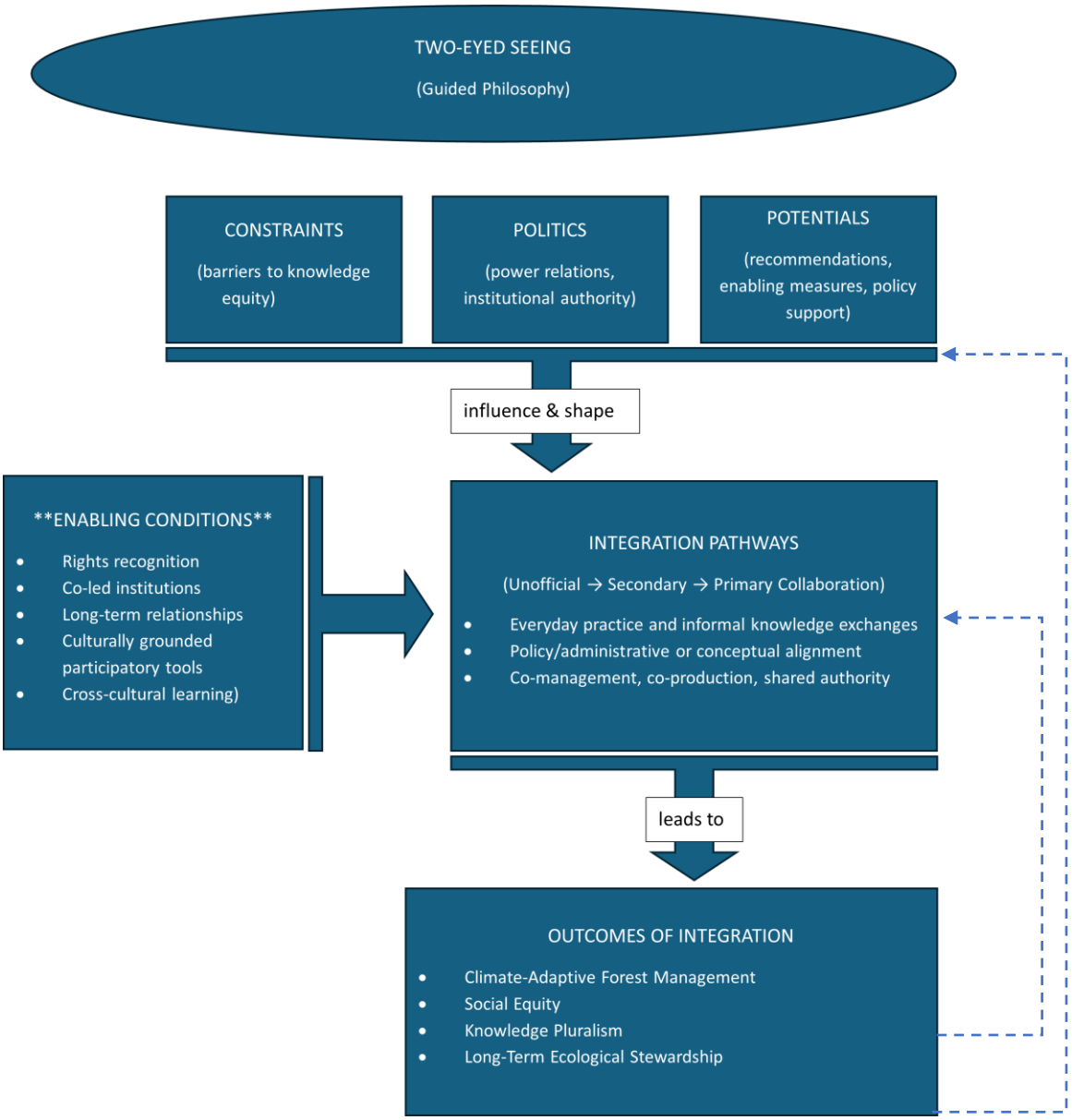

Figure 15: Analytical Framework

The analytical framework developed in this thesis contributes towards a step in identifying key elements for efficient, socially just integration in the climate changed adapted forest management. It reconceptualizes Indigenous and scientific knowledge integration as a guided process shaped by systemic inputs (constraints, politics, and potentials) and translated into practical integration pathways under the overarching philosophy of Two-Eyed Seeing approach. These pathways are supported by a set of enabling conditions, which function as the structural and relational

foundations that allow integration to advance ultimately to intended outcomes. Rather than treating the integration of Indigenous Knowledge (IK) and Scientific Knowledge (SK) as a technical exercise, the framework positions it as a relational, political, and justice-oriented endeavor.

At its core, the framework begins with a set of contextual inputs, the structural, institutional and epistemic constraints that hinder integration, the political dynamics that shape knowledge authority, and the potentials identified in recommendations and supportive mechanisms across the literature. These inputs represent the real-world conditions under which Indigenous - scientific knowledge interactions occur. They frame what is possible, what is limited, and what avenues for transformation exist.

Through the guiding philosophy of Two-Eyed Seeing (Etuaptmumk), these inputs are interpreted in a way that honors the integrity of each knowledge system. Two-Eyed Seeing emphasizes the importance of learning to use "the best of Indigenous knowledge with the best of Western knowledge," without subsuming one under the other. This principle acts as the overarching orientation that informs how constraints are understood, how political realities are analyzed, and how potentials for more just climate adaptation are recognized.

Under this guiding lens, the framework identifies integration pathways, the concrete processes and mechanisms through which IK and SK interact in practice. These pathways range from informal, every day, community-driven integration to formalized co-design, co-production, and co-management structures. They represent the dynamic, on-the-ground ways that knowledge systems are woven together in forest management and climate adaptation.

From the analysis done in this study, these pathways are supported or impeded by a set of enabling conditions, which function as the structural and relational foundations that allow integration to advance to intended outcomes. Enabling conditions include recognition of Indigenous rights and tenure, Indigenous-led institutions, culturally grounded participatory methods, long-term trust-building, cross-scale coordination, and mutual capacity-building. When these are strong, integration moves toward equitable collaboration; when they are weak, integration stalls or becomes superficial.

Together, the interplay of inputs, pathways, and enabling conditions shape the outcomes of integration. Across the dataset, these outcomes are visible in a range of ecological, social, cultural,

and governance improvements. Climate-adaptive forest management emerges in initiatives where IK guides fire practices, species stewardship, or adaptive agroforestry (e.g., Hessburg et al., 2021, Balehegn et al., 2014, Negi et al., 2021). Enhanced ecological resilience and biodiversity protection appear through sacred groves, regeneration practices, and mixed management systems (e.g., Bhagyanathan & Dhayanithy, 2025, Herrmann, 2005, Scholastica Akalibey et al., 2024). Social equity and community empowerment are strengthened in co-governance and rights-recognition contexts (e.g., Cyr et al., 2022, O'Flaherty et al., 2008, Teitelbaum et al., 2023). Knowledge pluralism and more legitimate decision-making arise when scientific models and planning frameworks incorporate Indigenous values and worldviews (e.g., Bélisle et al., 2025, Nasr-Azadani et al., 2023, Karjala & Dewhurst, 2003, Natcher & Hickey, 2002). Together, these cases show how meaningful integration contributes to forest management outcomes that are not only technically effective, but can lead towards culturally grounded and socially just outcomes.

Importantly, the framework also recognizes that these outcomes are not final endpoints. Over time, successful outcomes can feedback into the system by strengthening enabling conditions, reshaping political relationships, reducing constraints, and opening new potentials for integration. In this way, integration is understood as an adaptive and evolving process, where learning, trust, and institutional change accumulate across cycles of practice.

In this way, the analytical framework can be step towards a holistic and justice - centered map for understanding how IK - SK integration unfolds, how it can be strengthened, and what conditions are necessary for it to contribute to transformative, climate-resilient forest management.

Chapter 6: Conclusion

This thesis examined how Indigenous Knowledge (IK) is integrated with Scientific Knowledge (SK) in forest management for climate change adaptation, and identified the conditions under which such integration becomes effective, equitable, and sustainable. Through a systematic review of peer-reviewed and grey literature, the study demonstrates that IK is not simply complementary to scientific approaches, but constitutes a robust, place-based system of ecological understanding that plays a critical role in climate-adaptive forest management. Across diverse contexts, IK contributes to biodiversity conservation, ecosystem functioning, forest regeneration, climate adaptation and mitigation, the sustenance of forest-based livelihoods and many other roles.

The findings show that IK operates through interconnected practices, governance systems, ethical worldviews, and intergenerational knowledge transmission, embedding sustainability within everyday land-use decisions. When meaningfully engaged alongside scientific tools and institutions, IK enhances the relevance, legitimacy, and effectiveness of forest management, particularly under conditions of climatic uncertainty. At the same time, the review reveals that integration is neither neutral nor purely technical. Different political dynamics and persistent constraints including insecure land tenure, weak legal recognition, power asymmetries, epistemological hierarchies, and institutional rigidity continue to limit the depth and equity of IK - SK collaboration, often resulting in the selective extraction or one-sided information exchange of Indigenous knowledge rather than its recognition as a living governance system, worldview and knowledge system.

By distinguishing between primary, secondary, and unofficial forms of integration, this study highlights that much IK - SK interaction occurs outside formal institutions, through community-led practices and informal collaborations that remain under-recognized in policy and research. Where higher levels of collaboration are achieved, they are consistently supported by enabling conditions such as legal recognition, Indigenous-led or co-led institutions, trust-based relationships, culturally grounded participatory tools, and mutual capacity-building. These insights informed the development of an analytical framework that conceptualizes knowledge integration as a guided, iterative, and justice-oriented process. Anchored in the Two-Eyed Seeing approach,

the framework emphasizes epistemological pluralism, and offers a holistic and justice - centered map for understanding how IK - SK integration unfolds, how it can be strengthened, and what conditions are necessary for it to contribute to transformative, climate-resilient forest management.

Beyond synthesizing existing evidence, this thesis contributes to the research agenda on Indigenous knowledge integration by shifting the focus from whether IK should be integrated toward how integration occurs, under what conditions, and with what implications for justice and governance. The findings also lay the groundwork for further research, building on the analytical framework and gaps identified here, future research shall examine integration processes in specific forest management contexts, with particular attention to Indigenous-led institutions, authority-sharing arrangements, and the lived dynamics of collaboration under climate change. In doing so, this work aims to advance both academic understanding and policy-relevant approaches to socially just, culturally grounded, and ecologically resilient forest governance.

Overall, this thesis contributes to the growing body of scholarship calling for more inclusive and adaptive approaches to forest governance. It underscores that effective climate change adaptation in forest management requires not only technical innovation, but also structural and institutional transformation in how indigenous knowledge and indigenous peoples' rights are valued and recognized. By centering Indigenous Knowledge systems and articulating the conditions necessary for their meaningful integration with scientific knowledge, this study contributes towards generating both empirical insight and conceptual guidance for researchers, practitioners, and policymakers seeking to foster resilient, just, and sustainable forest futures.

Chapter 7: Limitations of the Study

This study has several limitations that should be considered when interpreting its findings. First, the scope of the review was constrained by time limitations due to it being a master's thesis, which influenced both the breadth of the literature search and the depth of analysis. As a result, the review was conducted using two major academic databases, supplemented by selected grey literature. While these sources capture a substantial body of relevant research, they do not represent the full range of research on Indigenous Knowledge integration. In particular, studies published in regional journals, Indigenous-led outlets, non-English sources, or institutional reports not indexed in these databases may have been missed. The uneven geographical distribution of the included studies, which are predominantly drawn from Western contexts, particularly North America, is another limitation. This concentration suggests that the synthesized knowledge may reflect a Western-centric perspective, potentially limiting the representativeness of Indigenous Knowledge integration practices from other regions.

Second, time constraints limited the extent to which extended searching and cross-referencing could be conducted across disciplines. Although reference lists were reviewed to identify additional studies, a broader search across more databases could have strengthened coverage, especially in different fields.

Third, the study is based entirely on secondary data drawn from published literature. While this approach is appropriate for identifying patterns, themes, and integration pathways, it limits insight into how integration is experienced and evaluated by Indigenous communities themselves. The findings therefore reflect how integration is reported by authors rather than direct community perspectives. Future studies can complement this limitation by conducting empirical study to understand the views of Indigenous communities.

Finally, the analytical framework developed in this thesis is conceptual in nature and derived from synthesized literature rather than empirical testing in a single case-study context. Future field-based research will be needed to further refine and validate the framework across diverse forest governance settings.

Despite these limitations, the study provides a systematic and analytically grounded synthesis that contributes meaningful insights into Indigenous - scientific knowledge integration for climate-adaptive forest management.

Chapter 8: Reference

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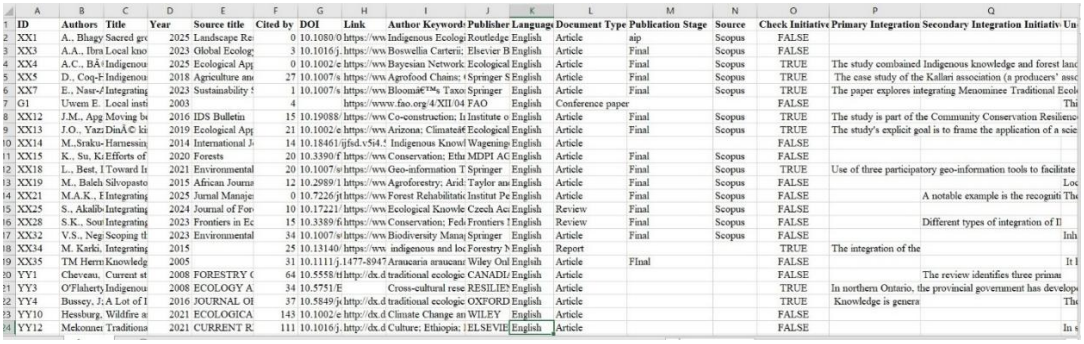
Chapter 9: Appendix



ID	Authors	Title	Year	Source title	Cited by	DOI	Link	Author Keywords	Publisher	Language	Document Type	Publication Stage	Source	Check Initiative	Primary Integration	Secondary Integration Initiativ	Un
XX1	A., Bhagy	Sacred gre	2025	Landscape Re	0	10.1080/0	https://ww	Indigenous Ecologi	Routledge	English	Article	aip	Scopus	FALSE			
XX3	A.A., Ibra	Local kno	2023	Global Ecolog	3	10.1016/j.	https://ww	Boswellia Carterii;	Elsevier B	English	Article	Final	Scopus	FALSE			
XX4	A.C., BÃ	Indigenou	2025	Ecological Apj	0	10.1002/e	https://ww	Bayesian Network	Ecological	English	Article	Final	Scopus	TRUE	The study combained Indigenous knowledge and forest land		
XX5	D., Coq-F	Indigenou	2018	Agriculture an	27	10.1007/s	https://ww	Agrofood Chains;	Springer S	English	Article	Final	Scopus	TRUE	The case study of the Kallari association (a producers' asso		
XX7	E., Nasr-A	Integrating	2023	Sustainability	1	10.1007/s	https://ww	Bloomâ€™s Taxo	Springer	English	Article	Final	Scopus	TRUE	The paper explores integrating Menominee Traditional Ecol		
G1	Uwem E.	Local insti	2003		4		https://www.fao.org/4/XII/04	FAO	English	Conference paper				FALSE			Thi
XX12	J.M., Apg	Moving be	2016	IDS Bulletin	15	10.19088/	https://ww	Co-construction; I	Institute o	English	Article	Final	Scopus	TRUE	The study is part of the Community Conservation Resilienc		
XX13	J.O., Yazz	DinÃ© kir	2019	Ecological Apj	21	10.1002/e	https://ww	Arizona; Climate#	Ecological	English	Article	Final	Scopus	TRUE	The study's explicit goal is to frame the application of a scie		
XX14	M., Sraku-	Harnessin	2014	International J	14	10.18461/ijfsd.v5i4.5		Indigenous Knowl	Wagening	English	Article			FALSE			
XX15	K., Su, Ka	Efforts of	2020	Forests	20	10.3390/f	https://ww	Conservation; Ethi	MDPI AG	English	Article	Final	Scopus	FALSE			
XX18	L., Best, I	Toward In	2021	Environmental	20	10.1007/s	https://ww	Geo-information T	Springer	English	Article	Final	Scopus	TRUE	Use of three participatory geo-information tools to facilitate		
XX19	M., Baleh	Silvopasto	2015	African Journa	12	10.2989/1	https://ww	Agroforestry; Arid	Taylor an	English	Article	Final	Scopus	FALSE			Loc
XX21	M.A.K., F	Integrating	2025	Jurnal Manaje	0	10.7226/jt	https://ww	Forest Rehabilitatic	Institut Pe	English	Article	Final	Scopus	FALSE		A notable example is the recogniti	The
XX25	S., Akalib	Integrating	2024	Journal of For	10	10.17221/	https://ww	Ecological Knowle	Czech Ac	English	Review	Final	Scopus	FALSE			
XX28	S.K., Sou	Integrating	2023	Frontiers in Ec	15	10.3389/f	https://ww	Conservation; Fed	Frontiers I	English	Review	Final	Scopus	FALSE		Different types of integration of II	
XX32	V.S., Neg	Scoping th	2023	Environmental	34	10.1007/s	https://ww	Biodiversity Mana	Springer	English	Article	Final	Scopus	FALSE			Inh
XX34	M. Karki,	Integrating	2015		25	10.13140/	https://ww	indigenous and loc	Forestry N	English	Report			TRUE	The integration of the		
XX35	TM Herm	Knowledg	2005		31	10.1111/j.	1477-8947	Araucaria araucan	Wiley Onl	English	Article	FInal		FALSE			It I
YY1	Cheveau,	Current st	2008	FORESTRY (	64	10.5558/tf	http://dx.d	traditional ecologic	CANADI/	English	Article			FALSE		The review identifies three prima	
YY3	O'Flaherty	Indigenou	2008	ECOLOGY A	34	10.5751/E		Cross-cultural rese	RESILIEN	English	Article			TRUE	In northern Ontario, the provincial government has develope		
YY4	Bussey, J	A Lot of I	2016	JOURNAL OI	37	10.5849/j	http://dx.d	traditional ecologic	OXFORD	English	Article			TRUE	Knowledge is genera		The
YY10	Hessburg,	Wildfire a	2021	ECOLOGICA	143	10.1002/e	http://dx.d	Climate Change an	WILEY	English	Article			FALSE			
YY12	Mekonne	Traditiona	2021	CURRENT R	111	10.1016/j.	http://dx.d	Culture; Ethiopia;	ELSEVIE	English	Article			FALSE			In s

Secondary Integration Initiativ	Unofficial Integration	Participants	Activities	Type of Knowledge	Location	Constraints	Benefits	Role of Indegenious Knowledg	Politics	Recommendation /Policy Implication
				Indigenous knowledg	India	The protectio	The paper	Indigenous Ecological Knowledge	(IEK) is t	It calls for "similar analyses in varying geogr
				Indigenous knowledg	Somalia	There are ins	Xeer' alon	The Somali people have ancient	The comn	The paper explicitly calls for the integration
Indigenous knowledge and forest	landscape simulations w	Researchers, c	A primary	Indigenous knowledg	Canada	There is risin	Both form	Indigenous people are first-hand	Power dy	Both forms of knowledge are complementa
Kallari association (a producers'	association currently op	Indigenous Ki	Discursive	Indigenous knowledg	Ecuador	There is a str	Cocoa pre	Indigenous systems of land utiliz	During the	As a worldview or as an emerging world, co
tegrating Menominee Traditional	Ecological Knowledge (T	Menominee co	Questiona	Indigenous knowledg	USA	The knowlec	Co-desig	Indigenous people play a signific	The Menc	By supporting the transmission of traditional
	This paper seeks to demonstrate that the relative			Indigenous knowledg	Nigeria	Due to both f	The relati	The utility of indigenous agro-ec	Due to bo	The best foundation for identifying improve
e Community Conservation Resilience Initiative (CCRI) i		Indigenous co	Participat	Indigenous knowledg	Paraguay	The resilience	Co-constr	IK is defined as "situated in instit	False assu	Recognition of IK was the first step in their
al is to frame the application of a scientific modeling tool		Diné (Navajo)	Scientific	Indigenous knowledg	USA	The epistemo	IK integra	Indigenous knowledge provides a critical co	Managers and tribal leaders must consider cl	
				Indigenous Knowled	Ghana	In Ghana infc	These indi	IK is a powerful resource of rura	In Ghana	IK must be protected by law and integrated i
				Indigenous knowledg	China	The lack of s	The applic	A Bulang village in the Yunnan l	It describ	There should be an intermeshing of indigeno
tory geo-information tools to facilitate integration of local/t		Local commu	For P3DM	Indigenous knowledg	Suriname,	Due to a hist	The partic	The communities' traditional life	Post-colo	Inclusive landscape governance thus goes be
	Locally developed prot	Local Farmers	Developi	Indigenous knowledg	Ethiopia	Despite their	Such local	Contrary to the view that indigenous people	The authors explicitly recommend that "Loc	
A notable example is the recogniti	The three villages in th	Spiritual Lead	Spatial ma	Indigenous knowledg	Indonesia	Historically,	By integra	Indigenous knowledge provides v	Until now	Recognizing and integrating traditional knowl
				Indigenous knowledg	Africa, Eu	The United N	The integr	Indigenous knowledge, ingrained	A quote fi	The two-eyed seeing framework (TESF) see
Different types of integration of II		Apache Triba	Triggering	Indigenous knowledg	USA	Lack of fina	Western A	Long-term landscape perspective	Only in th	Integration of TEK into land management an
	Inhabitants of the region	have lived in harmony v		Indigenous knowledg	India	The efforts c	1. The tra	Management of biodiversity by indigenous	Research has demonstrated that participatory	
		Sherpa Comm	Recognitic	Indigenous knowledg	Nepal	Where there	The findin	Rich and diverse types of indige	The indige	Not all indigenous practices in forestry are re
	It has been shown that	the indigenous knowledg		Indigenous knowledg	Chile	Yet Mapuch	Based on	The Mapuche Pewenche have a	The paper	It had been concluded that Mapuche Pewen
The review identifies three prima				Indigenous Knowled	N/A	"TEK is disa	Integratio	The paper provides the "most co	The centr	"TEK-gathering should be done by an interdi
he provincial government has developed a cross-scale plar		Ontario Mana	Joint field	Indigenous knowledg	Canada	The central c	The prim	Decision-making is "rooted in dir	"In Canad	The primary recommendation is that "resolvi
	The paper documents e	The Leech La	Worksho	Traditional ecologica	USA	The fundame	Co-mana	A cumulative body of knowledge	The relati	The authors recommend "formalizing existin
				Indigenous knowledg	North Am	"Public land	Indigenou	We are learning through integrati	Since the i	Indigenous and Western knowledge can joint
	In south and south west	Ethiopia forests are man		Indigenous knowledg	Ethiopia	Unpredictabil	Integratio	Regardless of the challenges from global cha	Policy makers and development planners sh	

Figure 16: Snaps of the Database

ID	Title	Year	Link	Publisher
XX1	Sacred groves and riparian conservation: nature-based solutions towards local climate adaptation in the Malabar Coast of India	2025	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85216192221&doi=10.1080%2F01426397.2025.2452439&partnerID=40&md5=564f6727f84a7ebb807ad9d395a442e6	Routledge
XX3	Local knowledge and attitudes of frankincense communities in northeastern Somalia	2023	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85179045404&doi=10.1016%2Fj.gecco.2023.e02748&partnerID=40&md5=4f38c5963d74220b32541b900a6ad8c1	Elsevier B.V.
XX4	Indigenous knowledge, forest landscape modeling, and the cumulative effects of environmental changes	2025	https://www.scopus.com/inward/record.uri?eid=2-s2.0-105011518657&doi=10.1002%2Feap.70053&partnerID=40&md5=7b0626d84d62719a9e4de34bdcdbecba	Ecological Society of America
XX5	Indigenous worldviews and Western conventions: Sumak Kawsay and cocoa production in Ecuadorian Amazonia	2018	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85021221459&doi=10.1007%2Fs10460-017-9812-x&partnerID=40&md5=b36465f8cb88c1fef9c52d10fb1742cc	Springer Science and Business Media B.V.
XX7	Integrating Menominee model for sustainable forestry with Systems Thinking competency through 3D virtual tours	2023	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85168570307&doi=10.1007%2Fs11625-023-01399-w&partnerID=40&md5=236fe84018f747cf9a23b04fd8d2311d	Springer

G1	Local institutions and indigenous knowledge in forest management: complementary or contradictory?	2003	https://www.fao.org/4/XII/0475-A3.htm	FAO
XX12	Moving beyond co-construction of knowledge to enable self-determination	2016	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85013965469&doi=10.19088%2F1968-2016.199&partnerID=40&md5=d5c907ad178017439b0becaadfad040d	Institute of Development Studies
XX13	DinÃ© kinship as a framework for conserving native tree species in climate change	2019	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85071757178&doi=10.1002%2Feap.1944&partnerID=40&md5=f82408c3af9cf2ecac81234db58e24bb	Ecological Society of America 1900 M Street NW, Suite 700 Washington DC 20036
XX14	Harnessing indigenous knowledge for sustainable forest management in Ghana	2014		Wageningen Academic
XX15	Efforts of indigenous knowledge in forest and wildlife conservation: A case study on bulang people in mangba village in yunnan province, china	2020	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85096037138&doi=10.3390%2Ff11111178&partnerID=40&md5=fd11d12f5982b1073c3d6adf117b4f97	MDPI AG
XX18	Toward Inclusive Landscape Governance in Contested Landscapes: Exploring the Contribution of Participatory Tools in the Upper Suriname River Basin	2021	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85112207546&doi=10.1007%2Fs00267-021-01504-8&partnerID=40&md5=1a9e3e362a6caae43d645fee88bf645e	Springer

XX19	Silvopastoral system based on Ficus thonningii: an adaptation to climate change in northern Ethiopia	2015	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85028210797&doi=10.2989%2F10220119.2014.942368&partnerID=40&md5=cf1dc2708d3d1f23f3b888c80f110a6b	Taylor and Francis Ltd. michael.wagreich@univie.ac.at
XX21	Integrating Indigenous Knowledge into Sustainable Forest Management for Climate Change Adaptation and Mitigation Strategies: Case from Southern Slopes of Mount Slamet, Indonesia	2025	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85218140789&doi=10.7226%2Fjtfm.31.1.41&partnerID=40&md5=8d6382d7eeb2e4aae52fc6c1ba52a608	Institut Pertanian Bogor, Department of Forest Management, Faculty of Forestry
XX25	Integrating indigenous knowledge and culture in sustainable forest management via global environmental policies	2024	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85197351490&doi=10.17221%2F20%2F2024-JFS&partnerID=40&md5=a5ae4e23f8212bcf47c041f424bfb700	Czech Academy of Agricultural Sciences
XX28	Integrating traditional ecological knowledge into US public land management: Knowledge gaps and research priorities	2023	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85150697266&doi=10.3389%2Ffevo.2023.988126&partnerID=40&md5=e6605a6b27bce3d513d69376c9c060e7	Frontiers Media S.A.
XX32	Scoping the Need of Mainstreaming Indigenous Knowledge for Sustainable Use of Bioresources in the Indian Himalayan Region	2023	https://www.scopus.com/inward/record.uri?eid=2-s2.0-85111796143&doi=10.1007%2Fs00267-021-01510-w&partnerID=40&md5=fa0d903a5812f8986aad1dba774e4956	Springer

XX34	Integrating indigenous, local and modern knowledge for sustainable conservation and management of forest ecosystems in Nepal.	2015	https://www.researchgate.net/publication/281235104_Integrating_indigenous_local_and_modern_knowledge_for_sustainable_conservation_and_management_of_forest_ecosystems_in_Nepal	Forestry Nepal
XX35	Knowledge, values, uses and management of the Araucaria araucana forest by the indigenous Mapuche Pewenche people: A basis for collaborative natural resource management in southern Chile	2005		Wiley Online Library
YY1	Current status and future directions of traditional ecological knowledge in forest management:: a review	2008	http://dx.doi.org/10.5558/tfc84231-2	CANADIAN INST FORESTRY
YY3	Indigenous Knowledge and Values in Planning for Sustainable Forestry: Pikangikum First Nation and the Whitefeather Forest Initiative	2008		RESILIENCE ALLIANCE
YY4	A Lot of It Comes from the Heart: The Nature and Integration of Ecological Knowledge in Tribal and Nontribal Forest Management	2016	http://dx.doi.org/10.5849/jof.14-130	OXFORD UNIV PRESS INC
YY10	Wildfire and climate change adaptation of western North American forests: a case for intentional management	2021	http://dx.doi.org/10.1002/eap.2432	WILEY

YY12	Traditional knowledge and institutions for sustainable climate change adaptation in Ethiopia	2021	http://dx.doi.org/10.1016/j.crsust.2021.100080	ELSEVIER
YY14	Obstacles to implementing indigenous knowledge in climate change adaptation in Africa	2025	http://dx.doi.org/10.1016/j.jenvman.2024.123678	ACADEMIC PRESS LTD-ELSEVIER SCIENCE LTD
YY17	Power-sharing between the Cree and Québec governments in Eeyou Itschee (Québec, Canada): sovereignties, complexity, and equity under the Adapted Forestry Regime of the Paix des Braves	2022		
YY18	Governance in the Boreal Forest: What Role for Local and Indigenous Communities?	2023	https://doi.org/10.1007/978-3-031-15988-6_20	Springer
G2	Aboriginal forestry in Canada	2003	https://doi.org/10.5558/tfc79779-4	NRC Research Press
G3	Including aboriginal issues in forest planning: a case study in central interior British Columbia, Canada	2003	https://doi.org/10.1016/S0169-2046(02)00196-2	Elsevier
G4	Putting the Community Back Into Community-Based Resource Management: A Criteria and Indicators Approach to Sustainability	2002	https://doi.org/10.17730/humo.61.4.dem6fx3npep78xaq	Society for Applied Anthropology

G5	Forest Dependent Indigenous Communities' Perception and Adaptation to Climate Change through Local Knowledge in the Protected Area - A Bangladesh Case Study	2016	https://doi.org/10.3390/cli4010012	MDPI
G6	Indigenous Knowledge and Sustainable Management of Forest Resources in a Socio-Cultural Upheaval of the Okapi Wildlife Reserve Landscape in the Democratic Republic of the Congo	2025	https://doi.org/10.3390/f16101523	MDPI

Table 3: Some variables of the main database