

Indigenous peoples' forest management practices for climate change adaptation: a systematic literature review

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Abstract

Indigenous Peoples manage extensive forest landscapes worldwide and possess long-standing knowledge systems that are increasingly recognised as important for climate change adaptation. However, evidence regarding how Indigenous forest management contributes to adaptation outcomes remains fragmented across regions, ecosystems, and disciplinary perspectives. This study aims to systematically synthesise global evidence on Indigenous and community-based forest management practices for climate change adaptation. Following the PRISMA 2020 framework, 59 peer-reviewed studies published between 2000 and 2025 were systematically reviewed and analysed using thematic synthesis. The findings identify four dominant forest management strategies: Traditional Ecological Knowledge (TEK) and seasonal practices, community-based forest management, Indigenous fire management and controlled burning, and agroforestry and sustainable harvesting systems. These practices contribute to four key adaptation outcomes: enhanced ecosystem resilience, reduced climate-related risks, improved livelihood sustainability, and biodiversity conservation. The review further demonstrates that Indigenous forest management functions as an integrated socio-ecological adaptation system in which adaptive capacity emerges through interactions among ecological processes, cultural values, customary institutions, and governance arrangements. The effectiveness of these systems is influenced by ecological thresholds, continuity of knowledge transmission, secure land tenure, and recognition of Indigenous governance authority. While collaboration between Indigenous knowledge systems and scientific or policy frameworks can strengthen adaptation outcomes through co-production and shared decision-making, ineffective or tokenistic integration may undermine Indigenous institutions and adaptive capacity. Overall, the review highlights Indigenous forest management as a place-based, relational, and multi-scalar approach to climate adaptation. Strengthening Indigenous rights, supporting governance autonomy, and promoting equitable knowledge integration are essential for advancing effective, just, and sustainable forest-based climate adaptation in an era of accelerating environmental change.

Keywords Indigenous forest management · Climate change adaptation · Social-ecological system · Traditional ecological knowledge (TEK) · Environmental management

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1 Introduction

Climate change has intensified over recent decades, resulting in unprecedented environmental and socio-economic disruptions worldwide [3]. Rising temperatures, shifting rainfall patterns, prolonged droughts, and the increasing frequency of extreme weather events threaten ecosystem stability and the well-being of communities that depend on natural resources. Forest ecosystems are particularly sensitive to climatic disturbances yet play a crucial role in buffering societies from their impacts. Forests regulate local microclimates, stabilize watersheds, conserve biodiversity, and support essential livelihood systems [1]. As international climate frameworks increasingly emphasise both mitigation and adaptation, forest-based strategies have emerged as central components of climate-resilient development. Ecosystem-based adaptation approaches highlight the interconnectedness of ecological integrity, sustainable livelihoods, and adaptive capacity, positioning forest-dependent communities, particularly Indigenous peoples, as key actors in global adaptation efforts [81].

Indigenous peoples manage and occupy an estimated one-third of the world's intact forest landscapes, making them among the most significant forest stewards globally [25, 40]. Their forest management systems, developed through long-term interactions with local environments, represent dynamic and context-specific knowledge systems that enable communities to respond effectively to climate variability. These systems incorporate practices such as selective harvesting, rotational cultivation, sacred forest protection, agroforestry diversification, and traditional fire management, all of which contribute to ecological resilience. Beyond their ecological dimensions, Indigenous forest management is deeply embedded in cultural values, spiritual worldviews, and customary governance structures that regulate resource access, use, and stewardship responsibilities [6]. Consequently, Indigenous knowledge systems contribute not only to the sustainable management of forests but also to long-term adaptation strategies that maintain ecosystem functions and community livelihoods.

The growing importance of Indigenous knowledge in climate adaptation has been increasingly recognised within international policy arenas. Organisations such as the Intergovernmental Panel on Climate Change (IPCC), the Convention on Biological Diversity (CBD), and the United Nations Framework Convention on Climate Change (UNFCCC) acknowledge the value of Indigenous knowledge in understanding environmental change and informing adaptation strategies [92]. The IPCC Sixth Assessment Report emphasises that climate-resilient development pathways are strengthened when Indigenous knowledge systems are integrated with scientific and technical knowledge [48]. Similarly, the Local Communities and Indigenous Peoples Platform (LCIPP) highlights the importance of meaningful Indigenous participation in climate governance and adaptation planning [26]. This growing recognition reflects a broader shift towards more inclusive and pluralistic approaches to environmental governance, particularly in forest-rich regions where conventional state-led approaches often prove insufficient.

Nevertheless, the concept of Indigenous peoples is not uniformly defined across countries and regions. While international instruments such as the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) provide broad principles related to self-identification, historical continuity, and collective relationships with land and resources, legal recognition varies considerably among jurisdictions [13]. In some countries, Indigenous identities are formally recognised through constitutional or legislative frameworks, whereas in others, similar communities may be classified as ethnic minorities, tribal communities, customary communities, or local communities. These differences should be considered when interpreting global evidence on Indigenous forest management and climate adaptation.

Despite increasing recognition, the literature on Indigenous forest management and climate adaptation remains fragmented. Existing studies are often dominated by localised case studies or thematic investigations focused on specific regions such as the Amazon Basin, Australia, the Pacific Islands, Canada, and Scandinavia [94]. While these studies provide valuable insights, their dispersed nature makes it difficult to identify broader patterns, recurring adaptation strategies, and common governance themes across diverse ecological and cultural contexts while respecting the place-based character of Indigenous knowledge systems. Moreover, limited effort has been devoted to synthesising how specific forest management practices contribute to adaptation outcomes such

as enhanced water regulation, reduced fire risk, livelihood diversification, and social resilience [12]. Research addressing institutional and governance dimensions—including land tenure security, co-management arrangements, and state–Indigenous collaborations—also varies considerably in scope and methodological rigor.

A further gap concerns the geographical distribution of research. Much of the existing literature focuses on contexts in the Global North or regions with relatively strong Indigenous rights frameworks, whereas communities in Southeast Asia, Sub-Saharan Africa, and parts of Latin America remain comparatively underrepresented. This uneven distribution raises concerns regarding the inclusivity and representativeness of current evidence. Furthermore, although interest in integrating Indigenous and scientific knowledge systems continues to grow, relatively few studies examine how such integration is implemented in practice or the conditions under which it strengthens or undermines adaptation outcomes.

These limitations point to a broader challenge. Although Indigenous peoples possess rich ecological knowledge and sophisticated forest management systems that support climate adaptation, there remains no comprehensive synthesis that systematically consolidates this evidence. This gap is particularly significant given the increasing risks faced by Indigenous and forest-dependent communities. Climate-related disruptions affect food security, access to clean water, forest-based livelihoods, and the availability of culturally significant species and ecosystem services. Changes in rainfall patterns, prolonged droughts, more frequent wildfires, flooding events, and shifting seasonal cycles can undermine both ecological stability and community well-being. Such challenges are often exacerbated by insecure land tenure, resource competition, and policy frameworks that inadequately recognise Indigenous governance systems. Consequently, policymakers, practitioners, and scholars lack a comprehensive understanding of how Indigenous forest management contributes to climate adaptation, how these practices vary across ecological and cultural contexts, and which governance conditions enable or constrain their effectiveness [5].

This systematic literature review addresses these gaps through a rigorous and transparent synthesis of global evidence on Indigenous forest management for climate change adaptation. The review aims to consolidate dispersed knowledge, identify patterns across diverse case studies, and assess the strengths and limitations of the current evidence base. Specifically, it pursues three objectives: (1) to identify the range of forest management practices employed by Indigenous peoples to respond to climatic stressors such as droughts, floods, wildfires, pests, and shifting seasonal cycles; (2) to examine the ecological, socio-cultural, and governance factors influencing the effectiveness of these practices; and (3) to analyse how Indigenous knowledge is integrated with scientific, technical, and policy frameworks.

The significance of this review lies in its contribution to both scientific understanding and policy development. By synthesising evidence on Indigenous-led forest adaptation strategies, the review identifies practices that can inform national adaptation plans (NAPs), community-based forest management programmes, and ecosystem-based adaptation initiatives. It also highlights governance arrangements that support Indigenous stewardship, including secure land rights, co-management institutions, and culturally grounded decision-making processes. At the same time, the review responds to growing calls for more inclusive climate research that recognises Indigenous peoples as active agents of climate resilience rather than passive victims of climate change.

Importantly, the effectiveness of Indigenous forest management should not be assumed to be uniform across all contexts. Indigenous communities operate within diverse ecological, political, and socio-economic environments, and their capacity to maintain customary governance systems may be constrained by insecure land tenure, external resource pressures, state regulations, and broader processes of environmental and social change. Recognising these contextual differences is essential for understanding both the opportunities and limitations of Indigenous-led adaptation strategies.

In doing so, this review contributes to broader international commitments associated with the Sustainable Development Goals (SDGs), particularly SDG 13 (Climate Action), SDG 15 (Life on Land), and SDG 16 (Peace, Justice, and Strong Institutions). It also contributes to ongoing debates in environmental governance, justice, and decolonisation by synthesising evidence on how Indigenous forest stewardship enhances resilience while challenging conventional top-down approaches to climate adaptation.

2 Research methodology

2.1 Preferred reporting items for systematic reviews and meta-analyses (PRISMA 2020)

This study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) framework to ensure transparency, methodological rigor, and reproducibility throughout the review process [73]. PRISMA 2020 provides an evidence-based reporting framework for systematic reviews, covering procedures from literature identification and screening to eligibility assessment, quality appraisal, and evidence synthesis.

The framework was applied to guide the identification, screening, eligibility assessment, and inclusion of studies. A PRISMA flow diagram was used to document the number of records identified, screened, excluded, and retained at each stage of the review process. In addition, the PRISMA checklist was used to ensure comprehensive reporting of key methodological components, including the search strategy, study selection procedures, quality appraisal, and data synthesis methods.

By adopting PRISMA 2020, this review aligns with internationally recognised best practices for systematic literature reviews, thereby enhancing the transparency, consistency, and credibility of the findings.

2.2 Formulation of research questions

The research questions were developed to examine the role of Indigenous forest management in climate change adaptation from both practical and conceptual perspectives. They were designed to guide a comprehensive synthesis of global evidence by capturing the diversity of Indigenous forest management practices, the socio-ecological conditions that influence their effectiveness, and the ways in which Indigenous knowledge interacts with scientific and policy frameworks.

The review was guided by the following research questions:

1. What types of forest management practices do Indigenous peoples employ to adapt to climate change?
2. What ecological, socio-cultural, and governance factors influence the effectiveness of Indigenous forest management for climate adaptation?
3. How is Indigenous knowledge integrated with scientific, technical, or policy frameworks in forest-based adaptation initiatives?

Together, these questions provide the analytical structure for examining Indigenous-led adaptation strategies, identifying enabling and constraining factors, and highlighting knowledge gaps and future research priorities.

2.3 Searching strategy

2.3.1 Identification

The identification stage involved a systematic search of two major bibliographic databases: Scopus [83] and Web of Science [98]. These databases were selected because of their broad interdisciplinary coverage, rigorous indexing standards, and extensive citation records across environmental science, forestry, climate change, and Indigenous studies.

The search was restricted to peer-reviewed journal articles published in English between 2000 and 2025. This period was selected to capture both foundational and contemporary scholarship on Indigenous forest management, Traditional Ecological Knowledge (TEK), community-based forest governance, and climate change adaptation. The broader temporal coverage enabled the review to examine the evolution of research trends, conceptual developments, and adaptation practices across diverse ecological and socio-political contexts.

A combination of keywords and Boolean operators was used to maximise search sensitivity and specificity [71]. The search strategy incorporated three principal concept groups:

- Indigenous peoples and communities;
- Forest management and governance;
- Climate change adaptation and resilience.

To improve retrieval, additional terms such as “Traditional Ecological Knowledge (TEK)”, “forest stewardship”, “sustainable forest management”, and “ecosystem-based adaptation” were incorporated into the search strings. Region-specific terminology, including “Orang Asli”, was also included to capture literature using locally recognised Indigenous descriptors and to improve geographical inclusiveness.

For the purposes of this review, forests were broadly defined as tree-dominated ecosystems that provide ecological, cultural, and livelihood functions for Indigenous and local communities. Studies involving transitional ecosystems, including wooded savannas and forest–savanna mosaics, were included when forest-related management practices, governance systems, or climate adaptation strategies constituted a substantive component of the analysis.

The final search strings used in Web of Science and Scopus are presented in Table 1. In addition to database searches, the reference lists of key articles and relevant review papers were manually examined to identify potentially relevant studies not captured through the initial search process.

As shown in Table 1, the combined search of both databases initially identified 2,113 records relevant to the objectives of the review.

2.3.2 Screening

Following the identification stage, all retrieved records were imported into a reference management database and screened for duplicates. After removing 393 duplicate records, 1,720 unique articles remained for title and abstract screening. The screening process was conducted against predefined inclusion criteria aligned with the review objectives.

Studies were retained if they explicitly focused on Indigenous peoples or communities, examined forest management practices, and addressed climate change adaptation or resilience. Studies were excluded if they focused solely on climate change mitigation, lacked an Indigenous context, or did not establish a clear connection between forest management and adaptation outcomes.

Particular attention was given to the representation of Indigenous knowledge and practices. Studies were assessed not only for the inclusion of Indigenous perspectives but also for the extent to which Indigenous knowledge systems informed forest management and adaptation processes. Following title and abstract screening, 449 articles were considered potentially relevant and advanced to full-text assessment.

Table 1 Search strings

Database	Search strings
Web of Science	TOPIC: ((“Indigenous peoples” OR “Indigenous communities” OR “Indigenous groups” OR “First Nations” OR “Native peoples” OR “Aboriginal peoples” OR “Orang Asli”)) AND TOPIC: ((“forest management” OR “community forestry” OR “traditional ecological knowledge” OR “TEK” OR “customary forest governance” OR “forest stewardship” OR “sustainable forest management”)) AND TOPIC: ((“climate change adaptation” OR “climate adaptation” OR “resilience” OR “adaptive capacity” OR “climate resilience”))
Scopus	TITLE-ABS-KEY ((“Indigenous peoples” OR “Indigenous communities” OR “Indigenous groups” OR “First Nations” OR “Native peoples” OR “Aboriginal peoples” OR “Orang Asli”)) AND TITLE-ABS-KEY ((“forest management” OR “community forestry” OR “traditional ecological knowledge” OR “TEK” OR “customary forest governance” OR “forest stewardship” OR “sustainable forest management”)) AND TITLE-ABS-KEY ((“climate change adaptation” OR “climate adaptation” OR “resilience” OR “adaptive capacity” OR “climate resilience”))

2.3.3 Eligibility

During the eligibility stage, the full texts of the 449 shortlisted articles were retrieved and assessed against pre-defined inclusion and exclusion criteria.

Studies were included if they:

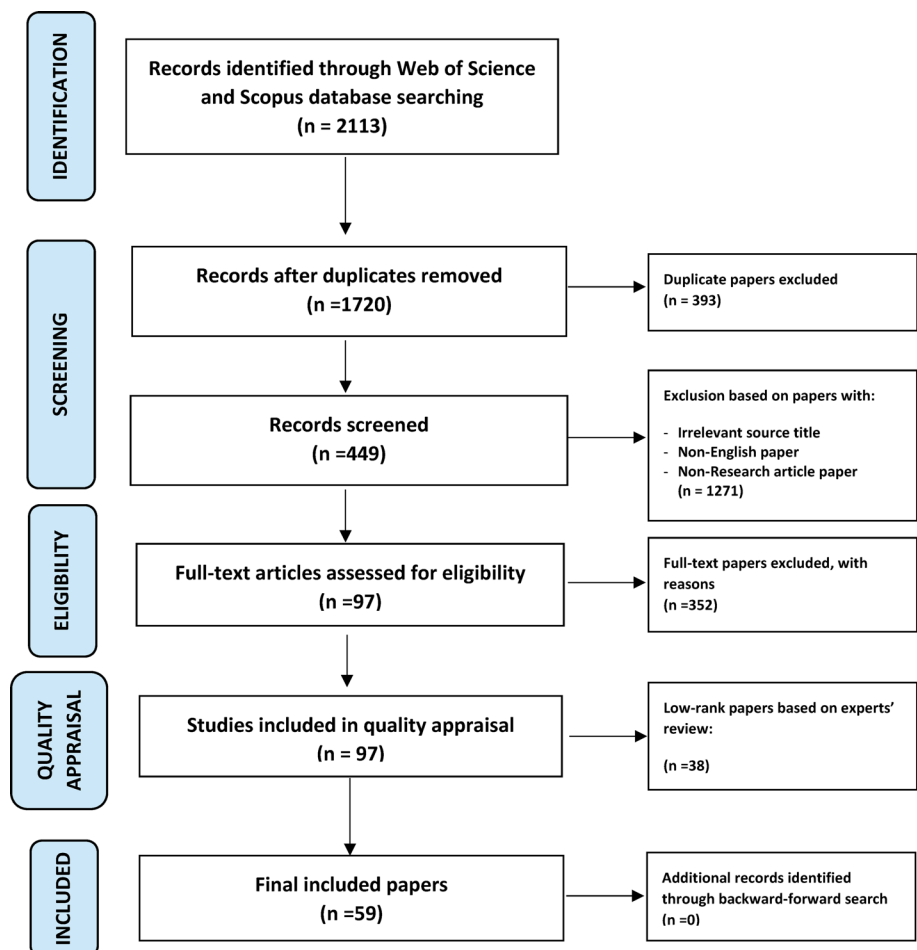
1. Reported empirical, theoretical, or conceptual research on Indigenous forest management practices;
2. Examined climate change adaptation, resilience, or adaptive capacity in forest-related contexts; and
3. Provided sufficient methodological information to enable critical assessment of the study.

Studies were excluded if they:

1. Were non-peer-reviewed publications or grey literature;
2. Lacked substantive analytical or theoretical engagement with the research topic; or
3. Were unavailable in full-text form.

In addition, consideration was given to the representation of Indigenous voices, community participation, and evidence of collaborative or co-produced research approaches. Following full-text assessment, 97 studies satisfied the eligibility criteria and proceeded to the quality appraisal stage. These studies were subsequently evaluated for methodological quality before determining their inclusion in the final synthesis. The study selection process is summarised in the PRISMA 2020 flow diagram (Fig. 1).

Fig. 1 Flow of diagram



2.4 Appraisal of quality

To ensure the methodological rigor and reliability of the review, all studies that satisfied the eligibility criteria underwent a quality appraisal process [75]. The appraisal assessed the methodological quality, transparency, and relevance of each study to ensure that the synthesis was based on robust and credible evidence.

Given the diversity of research designs represented in the literature, different appraisal tools were applied according to study type. Qualitative studies were assessed using the Critical Appraisal Skills Programme (CASP) checklist, which evaluates research aims, study design, data collection procedures, analytical approaches, and the credibility of findings. Quantitative and mixed-method studies were assessed using the Mixed Methods Appraisal Tool (MMAT), which evaluates methodological rigor, measurement validity, and coherence between research questions, methods, and conclusions.

The appraisal was conducted independently by two reviewers, with any discrepancies resolved through discussion and consensus. Particular attention was given to the representation of Indigenous knowledge systems, including the extent of community engagement, collaborative research practices, and the use of culturally appropriate methodologies.

Studies were subsequently classified as high, moderate, or low quality. Following appraisal, 42 studies were rated as high quality, 17 as moderate quality, and 38 as low quality. Consistent with the review protocol, studies rated as low quality were excluded from further synthesis because they did not meet the minimum methodological quality threshold established for the evidence base. Consequently, 59 studies (42 high-quality and 17 moderate-quality studies) were retained for inclusion in the final review. A detailed summary of the quality appraisal results is provided in Supplementary Table S1. Because the 38 low-quality studies were excluded before the final data extraction and thematic synthesis, a formal sensitivity analysis including those studies was not undertaken. Accordingly, the four-theme structure is interpreted as a synthesis of the retained evidence, and we do not assume that inclusion of the excluded studies would necessarily produce the same thematic structure.

The quality appraisal process enhanced the credibility of the review by ensuring that conclusions were derived from methodologically sound studies while also identifying methodological limitations and research gaps within the existing literature.

2.5 Data analysis

Data were analysed using a thematic synthesis approach [23], which is well suited for integrating evidence from qualitative, quantitative, and mixed-method studies. Following eligibility assessment and quality appraisal, relevant information was extracted from each study using a structured data extraction matrix.

The extracted information included authorship, publication year, study location, Indigenous community, forest management practices, climate adaptation strategies, governance and institutional contexts, methodological approaches, and key findings. Coding was conducted iteratively using NVivo 12 software. Initially, open coding was employed to identify recurring concepts related to Indigenous forest management and climate adaptation. Similar codes were subsequently grouped into higher-order themes that reflected common patterns across the literature.

Thematic synthesis enabled the identification of both shared and context-specific adaptation practices, governance arrangements, and adaptation outcomes. In addition, quantitative information, including publication trends, geographical distribution of studies, and the frequency of reported management practices, was extracted and descriptively analysed to complement the thematic findings.

This analytical approach facilitated the development of a comprehensive synthesis of Indigenous forest management practices and their contributions to climate change adaptation, while also identifying key knowledge gaps and priorities for future research.

3 Results

3.1 Spatial and temporal distributions

This section synthesizes the geographical spread and publication trends to provide contextual understanding of the evidence base, this section presents descriptive analyses of publication trends and geographical distributions among the included studies. These analyses are intended to characterize the development and spatial coverage of the literature rather than represent primary objectives of the review.

3.1.1 Temporal trends in publication output

Figure 2 illustrates a gradual increase in publications over time, with very limited output prior to 2005. A noticeable rise begins after 2010, followed by a sharp acceleration post-2015, coinciding with heightened global attention to climate change adaptation, Indigenous knowledge systems, and nature-based solutions. The peak publication period occurs between 2018 and 2023, indicating that research on indigenous forest management and climate adaptation is a relatively recent but rapidly expanding field. This trend suggests increasing scholarly recognition of Indigenous and community-based practices as critical components of climate resilience strategies.

3.1.2 National distribution of research

Figure 3 shows that research output is unevenly distributed across countries. The largest numbers of studies are from the United States (11), Canada (9), and India (8), followed by Congo and Indonesia (4 each). Brazil and Russia each contribute three studies, while Bolivia, Peru, the United Kingdom, Australia, and several other countries contribute smaller numbers. This distribution indicates that the evidence base is geographically uneven, with substantial representation from North America and Asia as well as selected tropical forest regions.

3.1.3 Continental distribution of studies

At the continental scale, Fig. 4 shows that North America has the largest number of studies (23), followed by Asia (14), Africa (8), South America (7), Europe (6), and Oceania (1). The distribution therefore reflects an uneven geographical coverage of the evidence base, with North America and Asia accounting for the largest shares of the included studies. These descriptive patterns provide context for interpreting the scope of the review rather than indicating differences in the effectiveness of Indigenous forest management across continents.

Fig. 2 Number of articles published by year

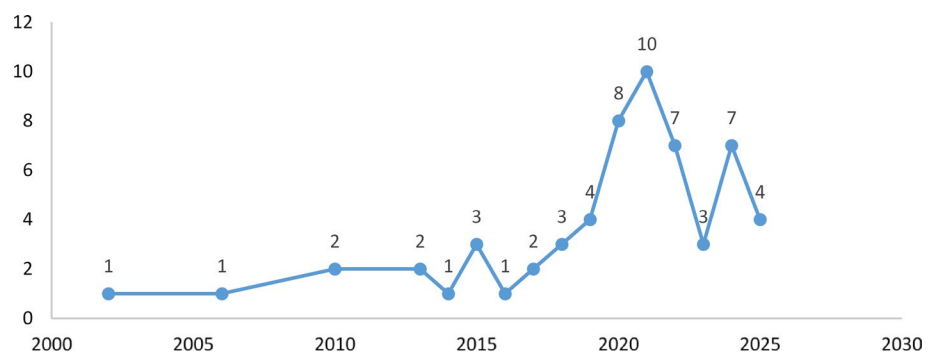


Fig. 3 Number of articles published by country

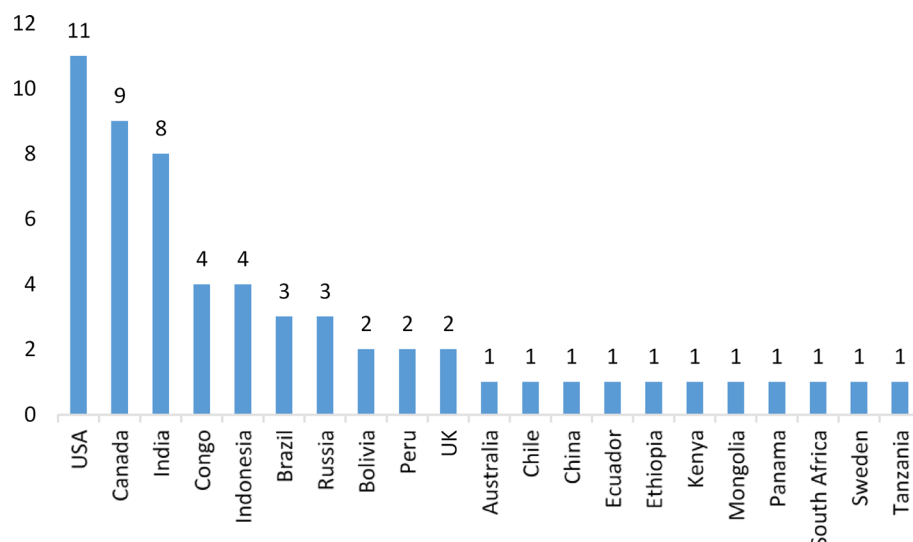
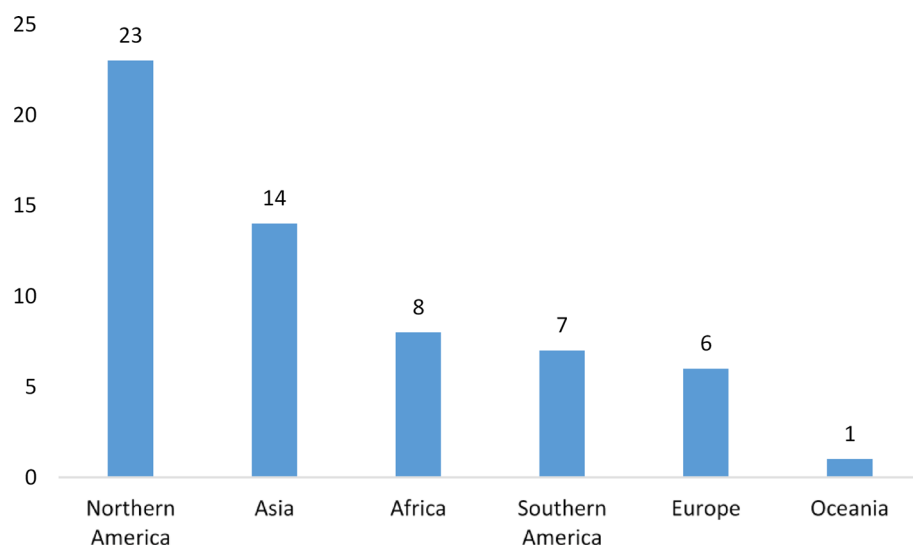


Fig. 4 Number of articles published by continent



3.2 Indigenous and community-based forest management practices

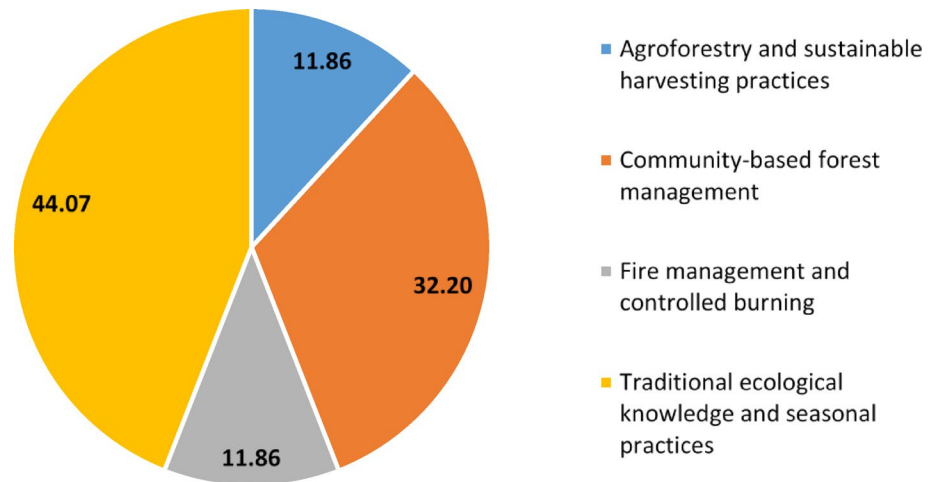
This section synthesizes the types of forest management practices documented across the reviewed studies. Figure 5 indicates that research emphasizes a diversity of Indigenous-led and community-based strategies that are deeply embedded in local ecological knowledge systems.

3.2.1 Traditional ecological knowledge and seasonal practices

This review shows that Traditional Ecological Knowledge (TEK) and seasonally grounded practices are among the most widespread and resilient forms of indigenous forest management across tropical, temperate, montane, and Arctic ecosystems. Across the literature, TEK is consistently characterised as a dynamic and adaptive knowledge system that guides forest use, resource timing, mobility, and stewardship under climatic variability, rather than as static tradition.

Evidence from Australia illustrates how TEK functions through long-term seasonal observation. Sloane et al. [86] demonstrate that Yolŋu Knowledge Custodians in the Laynhapuy Indigenous Protected Area detected

Fig. 5 Indigenous and community-based forest management practices



dieback in culturally significant *Melaleuca* forests by observing changes in flooding patterns, soil salinity, and vegetation health. Their ecocultural framework highlights how seasonal Indigenous knowledge enables early identification of ecosystem stress and supports collaborative adaptation with scientific approaches.

In cold and sub-Arctic environments, TEK plays a critical role in managing climate sensitivity and food security. Studies from Western Siberia [20] and Arctic Alaska [43, 80] show that warming temperatures, extended off-seasons, and unstable freeze–thaw cycles increasingly disrupt reindeer herding, hunting, and ice-based mobility. Despite these challenges, TEK continues to guide adaptation through the recalibration of seasonal calendars and risk management strategies.

In tropical and subtropical contexts, TEK is closely integrated with land-use planning and sustainable resource management. Huambachano and Cooper, [46] show that Indigenous communities in the Peruvian Amazon apply TEK to guide seasonal planting, forest use, and ecosystem valuation, producing more equitable and ecologically sensitive outcomes than externally imposed policies. Similarly, Rizki and Asteria, [77] demonstrate that Local Ecological Knowledge in Indonesia enhances forest sustainability by aligning seasonal resource use with biodiversity conservation and food security goals.

Pastoral and agro-ecological systems further highlight the operational role of seasonal TEK. Research among Sámi reindeer herders [11] and Mongolian pastoralists [50] shows that Indigenous seasonal indicators such as vegetation cover, snow conditions, and pasture quality closely align with scientific vegetation assessments, underscoring the empirical robustness of TEK-based monitoring.

Seasonal knowledge also shapes forest–agriculture interactions. Studies from South and Southeast Asia [69, 79, 96] show that Indigenous and local communities use seasonal climate cues to manage cropping patterns, forest dependence, and livelihood diversification, while cautioning that climate and conservation policies that disregard TEK may exacerbate vulnerability and social conflict.

Across North America, TEK is strongly associated with cultural keystone species and seasonal harvesting cycles. Research by Jacob et al. [49], Wyllie de Echeverria and Thornton [99], Mucioki et al. [66, 67], and Zahn et al. [100] shows that Indigenous observations of phenological change, resource productivity, and culturally significant species closely correspond with scientific evidence of climate change.

Overall, the literature demonstrates that TEK-based seasonal practices enhance forest management by aligning human activities with ecological rhythms, supporting regeneration, and reducing maladaptive exploitation. However, their effectiveness is increasingly challenged by rapid climate change, land-use transformation, erosion of intergenerational knowledge transmission, and governance systems that marginalise Indigenous knowledge. The evidence strongly supports integrating TEK into forest governance and climate adaptation frameworks as a co-equal system of environmental knowledge essential for long-term sustainability.

3.2.2 Community-based forest management

The reviewed literature demonstrates that community-based forest management (CBFM) is a key governance approach through which Indigenous and local communities respond to climate change while sustaining forest ecosystems, livelihoods, and cultural values. Across boreal Canada, the Amazon Basin, Africa, Southeast Asia, and South Asia, CBFM is consistently framed as a mechanism that integrates local knowledge, participatory decision-making, and adaptive governance under increasing environmental uncertainty.

A recurring theme is the shift from top-down forest governance toward collaborative and bottom-up arrangements. In boreal Canada, Bélisle and Asselin [16] show that participatory mapping and Indigenous-defined landscape indicators strengthen trust and communication between communities and external institutions. In contrast, Arias-Bustamante and Innes, Arias-Bustamante and Innes [9] demonstrate that inflexible, state-driven forest policies rooted in colonial governance constrain Indigenous adaptive capacity, particularly under accelerating climate change. Together, these studies indicate that CBFM enhances resilience when Indigenous institutions and values are embedded directly within forest planning frameworks.

Several studies highlight the role of knowledge co-production in strengthening adaptive forest management. Touchette et al. [93] show that genomics-based tools can support sustainable forest management when combined with Indigenous knowledge, but caution that technological approaches must be co-designed to avoid extractive research practices. Similarly, Bélisle et al. [17] integrate Indigenous landscape values with forest simulation models to assess long-term vulnerabilities, demonstrating how co-produced knowledge supports anticipatory and adaptive governance.

CBFM is also closely linked to livelihood resilience, particularly where communities depend on forest ecosystem services. Case et al. [28] show that participatory assessment frameworks help Indigenous communities in the Pacific Northwest identify climate risks to culturally important ecosystem goods and prioritise adaptation strategies. In the Bolivian Amazon, Bauer et al. [15] find that livelihood resilience is shaped by forest-based income strategies, social networks, and access to communal resources, underscoring the importance of community-driven forest governance in national adaptation planning.

At the same time, the literature highlights persistent power asymmetries and historical injustices. Domínguez and Luoma, [38] show how colonial land tenure systems and fortress conservation models in Africa undermine indigenous forest governance and livelihoods. Abdullah et al. [4] further demonstrate that even formal recognition of indigenous forest rights, as in Kajang, Indonesia, can produce new forms of enclosure and marginalisation when governance arrangements fail to address internal inequalities. These findings caution that CBFM is not inherently equitable and requires ongoing attention to justice and authority.

Emerging scholarship also extends CBFM beyond rural contexts. McMillen et al. [61] demonstrate how bio-cultural stewardship models rooted in Indigenous worldviews can be adapted to urban environments, while Ortiz et al. [72] show that post-wildfire restoration and multifunctional landscape approaches in Chile require deep collaboration among Indigenous Peoples, communities, and institutions.

Overall, the reviewed studies show that CBFM enhances adaptive capacity, livelihood sustainability, and ecological resilience when it is genuinely participatory, knowledge-inclusive, and justice-oriented. However, its effectiveness depends on addressing structural inequalities, aligning policies with Indigenous governance systems, and providing long-term institutional support. These findings reaffirm the central role of Indigenous and community-based forest management in responding to climate change while safeguarding forest ecosystems and cultural integrity.

3.2.3 Fire management and controlled burning

Fire management and controlled burning emerge from the reviewed literature as a core Indigenous and community-based forest management practice, particularly in fire-adapted ecosystems. Across North America, the Amazon Basin, and northern Eurasia, Indigenous fire practices are shown to be deeply embedded in Traditional

Ecological Knowledge (TEK) and long-term ecosystem observation, standing in contrast to modern fire suppression paradigms.

Multiple studies demonstrate that Indigenous peoples historically applied intentional, low-intensity burning to regulate vegetation structure, enhance habitat quality, and reduce the risk of catastrophic wildfires. Connor et al. [33] show that prescribed burns informed by Karuk fire knowledge in Northern California significantly improved elk winter habitat suitability. Burn regimes resembling traditional multi-year broadcast burning produced positive ecological outcomes, whereas narrowly focused fuel-reduction burns resulted in negative effects, underscoring the ecological sophistication of Indigenous fire regimes.

The consequences of prolonged fire suppression are examined by Eisenberg et al. [39] in their comparison of Indigenous-style prescribed burns and the 2017 Kenow wildfire in Waterton Lakes National Park. Their findings reveal that low-intensity, seasonally timed prescribed burns caused less ecosystem disruption, while the climate-amplified wildfire led to substantial structural change, reduced native grass diversity, and altered ecosystem composition. This illustrates how the removal of Indigenous fire stewardship has contributed to increased fire severity under climate change.

Historical dimensions of Indigenous fire management are highlighted by Sayles and Mulrennan [82], who document how Cree communities in eastern James Bay used burning alongside other landscape modifications to enhance goose hunting grounds in response to long-term environmental change. Their study shows that fire management was embedded within broader adaptive strategies linking ecological manipulation with cultural continuity and intergenerational learning.

In boreal and sub-Arctic regions, Vinokurova et al. [97] describe how Indigenous communities in the Republic of Sakha (Yakutia) face increasingly frequent and intense fires that threaten livelihoods and health. While Indigenous fire knowledge continues to shape risk perception and response, climate-driven changes are increasingly exceeding the adaptive capacity of traditional practices alone.

The governance implications of Indigenous fire exclusion are critically assessed by Boerigter et al. [19], who argue that more than a century of fire suppression in the United States has disrupted fire-adapted wilderness ecosystems. They demonstrate that excluding Indigenous cultural burning has led to fuel accumulation and ecological degradation, calling for the reintroduction of Indigenous-led intentional burning as a strategy to restore ecological integrity and reduce wildfire risk.

Evidence from tropical forests further shows the limits of resilience under compounding pressures. Silvério et al. [84] find that in the Território Indígena do Xingu (Brazil), interactions between drought, external ignition sources, and changing land-use practices have increased forest degradation and fire-driven forest loss, particularly in seasonally flooded areas. These findings suggest that climate change is pushing some systems beyond historical adaptive thresholds.

Finally, Souther et al. [87] demonstrate how Indigenous fire knowledge informs species-specific management. In Emory oak ecosystems, Western Apache Elders' observations of declining acorn production aligned with ecological analyses showing the combined influence of drought and altered fire regimes. The authors argue that restoring historical fire regimes guided by Indigenous knowledge could enhance ecosystem resilience under future climate conditions.

Overall, the reviewed studies show that Indigenous fire management functions as a powerful adaptive tool for regulating ecosystems, sustaining culturally important species, and reducing climate-related risks. However, its effectiveness is increasingly constrained by climate change, policy barriers, and historical fire exclusion. The evidence strongly supports the reintegration of Indigenous fire stewardship into contemporary forest governance, not merely as cultural recognition, but as an evidence-based strategy for enhancing ecosystem resilience in a warming climate.

3.2.4 Agroforestry and sustainable harvesting practices

In this review, agroforestry refers broadly to land-use systems that intentionally integrate trees with crops, live-stock, or other agricultural components within the same management unit. However, agroforestry systems vary considerably across ecological and cultural contexts, and their environmental outcomes depend on species composition, management intensity, land tenure arrangements, and local socio-economic conditions. Agroforestry and sustainable harvesting practices emerge from the reviewed literature as central Indigenous and community-based forest management strategies, particularly across tropical, subtropical, and montane regions. Rather than representing transitional land-use systems, these practices function as integrated socio-ecological systems that combine food production, forest conservation, and climate adaptation through long-standing Indigenous knowledge and adaptive management.

In Central Africa, Kasoki et al. [51] document how the Indigenous Mbuti and Efe peoples in the Okapi Wildlife Reserve (Democratic Republic of the Congo) sustain livelihoods through hunting, fishing, gathering, honey harvesting, and small-scale agriculture governed by customary taboos. These social norms operate as *de facto* ecological regulations that limit overexploitation and support forest resilience. While agroecological hybridization has emerged through intercultural exchange, the study also highlights growing vulnerabilities, including biodiversity decline, weakened intergenerational knowledge transmission, and increasing reliance on monetary income.

In East Africa, Kimaro et al. [53] analyse Indigenous agroforestry systems in northeastern Tanzania, showing that structurally complex, multi-layered systems support diverse provisioning ecosystem services. The selection of tree species reflects livelihood strategies, cultural values, and local environmental conditions, with agroforestry diversity and resilience shaped by climate, soil, historical land use, and market access.

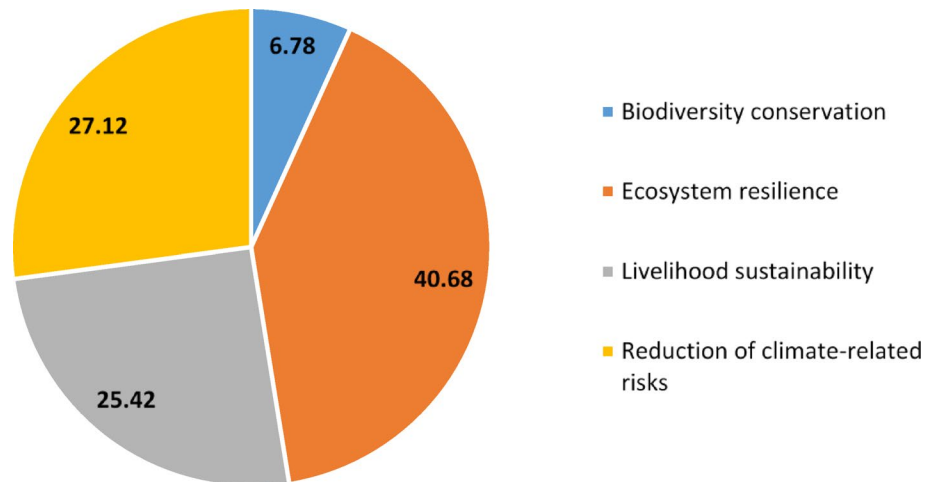
Traditional shifting cultivation systems, particularly Jhum, are reassessed in studies from India. Bhagawati et al. [18] demonstrate that Jhum represents a sophisticated agro-ecosystem based on cyclical land use, fallow regeneration, and Indigenous ecological knowledge. Contrary to dominant policy narratives, Jhum systems function as carbon sinks, maintain soil health, and conserve biodiversity. Complementing this, Singh, [85] shows how colonial forest policies disrupted Jhum while selectively appropriating its ecological logic through systems such as *taungya*, illustrating the long-term impacts of external governance on Indigenous agroforestry.

Evidence from the Horn of Africa further reinforces the adaptive role of agroforestry. Mekonnen et al. [62] find that in Ethiopia, traditional knowledge and institutions continue to guide agroforestry, sustainable harvesting, and climate adaptation, sustaining livelihoods and landscape resilience despite pressures from global change and cultural transformation.

From Latin America, Córdova et al. [34] show that Indigenous agroforestry systems in Ecuador exhibit lower exposure and sensitivity to climate change than conventional agriculture, reducing vulnerability to droughts, pests, and climatic extremes through diversification, tree cover, and microclimatic regulation. At the household scale, Mallick et al. [60] demonstrate that tribal home-gardens in India's Similipal Biosphere Reserve integrate crops, forest species, and livestock, simultaneously supporting biodiversity conservation, livelihood security, climate adaptation, and multiple Sustainable Development Goals.

Overall, the reviewed studies demonstrate that agroforestry and sustainable harvesting practices are core Indigenous strategies for managing forests under climatic and socio-economic uncertainty. These systems enhance biodiversity, stabilize livelihoods, and reduce climate-related risks through diversification, customary governance, and long-term ecological knowledge. However, their continued effectiveness depends on secure land tenure, intergenerational knowledge transmission, and policy frameworks that recognize Indigenous agroforestry as a legitimate and adaptive forest management approach rather than a relic of the past.

Fig. 6 Adaptation outcomes and effectiveness



3.3 Adaptation outcomes and effectiveness

This section examines the documented outcomes of Indigenous and community-based forest management practices in relation to climate change adaptation effectiveness (Fig. 6).

3.3.1 Ecosystem resilience

Across the reviewed literature, ecosystem resilience emerges as the most consistently reported adaptation outcome of Indigenous and community-based forest management. The studies collectively show that Indigenous knowledge systems, stewardship practices, and governance arrangements enhance forests' capacity to absorb disturbance, reorganize, and continue functioning under climatic variability and long-term environmental change.

A key mechanism underpinning resilience is the integration of Indigenous knowledge with ecological monitoring and adaptive management. In northern Australia, Sloane et al. [86] demonstrate how Yolŋu Senior Knowledge Custodians detected early signs of coastal *Melaleuca* dieback through long-term seasonal observation, enabling early intervention before ecological thresholds were crossed. Similarly, Touchette et al. [93] show that conservation initiatives using genomics strengthen ecosystem resilience only when co-designed with Indigenous knowledge systems and governance structures, highlighting that resilience depends as much on epistemic integration as on technological tools.

Traditional Ecological Knowledge (TEK) also underpins resilient land-use systems in tropical forests and agro-ecological landscapes. In the Peruvian Amazon, Huambachano and Cooper [46] show that TEK embeds relational and intrinsic values of nature into sustainable land management, promoting regeneration, diversity, and long-term ecological balance. However, they also note that policy misalignment and external development pressures increasingly strain these resilient systems.

Fire-adapted ecosystems feature prominently in resilience outcomes. Connor et al. [33] provide strong evidence that prescribed burns informed by Karuk Indigenous fire knowledge significantly enhance ecosystem resilience by improving elk winter habitat suitability, whereas simplified fuel-reduction burns yield poorer outcomes. Complementing this, Eisenberg et al. [39] show that Indigenous-style prescribed burns in Waterton Lakes National Park caused far less ecological disruption than the climate-amplified Kenow wildfire, illustrating how long-term fire exclusion undermines resilience.

Governance frameworks strongly shape resilience trajectories. Arias-Bustamante and Innes, [9] show that inflexible, top-down forest policies constrain the resilience of Nisga'a forest ecosystems, particularly under accelerating climate change, underscoring the need for adaptive and learning-oriented governance. At broader scales, Lapola et al. [54] report that more than 80% of Brazilian protected areas with moderate to high climate

vulnerability are managed by Indigenous populations. This finding indicates the substantial role of Indigenous populations in managing climate-vulnerable landscapes, but the association should be interpreted in relation to governance arrangements, land tenure, and ecological context rather than as evidence that management status alone determines resilience.

Beyond forests, resilience is also evident in pastoral and rangeland systems. Axelsson-Linkowski et al. [11] document how Sámi reindeer herding historically maintained rangeland resilience, though rapid climatic shifts now challenge traditional strategies. Similarly, Jamsranjav et al. [50] show that Mongolian herders' ecological indicators closely align with scientific vegetation measures, reinforcing the empirical validity of Indigenous monitoring systems.

Several studies extend resilience to biocultural dimensions. Huntington et al. [47] highlight the role of community workshops in strengthening social–ecological resilience through collective interpretation of climate impacts. Zahn et al. [100] and Mucioki et al. [67] further demonstrate that spiritual, relational, and stewardship-based connections to culturally significant species such as western redcedar and Arctic berries support long-term resilience under changing climatic conditions.

At landscape and species scales, resilience is shaped by spatial and historical dynamics. Antunes et al. [7] show that Amazonian terrestrial fauna exhibited greater resilience than aquatic species due to spatial refugia, supporting community-based co-management approaches. Craighead and Yacelga, [32] argue that biocultural strategies are essential for maintaining resilience amid climate-induced relocation, while Souther et al. [87] demonstrate that Indigenous-informed fire and water management can enhance resilience in Emory oak ecosystems under projected drought.

However, the literature also identifies clear limits to resilience. Silvério et al. [84] document increasing forest degradation in the Território Indígena do Xingu due to repeated drought and fire events, suggesting that climate change may be exceeding historical adaptive capacity. Similarly, Abdullah et al. [4] caution that formal recognition of indigenous forest rights does not automatically result in resilient ecosystems, as new governance inequalities may emerge.

In synthesis, ecosystem resilience is strongest where Indigenous knowledge systems, adaptive governance, and ecological processes are aligned. Indigenous and community-based forest management enhances resilience by fostering diversity, redundancy, and learning across scales. However, resilience is not unlimited; it depends on supportive policies, secure land tenure, and climate trajectories that do not overwhelm the adaptive capacity of socio-ecological systems.

3.3.2 Reduction of climate-related risks

The reviewed literature provides strong evidence that Indigenous and community-based forest management contributes substantially to the reduction of climate-related risks, including extreme weather impacts, ecosystem degradation, livelihood disruption, and maladaptive policy interventions. Rather than eliminating hazards, Indigenous approaches reduce risk by anticipating, buffering, and redistributing exposure through locally grounded knowledge systems, diversified livelihoods, and adaptive governance.

A central risk-reduction mechanism is community-based landscape assessment and planning. Bélisle and Asselin, [16] show that participatory mapping with the Abitibiwinni and Ouje-Bougoumou First Nations in boreal Quebec enabled the identification of vulnerable hunting grounds and the risk of rapid landscape transitions before ecological thresholds were crossed. Such bottom-up approaches contrast with conventional management systems that often respond only after damage has occurred.

Several studies highlight how Indigenous perceptions and cultural values shape risk-averse behavior. Chanza and Musakwa, [29] demonstrate that Indigenous communities in southern Africa conceptualize forests as relational entities, discouraging exploitative practices that increase long-term vulnerability. Conversely, Roy, [79] shows that top-down conservation and adaptation policies in the Indian Sundarbans have intensified displacement

and social conflict, ultimately increasing exposure to climate risks. These findings underscore that excluding Indigenous governance systems can amplify, rather than reduce, vulnerability.

The integration of Traditional Ecological Knowledge (TEK) with scientific tools is repeatedly identified as a powerful risk-reduction strategy. Case et al. [28] present a framework linking Indigenous priorities with climate and vegetation models to assess risks to tribally important ecosystem goods and services in the Pacific Northwest, enabling proactive planning for habitat loss and food insecurity. At household scales, Bauer et al. [15] show that the Tacana people in Bolivia use TEK-based weather indicators to anticipate floods and adjust livelihoods, while the complementary use of meteorological data improves situational awareness under increasing climate variability. Comparable findings are reported by Boissière et al. [21] in Papua, Indonesia.

Fire-related risks are another major theme. Vinokurova et al. [97] document how Indigenous communities in the Republic of Sakha (Yakutia) rely on historical fire knowledge to cope with recurring wildfire threats, although climate change is increasingly pushing fire regimes beyond past experience. In northern Canada, Golden et al. [43] show how culturally embedded concepts such as “blue-ice” enable First Nations communities to recognize risks to winter mobility, hunting safety, and supply routes that are often overlooked by conventional monitoring systems.

Water-related risks also feature prominently. Vijhani et al. [96] demonstrate that Indigenous and tribal perceptions of changing precipitation and water flows in Uttarakhand, India, closely align with geospatial datasets, strengthening the case for integrating Indigenous observations into formal risk assessments. Moving beyond incremental adaptation, Finn et al. [41] show that restoring Indigenous hydrological systems through managed retreat and floodplain restoration at Sumas Lake (Canada) can significantly reduce long-term flood risk while restoring ecosystem and food-system functions.

Livelihood diversification further reduces climate-related risks. Córdova et al. [34] find that Indigenous agroforestry systems in Ecuador exhibit lower exposure to droughts, pests, and temperature extremes than conventional agriculture, while Timko et al. [90] show that collaborative adaptation planning in the Teslin Tlingit Traditional Territory enhances capacity to address wildfire and habitat risks through integrated knowledge systems.

Finally, Arctic studies emphasize cultural continuity as a risk-coping mechanism. Sakakibara, [80] illustrates how Inupiat communities confront climate uncertainty through collective practices linked to bowhead whale hunting, reframing risk reduction as the maintenance of social cohesion and identity under rapid environmental change.

In synthesis, Indigenous and community-based forest management reduces climate-related risks by anticipating hazards, diversifying livelihoods, strengthening social networks, and aligning management with local ecological realities. However, these benefits depend on the recognition of indigenous rights, meaningful participation in decision-making, and climate policies that support rather than undermine local adaptive capacities.

3.3.3 Livelihood sustainability

The reviewed literature provides strong evidence that Indigenous and community-based forest management is central to sustaining livelihoods under climate change, particularly for forest-dependent communities whose subsistence, income, health, and cultural identity are closely tied to ecosystem goods and services. Livelihood sustainability in these contexts extends beyond economic continuity to encompass food security, health outcomes, cultural practices, and long-term adaptive capacity.

In Arctic and sub-Arctic regions, climate change directly threatens traditional livelihood systems. Bogdanova et al. [20] show that rising temperatures, melting ice, and increasing fires in Western Siberia have degraded reindeer pastures, undermining food security and contributing to adverse health outcomes among Indigenous herders. These findings highlight how livelihood sustainability is inseparable from ecological stability and environmental health.

Adaptive landscape management as a livelihood strategy is illustrated by Sayles and Mulrennan [82], who document how Cree communities in eastern James Bay modified landscapes through burning, fish weirs, and

forest corridors to enhance resource productivity and predictability. These practices reflect livelihood sustainability grounded in intergenerational knowledge and long-term stewardship rather than short-term optimization.

Historical and political factors strongly shape livelihood outcomes. Domínguez and Luoma, [38] demonstrate how colonial land tenure systems and fortress-style conservation policies across Africa and Asia have undermined Indigenous livelihoods by disrupting customary resource-use systems, increasing vulnerability to climate change. This underscores that livelihood sustainability depends as much on rights and governance justice as on ecological practices.

Climate impacts on subsistence activities further illustrate vulnerability. In central British Columbia, Jacob et al. [49] show that altered timing and abundance of sockeye salmon runs threaten St'át'imc food security and cultural continuity, as preservation practices are closely tied to seasonal conditions. The study highlights the limited scope for adaptation when foundational subsistence resources are disrupted.

Agroforestry and traditional farming systems emerge as key livelihood-sustaining strategies. Kimaro et al. [53] show that Indigenous agroforestry systems in northeastern Tanzania support diversified provisioning services and enhance resilience to climate variability. Similarly, studies on shifting cultivation such as Jhum demonstrate its adaptive capacity. Singh, [85] and Paul et al. [74] show that Jhum systems sustain livelihoods through crop diversity, adaptive calendars, and forest regeneration, with approximately 76% of cultivators adjusting practices in response to climate change.

Evidence from Africa reinforces the importance of Indigenous knowledge institutions. Mekonnen et al. [62] find that traditional knowledge in Ethiopia continues to underpin weather forecasting and natural resource management, sustaining livelihoods despite socio-cultural change. In the Congo Basin, Nkem et al. [70] and Carson et al. [27] show that livelihood strategies differ between nomadic forest-dwelling and sedentary forest-edge communities, resulting in varied vulnerabilities and adaptation pathways.

Institutional and policy frameworks further influence livelihood sustainability. Brown et al. [24] argue that mechanisms such as REDD + can support adaptation only if institutional coordination and community engagement are strengthened. In the Bolivian Amazon, Bauer et al. [15] show that Tacana household resilience depends on income diversification, social networks, and forest access, while national extractive development policies threaten to increase vulnerability.

At household and landscape scales, forest quality and access are decisive. Mallick et al. [60] show that Indigenous home-gardens in India function as integrated socio-ecological systems supporting biodiversity, food production, and income generation, contributing to climate adaptation and multiple Sustainable Development Goals. Similarly, Dobriyal et al. [37] find that households with access to intact forests in the Western Himalayas exhibit higher wellbeing and resilience than those dependent on degraded ecosystems or markets.

Finally, Arotoma-Rojas et al. [8] highlight trade-offs in livelihood transitions. Among the Shawi in the Peruvian Amazon, shifts from forest-based foods to agriculture may secure short-term food access but generate new vulnerabilities, including cultural loss and increased exposure to climatic extremes.

In synthesis, livelihood sustainability under climate change is strongest where indigenous forest management practices, secure rights, diversified livelihood strategies, and healthy forest ecosystems converge. Conversely, livelihoods become increasingly fragile where climate change intersects with ecological degradation, exclusionary conservation, and unsupportive policy environments. These findings reinforce the central role of Indigenous and community-based forest management in sustaining livelihoods amid accelerating climate change.

3.3.4 Biodiversity conservation

The reviewed literature provides strong, multi-scalar evidence that Indigenous and community-based forest management contributes substantially to biodiversity conservation, both as a direct objective and as a co-benefit of livelihood-oriented and culturally embedded practices. Across tropical forests, agro-ecosystems, and intact forest landscapes, Indigenous stewardship is consistently associated with higher species diversity, habitat integrity, and ecological regulation.

At the local scale, Kasoki et al. [51] demonstrate how Indigenous Mbuti and Efe communities in the Okapi Wildlife Reserve (Democratic Republic of the Congo) conserve biodiversity through customary hunting, fishing, gathering, and honey-harvesting practices governed by taboos and social restrictions. These norms function as informal ecological regulations, with floristic inventories revealing site-specific pressures but also the protective effect of persistent customary institutions. However, emerging vulnerabilities, including localized species loss and weakened intergenerational knowledge transmission, indicate that biodiversity outcomes depend on cultural continuity and socio-economic stability.

Evidence from Southeast Asia further highlights the role of Local Ecological Knowledge (LEK). Rizki and Asteria, [77] show that conservation initiatives in Indonesia integrating LEK across diverse Indigenous communities achieve stronger environmental and social sustainability outcomes. Indigenous forest management emphasizes harmony between social capital, forest ecosystems, and resource use, producing adaptive and flexible conservation approaches capable of responding to biodiversity loss and climate change.

At broader spatial scales, Fa et al. [40] report that at least 36% of the world's remaining Intact Forest Landscapes overlap with Indigenous lands and have experienced lower deforestation rates than non-Indigenous areas. This association should not be interpreted as evidence of an inherently conservationist Indigenous identity or as a simple causal effect of Indigenous status. Rather, the observed patterns reflect interactions among customary governance systems, land-tenure arrangements, ecological conditions, and broader historical and political processes. Biodiversity conservation is also evident in traditional agro-ecosystems. Liu et al. [57] document how the Dong people of southeast Guizhou, China, conserve agrobiodiversity through the long-term cultivation of Kam Sweet Rice (KSR). The identification of 57 distinct landraces valued for traits such as cold tolerance, pest resistance, and cultural importance demonstrates conservation at genetic, species, and ecosystem levels. The rice–fish–duck symbiotic system further illustrates how Indigenous farming systems function as artificial wetland ecosystems that sustain biodiversity while supporting livelihoods.

Overall, the reviewed studies indicate that biodiversity conservation outcomes are strongest where Indigenous knowledge systems, customary institutions, and secure land tenure converge. Indigenous forest management embeds biodiversity protection within everyday practices and livelihood strategies rather than separating conservation from human use. However, socio-cultural transformation, market integration, and external conservation and development pressures increasingly challenge these systems. The evidence suggests that sustaining biodiversity through Indigenous and community-based forest management depends on policy environments that support Indigenous rights, knowledge transmission, and adaptive governance.

4 Discussion

4.1 Indigenous forest management practices for climate change adaptation

This review demonstrates that indigenous peoples employ a diverse yet internally coherent set of forest management practices to adapt to climate change. Rather than functioning as isolated techniques, these practices operate as integrated adaptation systems grounded in long-term ecological observation, collective governance, and culturally embedded relationships with forest landscapes [78]. Across geographical regions and ecosystem types, indigenous forest management practices consistently reflect adaptive principles such as flexibility, diversification, redundancy, and learning key characteristics widely recognised in climate adaptation theory.

One of the most pervasive practices identified is the application of Traditional Ecological Knowledge (TEK) and seasonally grounded decision-making. Seasonal practices such as adjusting harvesting periods, cultivation calendars, mobility patterns, and fire timing enable Indigenous communities to anticipate and respond to climatic variability rather than merely react to environmental shocks [31]. The reviewed studies show that TEK-based seasonal indicators often align closely with scientific observations of phenological change, hydrological variation, and ecosystem stress, reinforcing their empirical validity. Importantly, TEK is not static knowledge; it is

continuously updated through lived experience and intergenerational transmission, allowing Indigenous communities to recalibrate forest use and management under changing climatic conditions.

Community-based forest management (CBFM) emerges as another core adaptation strategy. Across multiple contexts, collective governance arrangements such as customary tenure systems, participatory mapping, and locally defined management rules enhance adaptive capacity by enabling coordinated decision-making at the landscape scale. CBFM allows communities to distribute climate-related risks, manage trade-offs between conservation and livelihoods, and respond flexibly to environmental change. The effectiveness of these arrangements lies not only in local ecological knowledge, but in the social institutions that enable cooperation, accountability, and shared responsibility for forest stewardship [91].

The review further highlights Indigenous fire management and controlled burning as a highly context-specific yet critically important adaptation practice, particularly in fire-adapted ecosystems. Cultural burning regimes characterised by low-intensity, seasonally timed, and spatially heterogeneous fires function to reduce fuel loads, maintain habitat diversity, and prevent catastrophic wildfires under increasingly hot and dry conditions [10, 52]. These practices contrast sharply with dominant fire suppression and narrow fuel-reduction approaches, which have often amplified fire severity under climate change. Indigenous fire management thus represents an adaptive strategy that simultaneously addresses climate risk reduction, ecosystem resilience, and cultural continuity.

In tropical and subtropical regions, agroforestry and sustainable harvesting practices constitute a central pillar of climate adaptation. Indigenous agroforestry systems such as shifting cultivation with long fallow cycles, multi-layered home gardens, and integrated crop–livestock–forest systems buffer climatic shocks through structural and biological diversity [30]. By combining multiple species, functions, and income sources within a single landscape, these systems reduce dependence on any single resource that may be vulnerable to climate stress. The review indicates that such practices not only support food security and livelihoods, but also enhance soil health, water regulation, and biodiversity conservation, reinforcing their adaptive value.

Taken together, the evidence suggests that indigenous forest management practices should be understood as relational and place-based adaptation strategies, rather than discrete technical interventions. Their adaptive strength lies in the integration of ecological knowledge, cultural values, and social organisation, developed through long-term engagement with specific forest ecosystems. However, the review also indicates that the continued effectiveness of these practices depends on the maintenance of Indigenous land rights, governance autonomy, and knowledge transmission. Where these enabling conditions are undermined, the adaptive potential of indigenous forest management is significantly constrained.

In synthesis, Indigenous peoples employ a diverse suite of forest management practices to adapt to climate change, unified by a shared logic of working *with* ecological processes rather than attempting to control them. These practices represent a form of adaptation that is anticipatory, multi-functional, and deeply embedded in socio-ecological systems, offering valuable insights for broader climate adaptation strategies in forested landscapes.

4.2 Factors influencing the effectiveness of indigenous forest management for adaptation

While indigenous forest management practices demonstrate strong potential for climate change adaptation, the review shows that their effectiveness is highly context-dependent. Adaptation outcomes such as ecosystem resilience, livelihood sustainability, biodiversity conservation, and reduced climate-related risks are shaped by the interaction of ecological conditions, socio-cultural dynamics, and governance arrangements, rather than by the practices alone. Understanding these mediating factors is essential for explaining why similar management strategies yield divergent outcomes across regions.

4.2.1 Ecological context and environmental thresholds

Ecological conditions strongly influence the adaptive performance of indigenous forest management. The review indicates that practices such as cultural burning, agroforestry, and seasonal resource use are most effective when

climatic changes remain within or near historical variability. In fire-adapted ecosystems, for example, Indigenous burning regimes enhance habitat heterogeneity and reduce wildfire severity. However, where climate change intensifies beyond historical thresholds through prolonged droughts, extreme heat, or repeated disturbances adaptive capacity can be exceeded [56, 63]. This is evident in cases where recurrent drought and fire events accelerate forest degradation despite long-standing Indigenous stewardship, highlighting that resilience is not infinite.

Ecosystem type also matters. Agroforestry systems in tropical and montane environments tend to display high buffering capacity due to structural diversity and species redundancy, whereas pastoral and boreal systems are more sensitive to rapid climatic shifts affecting snow cover, permafrost, and pasture availability [44]. These findings suggest that indigenous forest management is most effective when ecological feedbacks remain predictable and when recovery processes can operate without being overwhelmed by cumulative stressors.

4.2.2 Socio-cultural continuity and knowledge transmission

Socio-cultural factors particularly the continuity of Traditional Ecological Knowledge (TEK) emerge as a critical determinant of effectiveness. The review consistently shows that adaptation outcomes are stronger where knowledge is actively transmitted across generations and embedded in daily livelihood practices. Seasonal indicators, species monitoring, and landscape stewardship rely on accumulated experience and collective memory; when these are disrupted by displacement, formal education systems, or market integration, adaptive capacity declines [95].

Cultural values that frame forests as relational entities rather than extractive resources further enhance effectiveness. Such values promote stewardship behaviors that prioritise regeneration, restraint, and long-term sustainability, reinforcing positive ecological outcomes [68]. Conversely, where cultural erosion occurs often driven by external economic pressures or policy interventions forest management practices may persist in form but lose their adaptive coherence. This underscores that adaptation is as much a cultural process as an ecological one.

4.2.3 Governance, rights, and institutional alignment

Governance arrangements represent one of the most decisive factors influencing effectiveness. The review shows that indigenous forest management yields the strongest adaptation outcomes where secure land tenure, decision-making authority, and institutional recognition are present. Community-based forest management systems that allow for flexible rule-making and local enforcement enable timely responses to climatic change and environmental uncertainty [91].

In contrast, rigid, top-down governance frameworks often undermine adaptation by constraining Indigenous practices or imposing conservation and climate policies misaligned with local realities. Even well-intentioned interventions such as protected area designation or climate mitigation programs can increase vulnerability when they restrict access to forest resources or marginalise Indigenous governance systems [88]. Importantly, the review reveals that formal recognition of Indigenous rights alone does not guarantee effective adaptation; outcomes depend on whether recognition translates into meaningful authority and adaptive governance.

4.2.4 Interactions and trade-offs across scales

Effectiveness is ultimately shaped by the interaction of ecological, socio-cultural, and governance factors across scales. Indigenous forest management performs best where ecological integrity, cultural continuity, and governance autonomy reinforce one another [58]. Where one or more of these elements is weakened, adaptation outcomes become uneven or fragile. The review also highlights trade-offs, such as short-term livelihood gains from market integration that may undermine long-term ecological resilience and cultural sustainability.

In synthesis, the effectiveness of indigenous forest management for climate adaptation cannot be assessed solely on the basis of practices. Instead, it emerges from place-specific alignments between ecosystems, cultures,

and institutions [2]. Recognising and strengthening these alignments is therefore essential for sustaining Indigenous-led adaptation strategies under accelerating climate change.

4.3 Integration of indigenous knowledge with scientific, technical, and policy frameworks

The reviewed literature demonstrates that the integration of Indigenous knowledge with scientific, technical, and policy frameworks in forest-based climate adaptation initiatives is uneven, context-dependent, and deeply shaped by power relations. While there is growing recognition of the value of Indigenous knowledge for climate adaptation, integration often remains partial, instrumental, or confined to technical domains, rather than extending to governance and decision-making authority.

4.3.1 Knowledge co-production and complementarity

Across multiple case studies, successful integration is most evident where Indigenous knowledge and scientific approaches are treated as complementary systems rather than hierarchical or extractive ones. Co-production processes such as participatory mapping, ecocultural research frameworks, joint monitoring, and collaborative landscape assessments enable Indigenous observations, seasonal indicators, and value systems to inform scientific analysis and adaptation planning [55]. In these contexts, Indigenous knowledge contributes fine-grained, place-based insights that enhance the accuracy and relevance of ecological assessments, particularly in relation to phenological change, ecosystem thresholds, and culturally significant species.

The review shows strong convergence between Indigenous indicators and scientific measurements in areas such as vegetation health, pasture condition, wildlife habitat suitability, hydrological change, and fire behavior. This convergence challenges persistent assumptions that Indigenous knowledge is anecdotal or unscientific, instead positioning it as empirically robust and operationally valuable [2]. However, the literature also cautions that complementarity requires sustained engagement, mutual learning, and respect for epistemological differences, rather than one-off consultation exercises.

4.3.2 Institutional and policy interfaces

Integration outcomes are strongly mediated by institutional design and policy context. Co-management arrangements, Indigenous Protected Areas, and community-driven adaptation initiatives provide institutional spaces where Indigenous knowledge can meaningfully shape forest governance and climate responses [101]. In these settings, integration extends beyond data sharing to include joint decision-making, adaptive rule-setting, and locally defined management objectives.

By contrast, integration is often constrained in policy environments characterised by rigid regulatory frameworks, centralised authority, or sector-specific mandates. Climate adaptation and conservation policies that prioritise standardized indicators, short planning horizons, or externally defined success metrics tend to marginalise Indigenous knowledge systems, particularly those grounded in relational values, long-term stewardship, and non-market priorities [59]. The review highlights that even when Indigenous knowledge is acknowledged in policy discourse, it is frequently decoupled from authority, limiting its influence on actual management outcomes.

4.3.3 Limits, risks, and tokenism in integration

A recurring concern across the literature is the risk of tokenistic integration, where Indigenous knowledge is selectively extracted to improve technical outcomes without addressing underlying issues of rights, governance, and equity. In such cases, Indigenous observations may inform scientific models or monitoring systems, but Indigenous communities remain excluded from decisions regarding land use, resource access, or benefit sharing.

[89]. This form of integration not only undermines trust but can also weaken adaptive capacity by eroding local institutions and knowledge transmission pathways.

The review also identifies risks associated with decontextualising Indigenous knowledge removing it from its cultural, ethical, and relational foundations. When Indigenous knowledge is reduced to discrete data points or indicators, its adaptive logic may be lost, leading to maladaptive interventions. Furthermore, integration efforts that fail to recognise Indigenous sovereignty and legal rights may inadvertently reinforce existing power asymmetries, limiting the long-term sustainability of adaptation initiatives [22].

4.3.4 Conditions for meaningful integration

Synthesising across studies, the review identifies several conditions under which integration is most likely to support effective forest-based climate adaptation. These include: (i) recognition of Indigenous land and resource rights; (ii) institutional arrangements that enable shared authority and adaptive governance; (iii) long-term, trust-based partnerships rather than project-based engagement; and (iv) respect for Indigenous knowledge as a living system embedded in social, cultural, and ecological relationships. Where these conditions are present, integration enhances not only technical understanding of climate impacts but also the legitimacy, equity, and resilience of adaptation responses.

In summary, the integration of Indigenous knowledge with scientific, technical, and policy frameworks holds significant promise for forest-based climate adaptation, but its effectiveness depends on how integration is conceptualised and enacted. The review suggests that integration should be understood not as a technical exercise, but as a governance process requiring power-sharing, institutional flexibility, and epistemological pluralism. Without these elements, integration risks remaining symbolic, limiting its contribution to meaningful and just climate adaptation.

4.4 Indigenous forest management as a socio-ecological climate adaptation system

This review demonstrates that indigenous forest management should be understood not as a collection of discrete practices or isolated knowledge elements, but as a socio-ecological climate adaptation system. This system is characterised by the dynamic interaction of ecological processes, cultural values, governance arrangements, and long-term learning, enabling Indigenous communities to anticipate, absorb, and respond to climatic change while sustaining livelihoods and biodiversity [6, 14].

Across diverse ecological and cultural contexts, indigenous forest management practices including Traditional Ecological Knowledge and seasonal decision-making, community-based governance, cultural fire regimes, and agroforestry systems exhibit a shared adaptive logic. These practices are fundamentally place-based, grounded in long-term relationships with specific ecosystems; multi-functional, simultaneously addressing food security, risk reduction, and ecological integrity; and flexible, allowing continuous adjustment as environmental conditions evolve. These characteristics closely align with core principles of climate adaptation and resilience theory, such as diversity, redundancy, sensitivity to feedbacks, and iterative learning [86].

The effectiveness of this adaptation system depends on the alignment between ecological context, socio-cultural continuity, and governance conditions. Where forest ecosystems retain functional integrity, where Indigenous knowledge is actively practiced and transmitted across generations, and where governance structures recognise Indigenous authority, strong outcomes are observed across ecosystem resilience, biodiversity conservation, livelihood sustainability, and the reduction of climate-related risks [35, 42]. Conversely, where one or more of these elements is weakened through accelerated climate extremes, cultural erosion, or restrictive governance the adaptive system becomes increasingly strained. This reinforces the understanding that adaptive capacity is emergent, arising from interactions among system components rather than from any single practice or intervention.

The review further shows that indigenous forest management systems are most effective when integration with scientific and policy frameworks occurs at the level of governance and decision-making, rather than being

confined to technical data exchange. Co-production initiatives, participatory monitoring, and collaborative planning processes enhance adaptive capacity by expanding the informational base and institutional reach of indigenous stewardship systems [45]. However, integration that is extractive or tokenistic where indigenous knowledge is used to refine technical outputs without corresponding shifts in authority can undermine the socio-cultural foundations upon which adaptation depends. This highlights that integration is not merely an epistemic challenge, but a fundamentally political and institutional one.

Taken together, the findings indicate that indigenous forest management operates as a nested adaptation system functioning across multiple scales. At the household and community level, seasonal practices and diversified livelihood strategies enable responses to short-term climatic variability. At the landscape level, community-based governance and fire management shape ecosystem dynamics and risk profiles. At broader spatial scales, Indigenous stewardship contributes to regional biodiversity conservation and climate regulation, particularly within intact forest landscapes. The strength of this system lies in its ability to connect these scales through culturally embedded institutions and knowledge networks [65].

This synthesis also reveals a critical distinction between adaptation as intervention and adaptation as a way of life. Indigenous forest management does not conceptualise climate adaptation as a separate policy domain or project-based response. Instead, adaptation is embedded within everyday practices, social relations, and ethical commitments to land and non-human life. This stands in contrast to dominant adaptation frameworks that prioritise short-term technical solutions, often detached from local governance structures and cultural contexts. Recognising indigenous forest management as a socio-ecological adaptation system therefore challenges prevailing approaches to climate adaptation and calls for frameworks that prioritise long-term stewardship, relational values, and Indigenous self-determination.

In summary, this review advances understanding of indigenous forest management by framing it as an integrated socio-ecological system that generates adaptive capacity through the co-evolution of knowledge, practice, and governance. Such systems offer critical lessons for forest-based climate adaptation globally, particularly in an era of accelerating climate change where technical solutions alone are insufficient. Strengthening indigenous forest management systems through rights recognition, institutional support, and genuine knowledge integration represents not only an effective adaptation strategy, but also a pathway toward more just, resilient, and sustainable forest futures.

4.5 Policy and practice implications

The synthesis of findings in this review carries important implications for climate adaptation policy, forest governance, and conservation practice. Recognising indigenous forest management as a socio-ecological adaptation system necessitates a shift away from narrowly technical or project-based approaches toward frameworks that support Indigenous governance, knowledge systems, and long-term stewardship.

First, climate adaptation policies must move beyond symbolic recognition of Indigenous knowledge toward institutional arrangements that enable Indigenous decision-making authority. The review shows that indigenous forest management practices are most effective where communities retain control over land use, resource access, and management rules. Policies that acknowledge Indigenous knowledge without securing land tenure or governance autonomy risk undermining adaptive capacity by separating knowledge from the social institutions that sustain it. Therefore, adaptation strategies should explicitly incorporate Indigenous governance structures as central actors rather than stakeholders consulted at the margins.

Second, forest and conservation policies should recognise that indigenous forest management contributes simultaneously to climate adaptation, biodiversity conservation, and livelihood sustainability. Dominant policy frameworks often treat these objectives as competing priorities, leading to interventions that restrict Indigenous livelihoods in the name of conservation or climate mitigation. The evidence reviewed here indicates that Indigenous-managed forests frequently maintain high levels of biodiversity and ecosystem integrity while supporting

human well-being. Integrating indigenous forest management into national climate strategies, biodiversity action plans, and protected area governance can therefore generate co-benefits across policy domains.

Third, the integration of Indigenous knowledge with scientific and technical tools should be pursued through co-production rather than extraction. Policies promoting climate monitoring, early warning systems, or ecosystem assessment should prioritise collaborative approaches that respect Indigenous epistemologies and values. This includes supporting participatory mapping, joint monitoring, and long-term research partnerships that build mutual trust and learning. Importantly, integration should not be limited to data collection, but extend to shared interpretation, planning, and evaluation of adaptation measures.

Fourth, funding mechanisms for climate adaptation and conservation need to align with the temporal and relational nature of indigenous forest management systems. Short-term project cycles and outcome metrics that prioritise rapid, quantifiable results are often incompatible with Indigenous approaches that operate through long-term stewardship and intergenerational knowledge transmission. Climate finance instruments including adaptation funds and results-based mechanisms should therefore be designed to support sustained institutional capacity, knowledge transmission, and governance processes rather than isolated interventions.

Finally, practitioners and policymakers should recognise that strengthening indigenous forest management is also a matter of climate justice. Indigenous communities often bear disproportionate climate risks despite contributing least to greenhouse gas emissions. Supporting Indigenous-led adaptation through rights recognition, governance empowerment, and equitable benefit sharing addresses both climate vulnerability and historical marginalisation. As such, indigenous forest management should be understood not only as an effective adaptation strategy, but as a pathway toward more just and resilient climate responses.

4.6 Limitations and future research directions

While this systematic review provides a comprehensive synthesis of indigenous forest management and climate change adaptation, several limitations should be acknowledged, which also point toward important directions for future research.

First, the reviewed literature exhibits geographical and thematic biases. A substantial proportion of studies focus on regions with relatively strong research infrastructure and policy visibility, such as North America, Australia, and parts of the Amazon Basin. In contrast, indigenous forest management systems in Central Asia, the Middle East, and portions of Africa remain underrepresented. This uneven coverage limits the generalisability of findings and underscores the need for more geographically diverse and comparative studies that capture the full range of indigenous forest-based adaptation practices.

Second, there is a notable methodological imbalance in the literature. Most studies rely on qualitative case-study approaches, which are well suited to documenting Indigenous knowledge, values, and practices, but often lack longitudinal or quantitative assessment of adaptation outcomes. Few studies systematically track ecological, social, or livelihood indicators over extended periods, making it difficult to assess long-term effectiveness or thresholds of adaptation under accelerating climate change. Future research would benefit from mixed-methods designs that combine indigenous knowledge, qualitative insights, and long-term ecological or socio-economic data.

Third, the review also reflects the effect of methodological quality filtering. Of the 97 studies that underwent quality appraisal, 38 were classified as low quality and excluded from the final synthesis. Because these studies were excluded before final thematic coding, the review cannot establish whether their inclusion would have changed the relative prominence or boundaries of the four themes identified from the retained evidence. Future systematic reviews could address this issue through sensitivity analyses or evidence-weighting approaches where the review protocol and study characteristics permit.

Fourth, although integration of indigenous knowledge with scientific and policy frameworks is frequently advocated, few studies critically evaluate the long-term impacts of integration initiatives. There is limited evidence on whether co-production arrangements persist beyond project timelines or translate into lasting institutional

change. Future research should therefore assess the durability of integration mechanisms, including how power-sharing arrangements evolve and whether Indigenous governance systems are strengthened over time.

Finally, this review is constrained by the scope of available peer-reviewed literature and the exclusion of much grey literature and Indigenous-authored knowledge that may not be captured in academic databases. While this reflects standard systematic review protocols, it also highlights the epistemic limitations of relying solely on published academic sources. Future reviews could explore more inclusive methodologies that engage directly with Indigenous organisations, community reports, and Indigenous-led research outputs.

In moving forward, research on indigenous forest management and climate adaptation should prioritise Indigenous-led and co-designed research agendas, longer temporal scales, and stronger attention to governance and justice dimensions. Such approaches are essential for advancing understanding of how indigenous forest management systems can continue to support adaptation in an era of rapid environmental and socio-political change.

5 Conclusion

This systematic literature review examined how Indigenous peoples use forest management practices to adapt to climate change, the factors that influence the effectiveness of these practices, and the ways Indigenous knowledge is integrated with scientific and policy frameworks. The findings demonstrate that Indigenous forest management is best understood as an integrated socio-ecological adaptation system in which ecological knowledge, cultural values, governance institutions, and environmental conditions interact to support resilience in forest-dependent communities.

The review addressed three key research questions. First, it identified Traditional Ecological Knowledge (TEK), community-based forest management, Indigenous fire stewardship, and agroforestry systems as the principal forest management approaches employed for climate adaptation. Second, it showed that the effectiveness of these approaches is shaped by the interplay of ecological conditions, governance arrangements, land tenure security, and the continuity of Indigenous knowledge transmission. Third, it revealed that while Indigenous knowledge is increasingly incorporated into scientific and policy processes, the quality and outcomes of integration depend largely on the extent to which Indigenous communities are able to participate meaningfully in decision-making.

A central finding of the review is that adaptation outcomes are influenced not only by management practices themselves but also by the broader governance and institutional environments in which they operate. Indigenous forest management tends to be most effective where communities retain authority over land and resources, maintain strong knowledge systems, and operate within supportive governance frameworks. Conversely, insecure tenure, restrictive policies, and unequal power relations may constrain adaptive capacity and weaken long-term resilience.

The review also highlights that meaningful integration of Indigenous knowledge requires more than the incorporation of local observations into scientific or policy processes. Effective integration depends on recognition of Indigenous rights, respect for diverse knowledge systems, and institutional arrangements that support shared decision-making and Indigenous self-determination. Without these conditions, integration risks becoming symbolic rather than transformative.

Several priorities emerge for future research and policy. Greater attention should be given to underrepresented regions, long-term assessments of adaptation outcomes, and the governance dimensions of knowledge integration. From a policy perspective, strengthening Indigenous land rights, supporting governance autonomy, and promoting equitable participation in climate decision-making remain essential for enhancing the effectiveness and sustainability of forest-based adaptation strategies.

Overall, this review demonstrates that Indigenous forest management offers important lessons for climate adaptation in forested landscapes. By emphasising long-term stewardship, relational approaches to environmental management, and locally grounded governance systems, Indigenous forest management contributes not

only to climate resilience but also to broader goals of biodiversity conservation, social justice, and sustainable development.

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Declarations

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