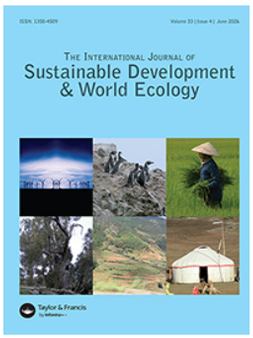

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Reframing biodiversity markets for sustainable agriculture: a systematic review and governance framework for effective nature-positive outcomes

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ABSTRACT

Biodiversity markets are gaining global attention as innovative mechanisms to mobilise private finance for conservation and support nature-positive transitions in sectors such as agriculture. Yet, empirical evidence on their design, effectiveness, and governance remains fragmented. This study presents a systematic review of biodiversity market literature, combining PRISMA-based screening of 671 peer-reviewed articles with bibliometric mapping and thematic synthesis. The review focuses on peer-reviewed studies with accessible full texts, which may have excluded some relevant literature. We traced the evolution of biodiversity market discourse beyond offsets to emerging credit systems, stacked financing models, and nature-positive outcome frameworks. The analysis reveals major challenges, including the absence of robust ecological metrics, inconsistent governance arrangements, and limited attention to equity in market design. It also highlights mounting concerns, raised across the literature, about greenwashing and the credibility of market-based claims. Without robust design and transparent oversight, biodiversity markets risk undermining conservation goals and public trust. Our findings underscore the urgent need for more rigorous, transparent, and evidence-based approaches to ensure biodiversity finance mechanisms deliver real, measurable ecological outcomes. In response, we propose a five-pillar governance framework to guide future biodiversity market development: (1) policy and institutional anchoring, (2) inclusive governance, (3) scientific and ecological integrity, (4) fit-for-purpose financial mechanisms, and (5) place-based implementation. This framework offers practical guidance for designing credible, equitable biodiversity markets that support long-term stewardship and sustainable land use.

HIGHLIGHTS

- Biodiversity markets are expanding rapidly, but weak ecological metrics, fragmented governance, and limited equity safeguards threaten their contribution to sustainable development.
- Biodiversity markets must be embedded within coherent policy and institutional frameworks, integrating environmental regulation, agricultural policy, and sustainable finance.
- Scientific integrity should be a core policy requirement, supported by standardised indicators, transparent verification, and long-term ecological monitoring.
- Inclusive governance is essential to ensure social legitimacy, protect Indigenous and smallholder participation, and enable fair benefit-sharing.
- Blended finance, biodiversity bonds, and stacked credit models can scale investment only when anchored to strong public oversight and place-based implementation.

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KEYWORDS
Transition finance; natural capital; stacked credits; blended finance; ecological metrics; biodiversity finance

1. Introduction

The loss of biodiversity and ecosystem integrity poses irreversible risks to environmental systems, human well-being, and long-term economic resilience. These risks stem from the degradation and depletion of natural capital, undermining ecological functions that support food systems, climate stability, and livelihoods (World Economic Forum 2020). While governments have long relied on protected areas and regulatory tools, these approaches alone have failed to halt global biodiversity decline (Manez and Clifton 2025). As a result, interest has grown in market-based instruments that can complement traditional conservation by attracting private investment into biodiversity protection, restoration, and sustainable use (Clifton and Mánez 2025).

Biodiversity markets are increasingly being promoted as scalable solutions for financing conservation

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and nature-positive land management. While these markets were once associated mainly with biodiversity offsets, they now encompass more diverse activities such as revegetation, invasive species control, and restoration integrated into agricultural and forestry systems (Lindenmayer et al. 2023; Das et al. 2025). These approaches align with broader sustainability goals and offer co-benefits for producers, ecosystems, and supply chains. In parallel, governments and multilateral organisations have begun adopting frameworks to standardise and scale these mechanisms. Notable milestones include the adoption of the Global Biodiversity Finance Strategy under the Convention on Biological Diversity (CBD) in 2025, which aims to close a US$700 billion annual funding gap through private investment, financial reform, and credit mechanisms (UNEP - United Nations Environment Programme 2025). The Kunming-Montreal Global Biodiversity Framework (GBF) similarly calls for the restoration of 30% of degraded ecosystems by 2030, with financial instruments playing a central role (UNEP - United Nations Environment Programme 2022). Within this broader biodiversity finance landscape, biodiversity markets represent a distinct subset of market-based instruments aimed at generating measurable ecological outcomes through tradable mechanisms and private investment flows.

In this study, biodiversity markets are understood as market-based financial mechanisms that generate tradable biodiversity-related credits or payments linked to measurable ecological outcomes. These mechanisms typically involve standardised methodologies, verification systems, and transactions between buyers and sellers seeking biodiversity improvements or risk mitigation (TNFD 2022). Emerging biodiversity credit systems further expand this concept by linking ecological restoration outcomes with voluntary investment flows (World Economic Forum 2025).

Biodiversity markets therefore represent one component of a broader set of biodiversity finance instruments, which also includes regulatory policies, public subsidies, and hybrid governance mechanisms that incentivise conservation outcomes (UNEP - United Nations Environment Programme 2022). It is important to distinguish biodiversity markets from biodiversity-aligned economic sectors, such as sustainable forestry, ecotourism, or regenerative agriculture, which may contribute to biodiversity conservation but do not necessarily involve tradable biodiversity credits or market transactions (Dasgupta 2021). While these sectors can generate positive ecological outcomes, they are not considered biodiversity markets within the conceptual framework adopted in this review, which focuses on market-based mechanisms involving financial transactions linked to measurable biodiversity outcomes (World Economic Forum 2025).

Despite growing interest, the conceptualisation, design, and effectiveness of biodiversity markets remain fragmented in the literature. At the same time, policy tools and voluntary initiatives increasingly support low-impact and regenerative farming practices in the agricultural sector (Eberhard et al. 2021). These include nature-positive agriculture, silvopastoral systems, agroecology, and other approaches that integrate biodiversity outcomes into production landscapes (Kaushal et al. 2025). Coupled with shifting consumer preferences and the expansion of biodiversity-aligned sectors such as sustainable forestry, organic agriculture, ecotourism, and fisheries, interest in financial mechanisms that reward biodiversity outcomes has increased (Moles 2001; Dasgupta 2021). Recent policy initiatives and biodiversity finance frameworks further highlight the potential for market-based instruments to support agricultural transitions by creating new incentives for land stewardship (OECD 2019; TNFD 2023).

However, biodiversity markets are not stand-alone solutions. As illustrated in Figure 1, they operate within a broader biodiversity finance landscape shaped by enabling policies and regulations, public and private financial instruments, and blended market mechanisms that collectively support biodiversity conservation outcomes (OECD 2019, Lockie 2020). What distinguishes biodiversity markets from these instruments is their reliance on market-based mechanisms that generate tradable biodiversity-related assets or credits linked to verified ecological outcomes. These mechanisms typically involve standardised methodologies, third-party verification, and credit issuance frameworks that allow biodiversity outcomes to be measured, validated, and transacted within financial systems. Recent developments such as the Taskforce on Nature-related Financial Disclosures (TNFD 2023) and the European Commission's Roadmap to Nature Credits reflect growing efforts to align biodiversity markets with ESG standards, enhance transparency, and strengthen investor confidence in nature-related investment mechanisms (McLaren and Carver 2023; Parker et al. 2023).

Despite their promise, the ecological performance, governance quality, and equity outcomes of biodiversity markets remain uncertain. Evidence of long-term effectiveness is limited (Legge et al. 2023), and concerns over greenwashing are widespread – particularly in weakly regulated or voluntary schemes (Bennett et al. 2021; Neuteleers 2022). Biodiversity offsets, while widely used, have been criticised for failing to achieve ecological equivalence and for allowing environmental harm to proceed under the guise of compensation (Maron et al. 2018). Many offset projects fall short of restoration targets or degrade over time and are often more about monetising biodiversity loss than securing ecological gains (Bull et al. 2013). These

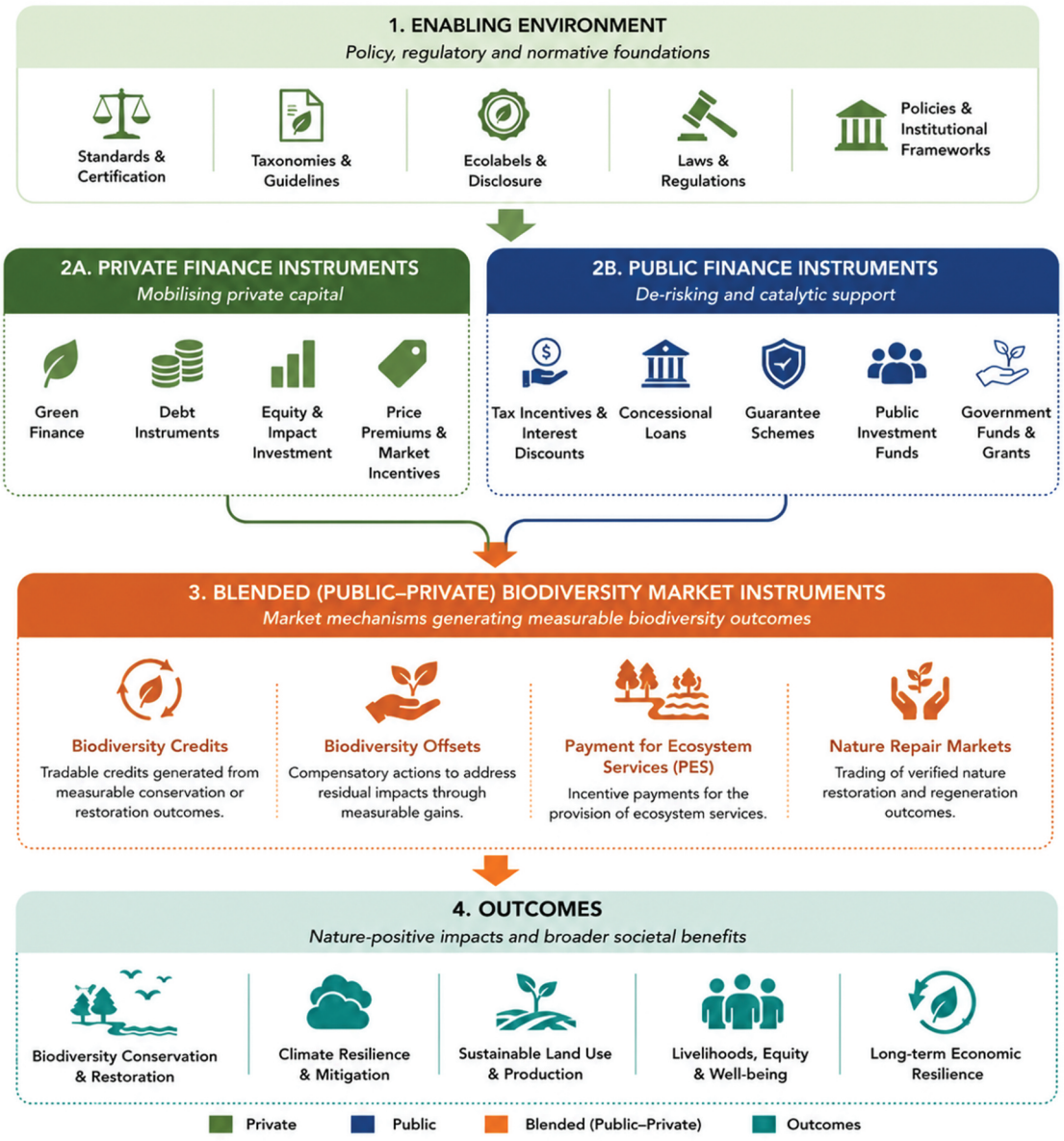

Figure 1. Biodiversity finance instruments and pathways supporting biodiversity conservation outcomes.

challenges raise critical questions about the integrity, monitoring, and equity of biodiversity market mechanisms.

This paper responds to these concerns by systematically reviewing the academic literature on biodiversity markets with a focus on agriculture and land use. We conducted a PRISMA-compliant review of 671 peer-reviewed articles, combining bibliometric mapping and qualitative thematic analysis. Based on this synthesis, we propose a five-pillar governance framework to guide the development of credible, equitable, and scalable biodiversity markets aligned with global sustainability objectives, including the GBF and TNFD.

To guide this analysis, the study addresses the following research questions: (1) How are biodiversity markets defined and conceptualised in the literature? (2) What design features, governance arrangements, and financial mechanisms underpin these instruments? (3) What challenges and limitations affect their effectiveness, legitimacy, and scalability? and (4) What principles and frameworks can support the development of more credible and equitable biodiversity markets?

2. Methodology

We used the *Preferred Reporting Items for Systemic Reviews and Meta-Analyses 2020* (PRISMA) approach (Page et al. 2021), followed by a bibliometric examination of the literature on biodiversity markets globally to perform a quantitative systematic literature review. PRISMA is a protocol delineated into four phases: identification, screening, eligibility, and inclusion.

Search and screening summary – We conducted a PRISMA-aligned search across Web of Science and Scopus databases up to 30 June 2025, using Boolean strings combining terms for 'Biodiversity markets'; 'Biodiversity credits'; 'Nature repair market'; 'Market-

based instruments' AND 'biodiversity'; 'Market-based instruments for biodiversity'; and 'Investments on biodiversity'. Although the search string included broader terms related to economic instruments to ensure comprehensive coverage, the screening process prioritised studies addressing market-based mechanisms or financial instruments linked to biodiversity outcomes, consistent with the conceptual focus of this review. Records were de-duplicated, and titles and abstracts were screened against pre-specified inclusion criteria: (1) relevance to biodiversity markets or economic instruments affecting biodiversity outcomes in agricultural or production landscapes; (2) publication in English; (3) publication in peer-reviewed academic journals; and (4) full-text availability online. Full texts meeting these criteria were subsequently coded thematically and included in the thematic analysis. The PRISMA checklist and flow diagram are provided in the Supplementary Material. The review focused on peer-reviewed studies with accessible full texts, which may have excluded some relevant literature not available through these databases.

A quantitative analysis of selected publications was conducted using Bibliometrix, an R package designed for bibliometric analysis. This statistical approach provides a comprehensive overview of the literature, enabling researchers to identify research trends, thematic areas, and potential future developments (Sharma et al. 2025). Bibliometric mapping reflects patterns in publication frequency, keyword selection, and database coverage, and therefore may not fully capture the conceptual depth or diversity of the field. As such, observed patterns should be interpreted cautiously, as they may reflect methodological artefacts rather than definitive conceptual or empirical gaps. To address this limitation, bibliometric insights were complemented with qualitative thematic analysis. The analysis examined scientific output by country, the most cited countries, key research themes, trending topics, and co-occurrence of keywords to better understand biodiversity markets. Bibliometric data were sourced from Scopus and Web of Science and analysed in RStudio (Echchakoui 2020; Lim et al. 2024).

The qualitative analysis was carried out using NVivo (R1.7), with selected publications imported for thematic coding and in-depth content analysis. The themes identified through the bibliometric analysis served as a reference framework for developing initial coding categories. These codes were then analysed to identify key patterns, insights, and emerging areas of knowledge related to biodiversity markets.

3. Results

Based on our review of the literature, we synthesised current insights on biodiversity markets and examined their role within a broader set of financial instruments supporting sustainable agricultural transitions, particularly in helping farmers manage the financial demands associated with adopting more sustainable practices.

3.1. PRISMA

A total of 671 peer-reviewed research articles were initially selected for analysis using the Bibliometrix tool (quantitative analysis). After removing 344 duplicates and excluding 40 articles that did not meet the inclusion criteria, 287 articles were retained for qualitative analysis using NVivo. The earliest publication in the dataset dates to 1997.

3.2. Bibliometrix analysis

Bibliometric techniques not only offer a comprehensive overview of the current state of biodiversity market research but also serve as a strategic tool for guiding scholarly inquiry, policymaking, and the design of new research agendas (Derviş 2019;

Country	Frequency
Australia	183
United Kingdom	122
United States	104
Germany	81
France	75
Netherlands	43
Finland	33
Sweden	30
Italy	29
Brazil	27

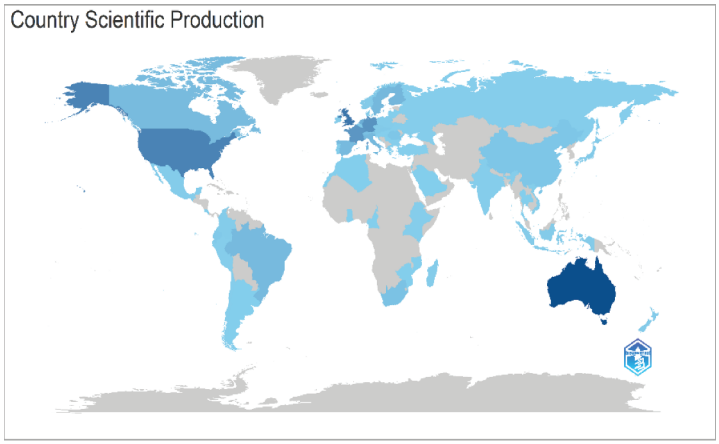

Figure 2. Country scientific production. Source: authors' analysis using Biblioshiny in R.

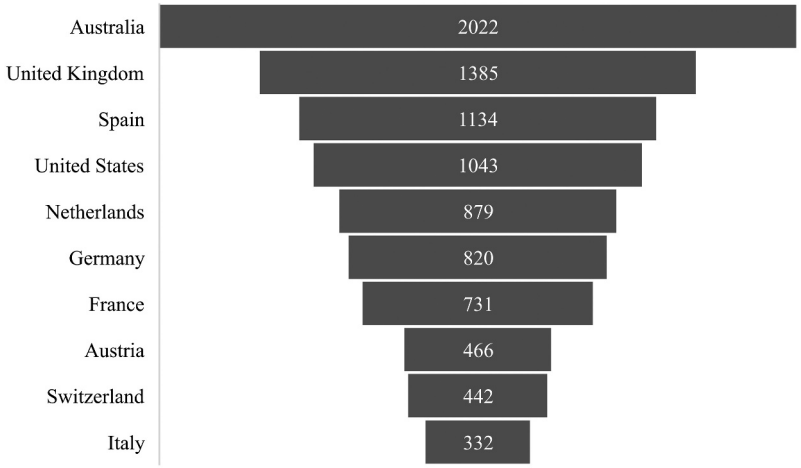

Figure 3. Most cited countries. Source: authors' analysis using Biblioshiny in R.

Hassan and Duarte 2024; Lim et al. 2024). Using the Bibliometrix tool we analysed 1) countries scientific production; 2) most cited countries; 3) key research themes and trending topics; 4) thematic evolution; and 5) co-occurrence network.

3.2.1. Countries scientific production

This indicator was used to enhance understanding of national research about biodiversity markets, including the nature repair markets. As shown in Figure 2, Australia emerges as the leading contributor to research on biodiversity markets, followed by United Kingdom and the United States. Comparing a country's research productivity with that of neighbouring or similar nations provides valuable context and serves as a meaningful benchmark for evaluating performance (Hassan and Duarte 2024). By examining scientific output by country, researchers can identify where the bulk of knowledge production is occurring, which may correlate with national priorities, policy developments, or investment in environmental research (Aria and Cuccurullo 2017).

3.2.2. Most cited countries

Identifying the most cited countries provides valuable insight into the global leaders shaping research and policy discourse on biodiversity markets (Donthu et al. 2021). As shown in Figure 3, Australia emerges as the

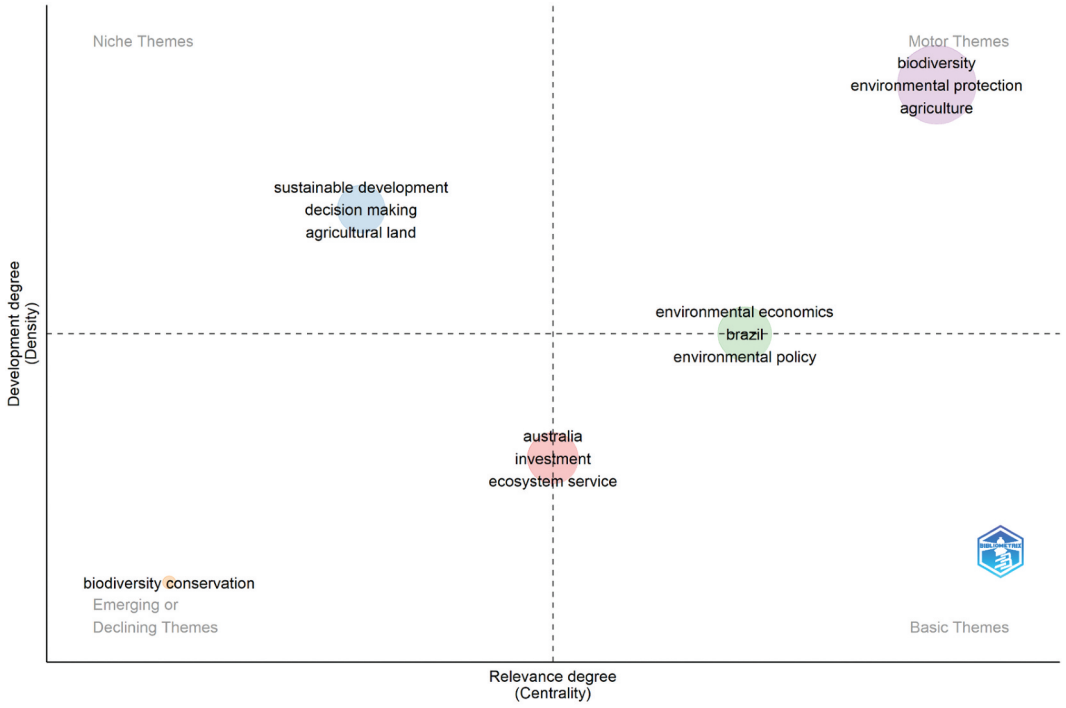

Figure 4. Thematic map of biodiversity-market literature. Quadrants indicate theme centrality (x-axis) and development (y-axis). Upper-right = motor themes (central, well-developed); upper-left = highly developed but niche; lower-right = basic/transversal; lower-left = emerging/declining. Bubble size reflects keyword frequency; edges show co-occurrence strength. Source: authors' analysis using Biblioshiny in R.

most cited country, with 2,022 citations, followed by the United Kingdom (1,385) and Spain (1,134). This prominence underscores Australia's leadership and growing influence in advancing biodiversity market frameworks and contributing to global sustainability dialogues.

3.2.3. Thematic map

The thematic map helps identify research directions and emerging topics within the literature. By analysing keyword co-occurrence patterns, thematic mapping highlights areas of scholarly concentration and potential gaps for future research (Zupic and Čater 2015). The thematic map was generated through keyword co-occurrence analysis, where clusters of related terms were identified algorithmically and subsequently interpreted to delineate the main thematic blocks presented in Figure 4. In this approach, centrality measures the degree of interaction between a theme and other themes in the network, indicating its relative importance within the research field, while density reflects the internal strength of connections within a cluster, indicating the level of development and conceptual cohesion of that theme. Figure 4 illustrates these thematic trends through a strategic diagram in which the x-axis represents centrality (relevance of a theme within the research field) and the y-axis represents density (degree of development of the theme) (Bagdi et al. 2023). Overall, the analysis suggests that biodiversity market research is currently shaped by themes related to environmental policy, governance, and implementation mechanisms, while some topics, such as biodiversity credit systems and conservation market design, remain less consolidated and present opportunities for further research.

The upper right quadrant keywords, labelled as motor themes, comprises instruments, environmental, and policy, indicating these are well-developed and central to the field. These topics reflect mature, action-oriented domains, often linked to the implementation of biodiversity market mechanisms and regulatory frameworks. These themes play a critical role in shaping the research agenda, reflecting growing institutional and regulatory focus on biodiversity-related governance. It suggests growing international engagement and a shift toward structured policy and financial mechanisms to support conservation (CBD 2022). The inclusion of biodiversity, conservation and market in this space in a lower level indicates these themes are foundational to the field, exhibiting high relevance but lower internal development. Their position suggests they are frequently discussed but may benefit from further conceptual or methodological refinement to advance the field. In contrast, the bottom right quadrant (basic themes) and upper-left quadrant (niche themes) are unpopulated. The absence of basic themes suggests key opportunities for further conceptual and methodological refinement and opportunity for deeper integration. In the case of niche themes, it suggests an absence of specialised yet well-developed topics that are peripheral to the field's core focus. Lastly, the lower left quadrant contains less developed and peripheral topics such as loss, species, and credits. While these may represent declining interest, they could also signal emerging areas of innovation, especially considering increasing attention to biodiversity credit schemes and species-level conservation strategies (Bell and Malerba 2025; Manez and Clifton 2025; Stoeckl et al. 2025). The topics land, study, and results are clustered in almost a central position in the lower left quadrant suggesting a methodological or empirical focus likely linked to land-based case studies and field results. Their relatively low development and centrality imply that while land-based evidence is

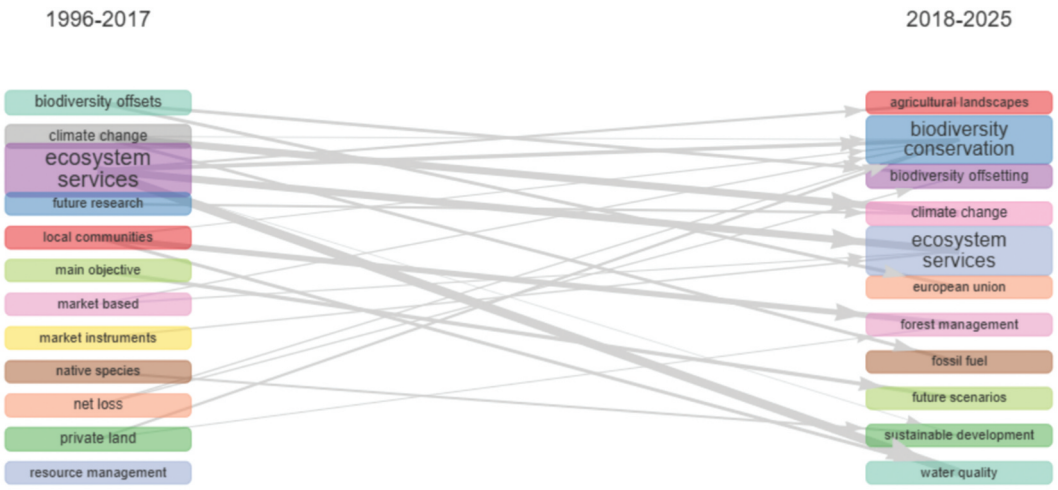

Figure 5. Thematic evolution over time. Key topics by period (1996–2017; 2018–2025). Line thickness reflects continuity/expansion; new nodes signal emerging areas. Source: authors' analysis using Biblioshiny in R.

present, it remains fragmented or under-theorised within the broader discourse.

3.2.4. Thematic evolution

Thematic evolution analysis, conducted using Bibliometrix, reveals significant shifts in the focus of research on biodiversity markets over time. Figure 5, illustrates the thematic progression in biodiversity market research across two distinct periods, revealing how scholarly focus has shifted over time. Overall, this shift illustrates a conceptual broadening from ecological and market mechanisms to systemic and policy-oriented approaches, driven by increasing demands for measurable outcomes and global coordination in biodiversity conservation and finance.

In the earlier phase (from 1996 to 2017), research was anchored in foundational environmental concepts such as ecosystem services, climate change, biodiversity offsets, and resource management. These themes were often linked to governance mechanisms (market instruments, private land), ecological values (native species), and stakeholder inclusion (local communities), reflecting a focus on establishing theoretical and institutional underpinnings. In contrast, in the second phase (from 2018 to 2025) the research landscape exhibits a clear shift toward applied and policy-relevant frameworks.

While ecosystem services and climate change remain central themes, additional topics such as biodiversity conservation, biodiversity offsetting, and agricultural landscapes emerge more prominently in recent years. This pattern reflects growing research attention to the land-use and governance contexts in which biodiversity-related financial mechanisms may operate, rather than a direct shift toward market implementation. The appearance of themes such as forest management, water quality, fossil fuel, and sustainable development indicates increasing connections between biodiversity market discussions and broader environmental policy and sustainability debates. References to the European Union and future scenarios further highlight the influence of regional policy frameworks and forward-looking governance discussions in shaping the literature. Overall, the thematic evolution indicates increasing interaction between biodiversity market research and broader environmental governance debates.

3.2.5. Keyword co-occurrence network

The analysis of keywords can offer opportunities to uncover the main research interests in any scientific field (Darko and Chan 2021). The co-occurrence of keywords creates a network map of how concepts are related and clustered within the literature. This helps uncover the intellectual structure of the field, revealing dominant topics, thematic intersections, and underexplored connections that could offer fruitful avenues for future research.

Overall, as shown in Figure 6, the term biodiversity serves as a central node connecting ecological, economic, and policy domains, suggesting its role as an integrative concept across diverse research agendas. The network structure indicates an increasingly interdisciplinary field, with growing convergence between ecological science, market mechanisms, and environmental governance. Two dominant clusters, in blue and red colours, represent distinct thematic dimension. The blue cluster, anchored by biodiversity and conservation, reflects an ecologically grounded research stream. This cluster connects strongly with

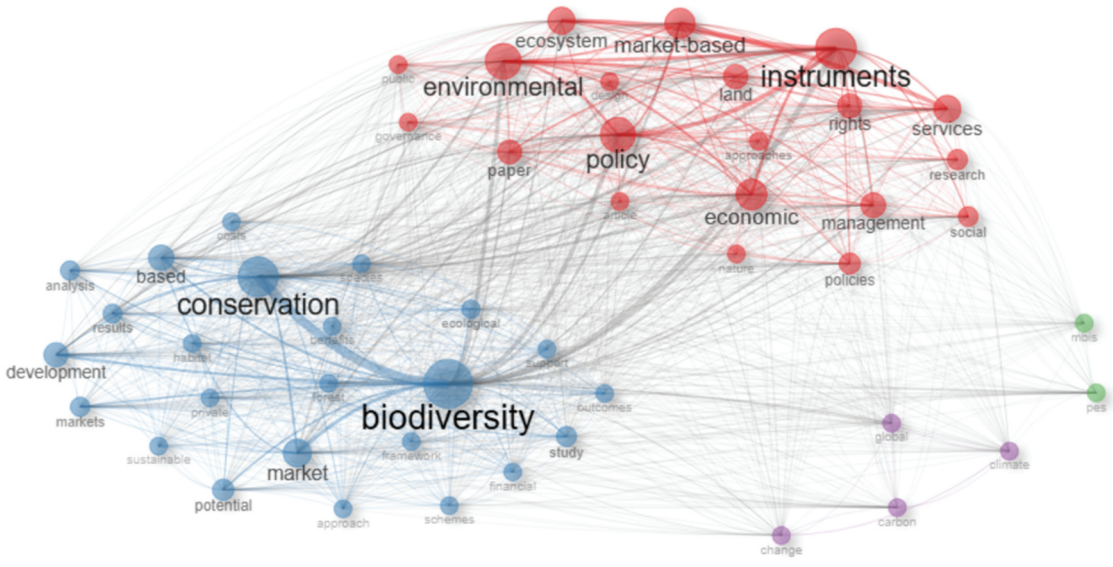

Figure 6. Keyword co-occurrence network. Communities (colours) indicate clusters. Node size = frequency; edge weight = co-occurrence strength. Bridging terms connect policy, finance and agricultural practice. Compiled by the authors using the biblioshiny interface in R.

terms such as development, market, ecosystem, sustainable, and forest, suggesting an emphasis on biodiversity management in land-based systems and conservation-focused market schemes. It also includes methodological keywords like analysis, results, and study, pointing to the empirical foundation of this body of work. The red cluster centres around instruments, environmental, and policy, indicating a strong policy and governance orientation. Terms like market-based, economic, management, services, and rights suggest a focus on institutional design, regulatory mechanisms, and socio-economic frameworks underpinning biodiversity markets. This cluster highlights the role of policy instruments in operationalising biodiversity outcomes and the integration of ecosystem services into decision-making processes. Other two smaller clusters, green and purple, represent specialised areas. The purple cluster links climate, carbon, and change, pointing to the intersection between biodiversity markets and climate policy, including potential synergies through carbon credits and nature-based solutions. The green cluster, featuring terms such as payments for ecosystem services (PES) and market-based instruments (MBIs), underscores specific economic tools used in biodiversity finance.

4. Thematic analysis

Overall, this analysis highlights important directions for future research and indicates evolving discussions in the biodiversity markets literature since 2018. Recent studies increasingly examine the governance, financing, and policy contexts relevant to biodiversity conservation, including how market-oriented instruments may complement traditional conservation approaches. To better understand these developments, we conducted an in-depth review of post-2018 literature, identifying emerging themes and evolving governance models. Our findings also emphasise the importance of improving policy coherence, institutional design, and monitoring frameworks to strengthen the credibility, effectiveness, and scalability of biodiversity markets.

To structure the qualitative synthesis of the post-2018 literature, the reviewed studies were grouped into five analytical themes reflecting recurring governance, financial, monitoring, and institutional challenges discussed across the literature. These themes represent interpretive categories derived from the thematic analysis rather than rigid classifications of the studies.

4.1. Scientific integrity and inclusive participation

Several studies highlight the importance of scientific integrity, transparency, and inclusive participation in the design and governance of biodiversity market mechanisms (Cailleux 2025; Manez and Clifton 2025; Streit et al. 2025). These themes are central because biodiversity markets operate at the intersection of ecological outcomes, stakeholder values, and institutional legitimacy. The literature consistently argues that market-based approaches must avoid shortcomings observed in other environmental credit systems, including greenwashing, superficial compliance, and inequitable benefit distribution. For example, Antonelli et al. (2024) emphasise verifiable conservation outcomes and long-term community benefits, while Head (2025) advocates adaptive governance frameworks that promote resilience, policy coherence, and institutional learning.

A recurring theme concerns participation, social legitimacy, and stakeholder engagement. Stoeckl et al. (2025) propose hybrid valuation approaches that integrate social, cultural, and ecological dimensions and recognise human stewardship. Similarly, Seidl et al. (2024) call for inclusive financial flows that prioritise Indigenous Peoples, local communities, and smallholders, while Lindenmayer et al. (2023) highlight the importance of ecological literacy and transparent benefit-sharing arrangements. Participatory governance is also emphasised by Garcia et al. (2025), who examine forest biomass conflicts in Germany, and by Sarkki et al. (2023), who advocate rights-based approaches and co-developed policy simulations that better incorporate Indigenous and Nature's rights. Related concerns are raised by Cailleux (2025), who identifies limited understanding of NGO influence in environmental governance, and by Schaal et al. (2022), who demonstrate how biodiversity policies often overlook the diversity of stakeholder perspectives within agricultural systems.

The literature further highlights the importance of aligning biodiversity market design with social values, governance arrangements, and institutional contexts. Sponagel et al. (2024) identifies a disconnect between biodiversity labelling schemes and their uptake, credibility, and effectiveness, while Ackerschott et al. (2023) call for policy experiments to better understand interactions between economic instruments, planning systems, and social-ecological conditions. Similar concerns are evident in studies examining conservation incentives and valuation approaches. Cooke and Corbo-Perkins (2018) identify tensions between stewardship ethics and market logic in reverse auctions, Maron and Louis (2018) advocate greater transparency in offset motivations, and Taherzadeh and Howley (2018) emphasise the importance of perceived fairness in shaping participation. More recently, Ghosh and Wolf (2024), Ochieng et al. (2023), Voglhuber-Slavinsky et al. (2023), Cialdella et al. (2022), and Barkley et al. (2024) similarly stress the need to

incorporate social values, equity considerations, and diverse governance arrangements into biodiversity market design.

Another prominent finding across the literature is the limited empirical evidence available to evaluate biodiversity market effectiveness. Cai et al. (2023) note the heavy reliance on modelling within China's carbon trading schemes, while Poulton and Kaplinsky (2022) and Tsakiridis et al. (2022) identify insufficient evidence regarding uptake, implementation, and ecological outcomes in conservation programs. Similar evidence gaps are reported by Barral (2022) for species-credit instruments, Mostafavi et al. (2022) for environmental market policy reversals, Martin (2022) for Australia's Agriculture Biodiversity Stewardship initiatives, Ribeiro and Soares Filho (2022) for biodiversity markets in Brazil, and Martin-Ortega et al. (2019) for ecosystem service valuation in Mexico. Studies of biodiversity offsetting and net-gain mechanisms also identify persistent uncertainties regarding enforcement, ecological effectiveness, and long-term outcomes (Baumber et al. 2019; Koh et al. 2019; Needham et al. 2019; Rea 2019; Zu Ermgassen et al. 2021).

Concerns regarding ecological effectiveness are reinforced by studies examining specific biodiversity market applications. Cinner et al. (2021) highlight the potential for market mechanisms to crowd out pro-environmental behaviours, while Corey et al. (2020), and Tabaichount et al. (2019), and call for stronger biodiversity monitoring frameworks across carbon, water-quality, and fire-management initiatives. Emerging issues are also receiving increasing attention, including climate adaptation and species representation. Ranjan (2024) argues that market-based instruments must adapt to support endemic species under climate change, Duffus et al. (2023) identify the absence of insect-specific conservation metrics, and Ruelas and Dunlap (2023) highlight social and ethical concerns associated with jaguar conservation initiatives.

Collectively, these studies suggest that successful biodiversity markets depend on scientifically credible methodologies, inclusive governance structures, equitable benefit-sharing arrangements, and robust empirical evaluation. While biodiversity markets continue to evolve, significant gaps remain regarding their long-term ecological effectiveness, social legitimacy, and institutional performance across diverse geographic and political contexts.

4.2. Aligning biodiversity market policies

Another strand of the literature focuses on the policy frameworks required to enable biodiversity markets and align them with existing conservation policies. These studies emphasise the importance of policy design, institutional coordination, and political context in shaping the effectiveness of biodiversity-related financial mechanisms. While not all studies reviewed in this section analyse biodiversity markets directly, they provide valuable insights into the governance, policy, and financial arrangements that influence the design, effectiveness, and legitimacy of market-based conservation approaches.

Evidence from agricultural and environmental policy instruments highlights the limitations of fragmented approaches and the potential benefits of coordinated policy mixes. Within the European Union's Common Agricultural Policy, second-pillar measures continue to cover relatively little land and remain costly to administer (Pufahl et al. 2022). Pe'er et al. (2022) therefore advocate coordinated field trials that combine results-based payments, enhanced monitoring, and collective-action models to assess whether these instruments can deliver simultaneous biodiversity, climate, and animal welfare benefits. Similarly, Salazar-Ordonez et al. (2021) report strong farmer willingness to adopt bird-diversity measures in Spanish olive groves when supported by compensation mechanisms, while highlighting opportunities for product labelling, price premiums, and hybrid public – private payment schemes. Research from Scotland further demonstrates the importance of policy integration, with Blackstock et al. (2021) showing that ecological outcomes may be strengthened when complementary instruments are designed and managed together rather than in isolation. Likewise, Berthet et al. (2021), in their review of 62 innovative schemes, identify outcome-based payments, stakeholder collaboration, and supply-chain certification as promising approaches, while emphasising the need for stronger evidence regarding how mixed policy instruments perform across governance levels.

The importance of governance design is also evident in habitat banking and biodiversity offsetting initiatives. Maestre-Andrés et al. (2020) describe how Spain's habitat banking system struggled due to limited transparency, weak ecological evidence, and civil-society opposition. In contrast, Gorissen et al. (2020) highlight the potential of voluntary, bottom-up approaches in the Netherlands but note persistent uncertainties regarding valuation methods and institutional fit. Together, these studies suggest that transparency, participation, and credible ecological data are essential for securing both social legitimacy and ecological effectiveness.

Broader policy dynamics may also influence the long-term success of biodiversity markets. Bezin (2019) argues that cultural transmission and pro-

environmental preferences can shape environmental behaviour, although empirical evidence remains limited. Similarly, Essl et al. (2018) identify key challenges in aligning carbon-pricing mechanisms with biodiversity objectives, including leakage risks, land-use tradeoffs, and policy coherence. Both studies point to the need for integrated assessments capable of evaluating interactions between behavioural, economic, and policy drivers across different institutional contexts.

Overall, the literature suggests that biodiversity markets are most likely to succeed when embedded within coherent policy mixes that combine regulatory, financial, and voluntary instruments. Effective implementation depends not only on market design but also on institutional coordination, stakeholder participation, policy coherence, and the availability of robust ecological evidence to guide decision-making and evaluate outcomes.

4.3. Embedding inclusive financial flows in financial systems

A third group of studies examines how biodiversity-related financial flows can be integrated into broader financial systems and investment frameworks. Collectively, these studies suggest that the long-term viability of biodiversity markets depends on their alignment with institutional frameworks, financial governance structures, and policy environments. For example, Prober et al. (2025) demonstrate that biodiversity improvements, such as increased bird diversity from native woody plantings, can be quantified and monetised through biodiversity or stacked credits (e.g. carbon + biodiversity), transforming ecological gains into tangible assets for landholders. However, Flammer et al. (2025) and Seidl et al. (2024) caution that biodiversity markets remain fragmented and underfunded, limiting their capacity to meet global conservation goals. This concern is echoed by the UNEP - United Nations Environment Programme (2022) State of Finance for Nature report, which calls for a tripling of nature-based investment by 2030 and the redirection of US$500 billion in environmentally harmful subsidies. Achieving scale and credibility will require stronger public – private partnerships, blended finance mechanisms, and innovative financial instruments such as green and biodiversity bonds (Thompson 2023).

Emerging innovations seek to address these challenges. Jones et al. (2024) and Webb et al. (2025) advocate stacked credit models that better reflect the multiple ecosystem services provided by multifunctional landscapes, while Clifton and Mánez (2025) and Seidl et al. (2024) emphasise that well-designed payments for ecosystem services and inclusive investment strategies can direct resources towards ecologically vulnerable and economically marginalised regions. Together, these studies highlight the need for financial architectures that support both conservation outcomes and social resilience.

At the farm scale, Parkhurst et al. (2024) argue that biodiversity markets are most effective when embedded within ecosystem accounting frameworks that track ecosystem conditions over time. Similarly, Rainsford et al. (2025) show that farm-level biodiversity accounts can improve environmental reporting, traceability, and access to sustainability markets. Manez and Clifton (2025), Webb et al. (2025), and Rossberg et al. (2024) further emphasise the importance of accessible, co-designed schemes supported by robust ecological metrics and fair reward structures. However, Antonelli et al. (2024) caution that recognising landholder rights and providing tailored support for smallholders are essential to maintaining social legitimacy. This is reinforced by Kaufman and Meis-Harris (2022), who demonstrate that participation is strongly influenced by opportunity costs, social norms, and perceived conflicts.

Even relatively small interventions may offer significant opportunities for market participation. Malerba et al. (2023) find that modest improvements to farm dams, including enhanced vegetation and livestock exclusion, can substantially increase frog diversity without reducing productivity. Crediting such low-cost, high-impact actions could broaden participation and extend biodiversity market benefits across agricultural landscapes.

Despite these opportunities, concerns remain regarding the broader socio-political implications of scaling market-based conservation. Chausson et al. (2023) argue that the expansion of nature-based solutions within growth-oriented financial systems may reinforce existing power asymmetries, facilitate greenwashing, and divert attention from the structural drivers of biodiversity loss. Similarly, Spash (2022) questions whether corporate-led biodiversity markets can deliver meaningful ecological and social outcomes, highlighting persistent gaps in evidence regarding equity, governance, and long-term effectiveness.

Several institutional mechanisms also remain insufficiently evaluated. Doinjashvili et al. (2021) note that despite their widespread application, Conservation Trust Funds have received limited assessment of their ecological outcomes, governance performance, and resilience to market shocks. Likewise, Fitzsimons and Cooke (2021) identify major knowledge gaps surrounding conservation tenders, including limited post-agreement monitoring, unclear ecological outcomes, and weak understanding of landholder motivations. Evidence from mature biodiversity credit systems is similarly constrained. Poudel et al. (2019) report the expansion

of habitat conservation banking in the United States but find that post-sale stewardship, ecological additionality, and long-term species outcomes remain largely unmeasured.

Collectively, these studies suggest that biodiversity markets require more inclusive and diversified financial architectures that combine public and private capital, strengthen participation by landholders and local communities, and support robust monitoring and accountability mechanisms. At the same time, significant evidence gaps remain regarding the long-term ecological, social, and governance outcomes of many biodiversity finance instruments, highlighting the need for comparative and longitudinal evaluation.

4.4. Cost-efficient monitoring of biodiversity markets outcomes

Monitoring and verification systems represent another major theme in the literature. Several studies emphasise that the credibility of biodiversity markets depends on rigorous ecological assessment, reliable monitoring systems, and transparent verification methodologies capable of demonstrating measurable biodiversity outcomes (Manez and Clifton 2025; Prober et al. 2025; Shefy et al. 2025). Long-term, cost-efficient monitoring is essential, especially if smallholders are to participate at scale (Ford et al. 2024; Teixeira et al. 2024; Yan et al. 2024; Bell and Malerba 2025; Cailleux 2025). Standardised protocols, clear reporting rules, and open data platforms can strengthen accountability and public trust (Teixeira et al. 2024).

Emerging technologies are lowering entry barriers. Bell and Malerba (2025) show that combining eDNA, acoustic sensors, and classic field surveys in adaptive 'multi-method' packages balances cost, accuracy, and habitat coverage. Ford et al. (2024) add a modular toolkit of drones, AI, and citizen science that slashes monitoring costs and boosts credit credibility, while Teixeira et al. (2024) demonstrate that passive acoustic monitoring offers a low-cost, non-invasive option for farms. Together, these innovations make verification more inclusive and verifiable.

Yet biodiversity itself defies reduction to a single, universal unit (Griscom et al. 2017). Scientifically rigorous but context-specific crediting frameworks are therefore needed (da Fontoura et al. 2024; Rossberg et al. 2024; Wauchope et al. 2024). Streit et al. (2025) treat market-based instruments as governance tools, arguing that indicators of transparency, permanence, and monitoring quality are as important as financial design. Moilanen and Lehtinen (2025) propose response functions and calibrated multipliers that tie credits to measurable gains in ecosystem function. Rossberg et al. (2024) suggests a phylogenetic-diversity metric to steer investment toward globally irreplaceable habitats, while Yan et al. (2024) call for multidimensional accounting that captures ecological, spatial, temporal, and socio-economic dimensions, critical in complex agricultural landscapes.

Novel metrics are advancing quickly. da Fontoura et al. (2024) introduce the Equivalent Biodiversity Area for richer ecological comparisons; Falconi-Lopez et al. (2024) show species-specific responses across forest-recovery stages, underscoring the need for nuanced credit rules; and Ribeiro et al. (2024) propose bioeconomic models that align native-species markets with rural livelihoods. At the same time, Wauchope et al. (2024) warn that vague biodiversity 'units' undermine integrity, and Lindenmayer et al. (2023) caution that poorly governed credit schemes could repeat the failures of lax carbon markets. Sangha et al. (2025) further highlight the absence of integrated frameworks for assessing social, ecological, and climate co-benefits in nature-based solutions.

4.5. Additional themes requiring deeper investigation

A final group of studies examines related instruments and sector-specific challenges that provide insights for the design and implementation of biodiversity markets.

4.5.1. Payments for ecosystem services

Studies on payment for ecosystem services (PES) programs highlight persistent knowledge gaps regarding their design, effectiveness, and long-term viability across diverse socio-ecological contexts, offering important lessons for the development and governance of biodiversity market mechanisms. For instance, Shen et al. (2025) show that Costa Rican farmers' sustained participation in PES schemes depends on institutional trust, perceived benefits, transaction costs, and alternative income options, yet the determinants of long-term engagement and dropout remain underexplored. Complementing this, Bingham et al. (2024) emphasise the lack of comparative evaluations of ecosystem service auctions, citing issues of low participation, limited cost-effectiveness, and misalignment with conservation goals. Admasu et al. (2024) propose a PES model connecting urban water users with upstream farmers, but overlook critical governance, equity, and verification components that determine effectiveness.

A global review by Le et al. (2024) finds that while environmental benefits of PES are often reported, evidence on social equity, economic viability, and permanence of outcomes remains uneven. These concerns are echoed by Vaissiere et al. (2020), who identify persistent conceptual confusion between PES and biodiversity offsets (BO), leading to misapplication in policy and enforcement. They call for diagnostic

frameworks to guide policymakers in selecting appropriate tools, grounded in legal and institutional context. Comparative case studies are needed to document successes and failures where PES and BO have been conflated.

Stakeholder perspectives also reveal significant gaps. Báliková et al. (2019) find broad support for forest-water PES across Eastern and Mediterranean Europe, yet evidence on biodiversity outcomes is limited, and buyer-seller asymmetries persist. Their study relies on stated preferences, lacking observed behavioural or ecological data. They recommend piloting integrated water – biodiversity credit schemes and testing governance models that incorporate local knowledge and collective action mechanisms to ensure equity and effectiveness.

Fletcher and Büscher (2020) propose Conservation Basic Income (CBI) as an alternative to market-based instruments like PES and REDD+,[1] yet provide no empirical evidence on its feasibility, implementation costs, or comparative performance. Pilot CBI programs could assess ecological, equity, and poverty outcomes, while political economy research could identify conditions for transition from conditional to unconditional conservation payments.

Further critiques highlight both theoretical and empirical blind spots. Kolinjivadi et al. (2019) critique PES as a neoliberal performance but lack ethnographic evidence showing how communities resist or reinterpret these framings. Future work could document situated forms of disobedience or reimagine PES as relational, rather than transactional, conservation tools. Similarly, Wang and Wolf (2019) suggest that targeted-PES schemes may work best where ecological and socio-economic disparities are high, but empirical testing across gradients of inequality is lacking. Pilot programs should assess their ecological impacts, distributional outcomes, and community acceptance.

Overall, the PES literature highlights persistent challenges relating to long-term participation, governance effectiveness, equity outcomes, and the durability of ecological benefits. Studies consistently emphasise the importance of institutional trust, stakeholder engagement, and context-specific design in shaping participation and program performance (Waylen and Martin-Ortega 2018; Báliková et al. 2019; Shen et al. 2025). At the same time, concerns remain regarding conceptual ambiguity between PES and biodiversity offsets, the adequacy of monitoring and verification systems, and the limited empirical evidence available to assess long-term social and ecological outcomes (Vaissiere et al. 2020; Le et al. 2024). Alternative approaches, including Conservation Basic Income and relational conservation models, further highlight ongoing debates regarding the role of market-based mechanisms in conservation governance (Kolinjivadi et al. 2019; Fletcher and Büscher 2020). Taken together, these studies suggest that effective PES schemes require robust governance arrangements, transparent valuation and monitoring systems, and greater attention to equity, behavioural responses, and long-term conservation outcomes.

4.5.2. Forest sector challenges

Research on forest-based environmental market instruments highlights challenges in aligning policy design with diverse socio-ecological contexts, ownership structures, and the motivations of forest managers. These studies emphasise that effective biodiversity and carbon payment schemes depend on governance arrangements that are credible, equitable, and adapted to local institutional conditions. This is particularly critical in addressing smallholder needs and tailoring instruments such as the High Conservation Value Forest (HCVF) framework to more flexibly balance carbon, biodiversity, and social equity goals (Assmuth et al. 2024; Abbasnezhad and Abrams 2025; Tzemi et al. 2025). Research to date has largely focused on willingness-to-accept metrics, with insufficient attention to willingness-to-pay, long-term behavioural outcomes, and mixed-method assessments of market performance (Bruzzese et al. 2023). There remains limited evaluation of forestry market instruments beyond local scales, leaving governance gaps and stakeholder satisfaction underexplored.

Assmuth et al. (2024) argue for advancing comparative policy studies that incorporate co-benefits and extend analysis to soil carbon, peatlands, and scalable blended-finance models. These are crucial for increasing uptake of forest-based climate solutions. Abbasnezhad and Abrams (2025) further highlight the importance of designing context-sensitive instruments, particularly for smallholders, while recognising the need for more inclusive valuation frameworks that capture ecological, economic, and cultural dimensions.

In the European Union, biomass demand continues to exert pressure on forests, yet current governance frameworks inadequately address these risks. Stubenrauch and Garske (2023) point to the lack of quantitative analysis linking biomass policies to ecological impacts, and the uncertain interaction between the proposed Nature Restoration Law and existing directives. They call for scenario modelling and comparative policy research to assess how restoration mandates and sufficiency-oriented tools could work in tandem across member states.

Sharma et al. (2023) highlight that Scottish woodland expansion has triggered power shifts toward private actors but lacks systematic evaluation of ecological additionality, equity outcomes, and fiscal implications. The interaction between green finance and state regulation is underexplored.

Corporate-led forestry initiatives also warrant closer scrutiny. D'amato et al. (2022) report that Nordic

forestry firms claim to implement 17 biodiversity measures, but these rely on self-reported data without independent ecological verification, cost–benefit analysis, or stakeholder input. The integration of newer instruments such as biodiversity offsets and green bonds with conventional practices remains poorly understood. The authors call for independent audits using landscape-scale indicators and econometric analyses to compare financial and ecological performance. Cross-ownership comparisons may reveal governance models that optimise both biodiversity and profitability.

Delabre et al. (2020) take a broader view, critiquing dominant 'myths' in global forest governance that reduce biodiversity markets to narrow, carbon-centric and voluntary supply-chain solutions. These frameworks often fail to verify ecological additionality, obscure power dynamics in rent capture, and marginalise Indigenous and local stewards through opaque metrics and elite-driven participation. However, they also identify opportunities: pairing market signals with strong regulation, embedding plural values (cultural, biophysical, social) in credit systems, and fostering inclusive governance coalitions that span public, private, and Indigenous actors. Empirical research testing such hybrid models, comparing ownership regimes, and mapping institutional power shifts could help transform biodiversity markets from technocratic fixes into more credible and just conservation tools.

Overall, the forest-sector literature suggests that the effectiveness of biodiversity and carbon market instruments depends on governance arrangements that are responsive to local contexts, supported by credible monitoring systems, and capable of balancing ecological, economic, and social objectives (Assmuth et al. 2024; Abbasnezhad and Abrams 2025; Tzemi et al. 2025). Across studies, recurring challenges include limited empirical evaluation, uncertainty regarding long-term ecological outcomes, and insufficient understanding of how different ownership structures, financing mechanisms, and governance models influence both environmental performance and benefit distribution (D'amato et al. 2022; Bruzzese et al. 2023; Sharma et al. 2023). The literature also highlights the importance of integrating biodiversity, carbon, and social co-benefits within more inclusive and transparent governance frameworks capable of addressing power asymmetries and supporting meaningful stakeholder participation (Delabre et al. 2020). These findings suggest that future biodiversity markets will require context-sensitive, multi-scalar approaches that combine rigorous ecological evaluation with adaptive governance and equitable benefit-sharing mechanisms.

Figure 7. Five-pillar governance framework. Policy and institutional architecture; inclusive governance and social equity; scientific integrity and monitoring; fit-for-purpose finance; place-based implementation. Together, these pillars support credible, equitable and scalable biodiversity-market outcomes in agricultural landscapes.

5. Discussion

The review demonstrates that biodiversity markets are evolving from narrowly focused offset mechanisms towards more diverse financial instruments that seek to support nature-positive outcomes across agricultural landscapes. Across the literature, five recurring dimensions emerged as critical determinants of effectiveness: policy coherence, inclusive governance, scientific integrity, financial design, and place-based implementation.

Equally critical is the integration of governance and financial architectures capable of delivering durable, equitable, and transformative conservation impacts. This includes ensuring transparent benefit-sharing mechanisms, place-based design, and financial innovation that improves access for smallholders and underrepresented actors. Collectively, the evidence suggests that scaling biodiversity markets is not solely a technical or financial endeavour. It is a deeply political and institutional challenge. Nonetheless, these studies offer an essential foundation for developing biodiversity market instruments that are not only ecologically effective, but also socially legitimate and politically viable.

Drawing on the recurring themes identified across the review, as well as the knowledge gaps and emerging opportunities highlighted in the literature, we propose an integrated five-pillar framework for equitable, scalable, and effective biodiversity markets (Figure 7). The framework was developed as an integrative synthesis of the governance, ecological, financial, and implementation challenges identified across the reviewed studies. The literature consistently highlights that effective biodiversity markets depend on social legitimacy, coherent and durable policy frameworks, ecological integrity and long-term permanence, and equitable, economically viable financial mechanisms. Accordingly, the framework is structured around five interdependent pillars that together represent the key dimensions required for the design and implementation of effective biodiversity market mechanisms.

- Pillar 1–Policy and institutional anchoring: establish a strong conceptual, legal and regulatory foundation that ensures coherence across sectors and governance levels. Clarify institutional mandates and build capacity at national, regional, and local scales. Align biodiversity markets with broader environmental, agricultural, and financial policies to enable cross-sectoral coordination and long-term legitimacy.
- Pillar 2–Inclusive governance: embed participatory governance structures that centre the rights and voices of Indigenous Peoples, local communities, agricultural industries and smallholders. Design and implement equity safeguards to ensure the fair distribution of benefits and responsibilities. Foster transparency, accountability, and trust through inclusive decision-making processes and accessible grievance mechanisms.
- Pillar 3–Scientific integrity and ecological credibility: ensure credibility through the development of robust, standardised, and context-sensitive ecological and social performance indicators. Support long-term monitoring systems that are cost-effective, multi-scalar, and technologically enabled, while also leveraging community-based approaches. Build adaptive management processes that allow markets to respond to changing conditions and emerging evidence.
- Pillar 4–Integrated finance mechanisms: mobilise diverse sources of capital through instruments such as blended finance, biodiversity and green bonds, and stacked credit schemes (e.g. carbon + biodiversity). Reduce transaction costs and improve access for underrepresented stakeholders, including small-scale landholders. Introduce fiscal incentives and payment mechanisms that reward verifiable conservation outcomes and ongoing stewardship.
- Pillar 5–Place-based implementation: adapt market instruments and governance strategies to reflect the specific ecological, cultural, and institutional conditions of each landscape. Integrate biodiversity markets with landscape-scale planning efforts, place-based approaches to natural capital accounting, property or farm-level reporting systems, and regional restoration planning. Promote landscape-level coordination of investment to maximise synergies across conservation, agriculture, and climate initiatives.

6. Conclusion

Biodiversity markets are receiving increasing attention as mechanisms to support conservation and nature-positive transitions. However, the evidence reviewed in this study suggests that their effectiveness depends on far more than the creation of tradable biodiversity assets. Without robust governance, scientific integrity, transparency, and equitable participation, biodiversity markets risk reproducing existing challenges, including limited ecological outcomes, social inequities, and declining public trust.

Drawing on the recurring themes identified across the literature, this review proposes a five-pillar framework encompassing policy and institutional anchoring, inclusive governance, scientific integrity, financial mechanisms, and place-based implementation. Together, these pillars provide an integrated foundation

for designing biodiversity markets that are credible, effective, and socially legitimate. The review further highlights the importance of embedding biodiversity markets within broader policy frameworks, recognising diverse knowledge systems, and ensuring that benefits are distributed fairly among stakeholders, including Indigenous Peoples, local communities, and landholders.

Future research should move beyond conceptual and preference-based studies toward empirical evaluations of ecological, social, and economic outcomes across different market contexts. Particular attention should be given to inclusive payment for ecosystem services models, governance arrangements, and long-term monitoring approaches that can strengthen both market credibility and conservation effectiveness.

Finally, it is important to acknowledge the limitations of this review. While the study focused on academic literature explicitly addressing biodiversity markets and closely related terms, the evolving and context-specific nature of terminology means that some other relevant works may inadvertently have been excluded. Moreover, bibliometric methods, while valuable for mapping research trends, tend to underrepresent grey literature, policy documents, and Indigenous knowledge systems that are vital to practice on the ground. Future reviews should incorporate a broader spectrum of interdisciplinary and non-academic sources to build a more holistic and inclusive understanding of this rapidly evolving field. This review synthesises published literature rather than primary evaluations; thus, claims regarding integrity risks reflect concerns documented across studies rather than new empirical testing.

Note

1. REDD+ is a framework under the United Nations Framework Convention on Climate Change (UNFCCC) aimed at reducing emissions from deforestation and forest degradation in developing countries.

Author contributions

CRediT: **Ana Carla Leite de Almeida:** Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing; **Allan Dale:** Writing – original draft, Writing – review & editing; **Rachel Hay:** Writing – original draft, Writing – review & editing; **Yvette Everingham:** Writing – original draft, Writing – review & editing; **Stewart Lockie:** Writing – original draft, Writing – review & editing.

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