Voluntary biodiversity credits:

Emerging concepts in managed forests

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Emerging concepts in managed forests

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Abstract

Biodiversity is rapidly declining worldwide, which threatens ecosystems that provide support for food production, clean water, and climate stability. A major challenge to protecting biodiversity is that there is insufficient funding for nature conservation and restoration. Approximately 30% of the global land area is covered by forests used for wood production. In Sweden and other European countries, these production forests are economically important and present valuable opportunities for biodiversity preservation, restoration, and sustainable management. However, without viable economic incentives that stewards how to best balance productivity with ecological integrity, declines in biodiversity will likely persist. Biodiversity credits are an innovative financial tool that can compensate private forest owners for their contributions to biodiversity enhancement to address funding gaps and encourage participation in conservation initiatives. By purchasing biodiversity credits, companies can fund initiatives such as forest restoration, habitat protection, and species conservation. This thesis reviewed biodiversity credits as a market-based mechanism to incentivize conservation and restoration efforts in production forests in a manner that aligns with policies such as the EU Nature Restoration Law. Clear regulatory frameworks and reliable verification systems are needed for biodiversity credit implementation to be successful. However, biodiversity credit design still needs to be optimized to sufficiently balance conservation, carbon sequestration, and wood production. Creation of a well-structured biodiversity credit market will allow Sweden and the EU to make nature conservation a financially viable and scalable solution to ensure that forests remain productive while retaining their rich biodiversity.

Keywords: Biodiversity credits, compensation of forest owners, European nature conservation policy, market-based financing of biodiversity, payment for economic services, production forests

Frivilliga biodiversitetskrediter inom naturvård: framväxande koncept och relevans för produktionsskogar

Abstrakt

Produktionsskogar, som balanserar ekonomisk produktivitet med ekologiska funktioner, erbjuder betydande möjligheter för bevarande, restaurering och hållbar förvaltning av biologisk mångfald. Biodiversitetskrediter ger en ram för att kompensera privata skogsägare för deras insatser för att förbättra biologisk mångfald, vilket bidrar till att fylla finansieringsgap och uppmuntra deltagande i bevarandeinitiativ. Denna studie granskar kunskapsläget om biodiversitetskrediter som en marknadsbaserad mekanism för att stimulera bevarande- och restaureringsinsatser i produktionsskogar, samtidigt som de anpassas till globala och EU-policyer, inklusive EU:s naturrestaureringslag. En framträdande kunskapslucka kvarstår gällande den optimala balansen mellan rundvirkesproduktion och koldioxidinlagring i relation till förbättrade biodiversitetsutfall, liksom i utformningen av effektiva biodiversitetskrediter.

Nyckelord: Marknadsbaserad finansiering av biologisk mångfald, biodiversitetskrediter, produktionsskogar, kompensation av skogsägare, europeisk naturvårdspolitik

Dedication

To my children, and their children, because we live on this Earth, for a future where prosperity and nature grow hand in hand.

Contents

List of publications

This thesis is based on the work contained in the following paper, referred to by Roman numerals in the text:

I. Holmlund A., Aguilar, F.X., Ågren, A.M. & Lundmark, T. (2025). Voluntary biodiversity credits in conservation: emerging concepts and a production forest perspective (submitted manuscript).

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Abbreviations

EU	European Union
ESG	Environmental, social, and governance
MRV	Monitoring, reporting, and verification
CSRD	Corporate Sustainability Reporting Directive
USAID	U.S. Agency for International Development

1. Introduction

Global economic pressures driven by population growth and rising welfare demands have led the ongoing loss of biodiversity—a phenomenon that varies spatially and temporally (Nabuurs et al. 2024). Biodiversity loss is driven by both indirect pressures, such as increasing population and food demand, and direct pressures including intensive agriculture, urbanization, invasive species, modifications to water regimes, unsustainable forestry practices, and illicit wildlife exploitation (Nabuurs et al. 2024). In production forests, which are managed primarily for timber and other forest products, maintaining biodiversity is crucial for long-term ecological resilience and sustainability. These forests can serve as reservoirs of genetic and species diversity, providing vital ecosystem services such as nutrient cycling, soil stabilization, and water regulation. Integrating biodiversity conservation into the management of production forests enhances their capacity to support native species and maintain ecological processes, while also ensuring that economic benefits are realized in a sustainable manner (Nabuurs et al. 2024).

Approximately 30% of the global land area, equivalent to around 4 billion hectares, consists of production forests (FAO & UNEP 2020; World Resources Institute 2024). Within the European Union (EU), only 4% of the total forest area of 160 million hectares remains unaffected by human activity, indicating that most forests have been shaped by management practices (European Parliament 2023). In Europe, and particularly in the Nordic countries, production forests hold both local and global economic significance due to their extensive contributions to industrial wood supply. Historical logging and habitat fragmentation have resulted in declines in biodiversity, with future environmental changes projected to have substantial and long-term impacts on mid- and high-latitude European forests (Pussinen et al. 2009). Despite these challenges, production forests are expected to remain vital for sustainable wood production, which plays a critical role in advancing a circular bioeconomy (Salvador et al. 2023).

At the same time, extensive empirical evidence demonstrates that production forests can function as critical habitats for threatened and endangered species, thereby contributing to biodiversity conservation and restoration through multiple pathways (Brockerhoff et al. 2008). Key opportunities to mitigate biodiversity loss include the preservation of

ecologically significant areas, the integration of biodiversity restoration into forest management practices through measures such as enhanced tree species diversification and the establishment of structural habitat features (e.g., retention of dead wood), and the refinement of forest management by combining sustainable forestry with targeted conservation strategies. This integrative approach has the potential to simultaneously advance biodiversity conservation objectives and sustain the economic viability of production forests and has been tested in Sweden through the "Swedish forestry model."

Sweden is one of the largest wood producers in the EU, contributing approximately 78 million m^3 to the total annual roundwood production of 510 million m^3 in 2010. Alongside Germany (79 million m^3) and Finland (67 million m^3), it ranks among the EU's leading producers (Eurostat 2023). The "Swedish forestry model" (Lindahl et al. 2017) plays a pivotal role in the country's forest policies, emphasizing sustainable forest management within a heavily forested, export-driven economy. Established following the 1993 revision of the Swedish Forestry Act, the model introduced dual objectives—maintaining environmental protection alongside high wood production. This policy shift granted forest owners greater autonomy under the principle of "freedom with responsibility," expecting them to integrate biodiversity conservation into forest management while sustaining timber yields. Shaped by Sweden's natural conditions, historical traditions, and a culture of consensus and compromise, the model has been widely recognized for its attempts to balance industrial forestry with environmental goals. However, it has faced significant criticism from environmental organizations and stakeholders, particularly for its strong production-oriented focus and its failure to meet key biodiversity conservation objectives. The ongoing debate highlights the need for improved policy measures and alternative financial incentives, such as biodiversity credits, to effectively align forestry with ecological sustainability.

Currently, there is a mismatch between existing policy goals and implementation measures, governance inefficiencies, and insufficient integration of biodiversity-enhancing management practices (Lindahl et al. 2017). While even-aged forest management has long provided stable wood yields and has widespread acceptance in boreal regions, limited attention has been given to alternative approaches that also support biodiversity, recreation, rural development, and ecosystem services. These gaps have resulted in a "lock-in" effect among forestry experts and managers,

restricting the adoption of multifunctional forest management practices (Angelstam et al. 2022).

Recent public discourse has increasingly advocated for a shift towards multipurpose forest management that can deliver diverse ecosystem and landscape services, including biodiversity conservation, climate adaptation, and carbon storage besides wood production. The transition to such a system, however, requires significant international regulatory or market-based pressures or robust societal demands from diverse stakeholders, including non-industrial forest owners. To achieve this transformation, forest owners must be compensated not only to prioritize wood production but also become ecosystem stewards and support functional green infrastructures that support adaptation to climate change and biodiversity conservation (Angelstam et al. 2022).

The objective of this licentiate thesis is to critically assess existing applications of Payment for Ecosystem Services (PES), including voluntary biodiversity credits, and determine how voluntary biodiversity credits can be leveraged to finance biodiversity conservation and restoration within production forests. By synthesizing global experiences, this study aims to develop strategies for adoption of voluntary biodiversity credits that align with the EU policy framework and are adaptable to the Swedish production forest context.

2. Methods

This study critically evaluated current applications of PES for biodiversity conservation and restoration in production forests, and elucidated how voluntary biodiversity credits can be utilized to further enhance these conservation and restoration efforts within managed forest ecosystems. The focus was to synthesize global experiences and insights to develop potential strategies that align with the EU policy framework. An integrative review approach was employed involving a systematic process (Linnenluecke et al., 2020; Sauer and Seuring, 2023) that included: (1) defining the research question; (2) formulating a search strategy with specific inclusion and exclusion criteria; (3) retrieving a sample of potentially relevant literature; (4) selecting pertinent studies; (5) synthesizing the findings; and (6) reporting the results. These steps are described below.

1) Defining the research question:
The objective of this literature review was to consolidate existing perspectives and assess the efficacy of various market-based financing mechanisms for biodiversity conservation in production forests, thereby fostering the development of new insights. The literature review answered the research question: *What lessons can be drawn from existing PES models to inform the development and advancement of biodiversity credits as a market-based tool for financing biodiversity conservation within production forests?*

2) Formulating a search strategy with specific inclusion and exclusion criteria:
To systematically identify literature on the potential of biodiversity credits as a financing mechanism for biodiversity conservation within production forests, a targeted search was conducted using the following search string:
(“payments for forest ecosystem services” OR “biodiversity credits” OR “financing of biodiversity conservation” OR “incentives for biodiversity conservation” AND “carbon credits” AND “forestry”).

This search string incorporated key terms and synonyms related to PES and biodiversity credits, specifically in the context of forest ecosystems and forest carbon credits. Forest carbon credits were included as a proxy for biodiversity credits due to the more advanced development of voluntary

forest carbon markets, which are informed by established scientific frameworks in the field.

3) Retrieving a sample of potentially relevant literature:
A systematic literature search was conducted using ScienceDirect, Web of Science, and CABI Digital Library. An initial search on 10 August 2024, utilizing a combined search string, yielded 424 results. To ensure comprehensive coverage and minimize the risk of omitting relevant literature, an additional search was performed using individual terms separately rather than in combination. The following terms were searched independently: "payments for forest ecosystem services," "biodiversity credits," "financing of biodiversity conservation," "incentives for biodiversity conservation," and "forest carbon credits."

This expanded search, conducted on 12 August 2024, returned 3,625 results across the same databases. After removing duplicates, all relevant publications were retained without further screening at this stage, resulting in a final dataset of 4,095 publications, combining the initial 424 results and the 3,625 from the independent searches. Additionally, 46 publications were identified outside the predefined search string. These publications, which were not captured by the automated search, were considered highly relevant to the subject area and included reports from grey literature, the EU, the World Bank, and other organizations.

4) Selecting pertinent studies:
The collected literature was evaluated against predefined selection criteria for inclusion in the final review. The criteria were:

(a) Eligible sources included reviews, research articles, reports, and books, whereas encyclopedia entries and editorials were excluded.
(b) Relevant disciplines were forest management, environmental sciences, and economics, whereas unrelated fields such as energy, engineering, and molecular biology were excluded.
(c) Only studies on market-based mechanisms for sustainable forest management or biodiversity conservation financing were considered.
(d) Only publications in English were included.

Titles and abstracts were initially screened, and relevant publications were further assessed for inclusion.

The review focused on biodiversity credits in production forests, covering credit design, voluntary initiatives, lessons from forest carbon markets, market characteristics, and EU policy context. Emphasis was placed on forest management, business adoption, and policy frameworks to ensure biodiversity credits are credible, scalable, and aligned with sustainability goals.

5) Synthesizing the findings:

The selected literature was thoroughly reviewed, key focus areas were identified, and relevant information was synthesized.

6) Reporting the results:

The findings from the literature review were analyzed, reported, and discussed.

3. Results

Since the 1990s, market-based financing instruments have been employed to support biodiversity conservation (Bonneuil 2015; Hrabanski 2015). These instruments include PES as well as more recent innovations such as biodiversity credits. Biodiversity credits—also known as biocredits, biodiversity certificates, nature credits, or nature tokens—enable the quantification and trading of biodiversity enhancements, allowing developers to offset losses with the goal of achieving a no net loss outcome (Zynobia et al. 2023). Historically, biodiversity offset schemes have been mandatory and closely tied to regulatory compensation policies. However, contemporary approaches have shifted toward voluntary mechanisms that not only compensate for losses but also generate additional, net-positive outcomes. Unlike conventional offsets, voluntary biodiversity credits focus on proactive biodiversity enhancement, aiming to surpass a baseline scenario and thus deliver tangible conservation benefits. In this context, voluntary biodiversity credits can be seen as a specialized subset of PES (Wunder et al. 2024), sharing core elements such as voluntary transactions, clearly defined environmental services, and contractual frameworks that involve at least one buyer and one provider with conditional service delivery (Wunder 2008).

A critical distinction between traditional PES schemes and voluntary biodiversity credits lies in their market functionality. While PES schemes do not necessarily depend on fully developed markets, voluntary biodiversity credits are intended to be traded under competitive market conditions. This presents challenges, as the spatial specificity of biodiversity can limit true market competition (Wunder 2008). Despite these challenges, recent initiatives have focused on establishing high-integrity and technically rigorous frameworks to stimulate a robust global market for these credits (Biodiversity Credit Alliance 2023).

Recent trends in the design of voluntary biodiversity credit schemes target outcomes such as protection, regeneration, ecological stewardship, and, in some cases, adaptation to climate change (Pollination Group 2023; International Advisory Panel on Biodiversity Credits 2024). Biodiversity assessments in these schemes typically employ two levels of metrics: ecosystem-level indicators that evaluate overall environmental conditions and habitat-level indicators that focus on specific species or ecological attributes (Pollination Group 2023; Biodiversity Credit Alliance 2024).

Credit issuance is linked to rigorous verification processes conducted over defined crediting periods, ensuring that only measurable and additional biodiversity gains are recognized. The credibility of these schemes relies on key principles such as additionality and permanence. Additionality ensures that credits represent biodiversity outcomes that would not have occurred without the intervention, whereas permanence guarantees that these outcomes endure over time. Furthermore, many schemes integrate benefit-sharing mechanisms to ensure that local stakeholders and traditional land stewards are recognized and rewarded for their conservation efforts (Biodiversity Credit Alliance 2024).

There are several emerging voluntary biodiversity credit programs (Taskforce on Nature Related Markets 2023; Zynobia et al. 2023; OPIS 2024), that fall into the following categories: private-sector led, charity-led or not-for-profit, government-led, and independent. Biodiversity credit programs vary in their stages of development, with some actively issuing and selling credits, while others are still in their early phases. A standardized unit of measurement for voluntary biodiversity credits has yet to be established, and differences in project methodologies make direct comparisons challenging. Moreover, none of the existing voluntary biodiversity credit schemes specifically focus on biodiversity conservation and restoration within production forests (Holmlund et al. 2025).

We analyzed key elements shaping the credibility and impact of voluntary biodiversity credits, leveraging insights from forest-based carbon credit markets. These markets highlight essential principles that can guide the development of robust and effective biodiversity credit frameworks. These principles include 1) payment structures, 2) additionality, 3) permanence, 4) leakage, 5) transparency, and 6) stakeholder governance:

1) Payment structures in carbon credit markets vary between action-based and outcome-based models. Action-based payments issue credits for planned interventions, such as deferred logging, whereas outcome-based payments require verifiable conservation results. Although outcome-based systems enhance credibility (Kim and Langpap 2015), they often demand significant upfront investments. A recommendation for voluntary biodiversity credit schemes is therefore to apply an outcome-based combined with annualized payment system that allows projects to be developed and traded

without requiring long-term commitments from sellers and buyers (Parisa et al. 2022).

2) Additionality remains a challenge (Fiegenbaum 2024; Wunder et al. 2024), as projects must prove they would not have occurred without credit revenue. Voluntary credit systems typically assess additionality at the project level; however, research shows that additionality tests and baselines should be scaled to jurisdictional level to improve efficiency (van Benthem and Kerr 2013).

3) Permanence is a key concern due to risks of carbon loss from harvesting or natural disturbances (Wunder et al. 2024). Current solutions include liability mechanisms, temporary crediting, buffer reserves, and insurance models (Gren and Aklilu 2016; Li and Zhang 2024). Research suggests, however, that the optimal contract design is close to zero fixed payment and almost all payment upon delivery of conservation results (Cordero Salas et al. 2013). This switches contractual liability from the buyer to the seller (MacKenzie et al. 2012).

4) Leakage, or the displacement of environmental impacts, threatens the credibility of carbon credits (Haya et al. 2023; Fiegenbaum 2024). Strategies to mitigate leakage involve either reducing demand for extractive activities or scaling interventions to a jurisdictional level. However, there is no consensus on how leakage is best addressed (Wunder et al. 2024).

5) Transparency is essential in private-sector climate investments (Trouwloon et al. 2023). Companies must differentiate between long-term commitments (e.g., net-zero goals) and already-achieved reductions (e.g., carbon neutrality). Biodiversity credit markets should follow the mitigation hierarchy, prioritizing avoidance, minimization, restoration, and offsetting only as a last resort (Maron et al. 2023).

6) Finally, stakeholder governance is crucial for equitable and effective conservation efforts (Tedesco et al. 2023). Governance frameworks must ensure fair benefit distribution, inclusive decision-making, and consideration of socio-economic conditions that affect participation. Weak governance—characterized by

information asymmetry, unstable payments, and lack of local engagement—can undermine trust and conservation outcomes.

By integrating these lessons, voluntary biodiversity credit schemes can enhance credibility, effectiveness, and scalability while aligning with conservation and sustainability goals.

The development of biodiversity credits aligns closely with existing EU policies on biodiversity conservation, sustainable forest management, and climate action, such as the EU Biodiversity Strategy for 2030 (European Commission 2024a), the Habitats Directive (European Commission 2024b), the European Green Deal (European Commission 2024c), the Nature Restoration Law (European Commission 2024d), the EU Forest Strategy (European Commission 2024e), and the EU Taxonomy for Sustainable Activities (European Commission 2024f). The Nature Restoration Law sets ambitious targets, requiring at least 20% of the EU's land and sea to be restored by 2030 and all degraded ecosystems be restored by 2050. It outlines measures such as rewetting peatlands, enhancing ecological features in forests, promoting natural regeneration, and improving habitat connectivity, all of which can be effectively supported by biodiversity credits as a financing tool. The EU Forest Strategy promotes sustainable forest management and financial incentives for conservation, creating a strong foundation for integrating biodiversity credit markets into forest policy. Similarly, the EU Taxonomy for Sustainable Activities recognizes only net biodiversity gains—not offsets—as qualifying for sustainability financing, reinforcing the credibility of voluntary biodiversity credits as a means to drive private investment in nature restoration. The Corporate Sustainability Reporting Directive, which took effect in 2023, mandates that companies disclose their environmental impacts, further incentivizing businesses to invest in nature-positive activities such as biodiversity credits. Despite the strong policy foundation, market-based biodiversity financing remains underutilized in Europe, with limited PES and biodiversity credit schemes (Sarvašová et al. 2019).

The EU has adopted a regulation for voluntary carbon removals (European Commission 2024), which could serve as a blueprint for a similar biodiversity credit framework. Recent policy discussions, including statements from EU leadership on "nature credits" (European Commission 2024g), suggest growing recognition of their role in achieving EU biodiversity and climate goals. Establishing a structured and transparent

biodiversity credit market would complement existing EU policies by mobilizing private sector investment to scale up conservation and restoration efforts across Europe.

4. Discussion

The urgent need for biodiversity conservation requires substantial financial resources. Current estimates place the global biodiversity financing gap between USD 36 billion and 7 trillion per year (Deutz et al. 2020; Anyago-van Zwieten 2021). Despite the scale of this challenge, over 80% of funding for nature restoration still originates from public sources, primarily government expenditures (Deutz et al. 2020; zu Ermgassen and Löfqvist 2024). Given the limitations of public funding, engaging the private sector to contribute to financing of biodiversity conservation and restoration efforts is imperative, particularly as private investment decisions often contribute to ecosystem degradation. Biodiversity is financially relevant for businesses. Research shows that biodiversity risk premium exists (Naffa and Czupy 2024) and that companies in sectors with high exposure to biodiversity-related risks face a biodiversity risk premium, implying that businesses may have financial incentives to mitigate their ecological footprint (Coqueret et al. 2023).

PES have been widely recognized as an effective market-based mechanism for biodiversity conservation, providing multiple benefits beyond ecosystem restoration, including economic support for local communities and increased social well-being. Despite policy support, the implementation of PES schemes in the EU remains limited. The creation of a robust PES market could enhance the valuation of ecosystem services, incentivizing conservation efforts while offering alternative revenue streams to landowners.

However, the implementation of biodiversity credits faces several challenges, including market feasibility, capital mobilization, and ecological effectiveness. Although market-based approaches have gained traction as potential solutions for financing conservation, they are often met with skepticism due to concerns over the commodification of nature and potential conflicts of interest, as financial incentives may prioritize investment returns over ecological integrity (Kedward et al. 2022). Additionally, uncertainties persist regarding the effectiveness of PES, with existing biodiversity offset programs in forested ecosystems failing to demonstrate clear no-net-loss outcomes for habitats or species. The lack of standardized long-term monitoring and baseline data further complicates the evaluation of biodiversity credit schemes, raising questions about their scalability and

reliability (Josefsson et al. 2021). Moreover, applying PES in production forest landscapes could introduce new externalities, such as reduced commercial wood supply, potentially diminishing the role of wood as a sustainable material. What is more, prioritizing biodiversity alone may have trade-offs, such as lower carbon sequestration due to changes in forest management practices (Capparos & Jacquemont 2003). Addressing the risks associated with PES schemes—such as concerns over additionality, permanence, and leakage—will be crucial to ensuring the credibility and effectiveness of biodiversity credit markets. Furthermore, standardizing biodiversity credit methodologies and verification processes will be essential to building investor confidence and enabling market scalability.

Biodiversity credits present a promising pathway for scaling conservation finance, drawing lessons from carbon credit markets. The successful application of market-based instruments for carbon sequestration demonstrates that externalities such as biodiversity conservation can be quantified (Mei 2023a) and traded (Dong-Ho et al. 2018), potentially offering premium incentives to forest owners (Mei 2023b). By diversifying income streams, these mechanisms create economic incentives to transition toward more varied forest management practices (Satake et al. 2008; Mei 2023b). Moreover, biodiversity credits have the potential to integrate seamlessly into corporate sustainability strategies, as businesses increasingly seek solutions that mitigate their ecological footprint while aligning with evolving regulatory frameworks.

Production forests, which constitute a significant portion of Europe's managed landscapes, represent an untapped opportunity for biodiversity conservation and restoration. However, existing biodiversity credit frameworks do not sufficiently address biodiversity uplifting within these working landscapes. Some schemes even prohibit monocultures within project areas, disregarding the fact that production forests can provide critical habitat for certain species and contribute to biodiversity uplifting through sustainable management practices. The integration of biodiversity uplifting into production forestry aligns well with existing EU policies, such as the EU Biodiversity Strategy for 2030 and the Nature Restoration Law. These policies advocate for multifunctional landscapes that deliver a broad range of ecosystem services, including biodiversity enhancement, climate adaptation, and carbon storage. However, achieving these objectives requires significant regulatory or market-based incentives that transform forest

managers into ecosystem stewards who are responsible for implementing biodiversity uplifting measures within economically viable frameworks.

Moreover, individual forest owners manage a significant portion of Europe's forests and must be considered in biodiversity credit market development. In Sweden, for example, approximately 50% of forest land is privately owned by individuals, which is a relatively high share in the European context (Sténs and Mårald 2020). Given this ownership structure, ensuring the participation of smallholder forest owners is crucial for creating an effective and inclusive biodiversity credit market. However, their involvement in such credit systems is not straightforward. The transaction costs associated with credit certification and monitoring can be prohibitively high, making participation difficult for smaller forest owners. A biodiversity credit system must therefore be both scientifically robust and practically feasible, ensuring that the costs of project development do not exclude smaller landowners. To create an effective and inclusive market, mechanisms must be in place to reduce administrative burdens and financial barriers while maintaining ecological integrity and financial viability.

Our review highlights the potential for biodiversity credits to complement existing EU policy goals while providing financial incentives for conservation. A major opportunity lies in establishing jurisdictional-level additionality tests and standardized baseline recommendations within the EU framework, enabling scalability and trust in biodiversity credit markets. Furthermore, integrating biodiversity credits into the EU Taxonomy for Sustainable Activities and corporate sustainability reporting frameworks could drive greater investment by aligning conservation finance with broader environmental, social, and governance (ESG) goals.

5. Concluding Results

The Swedish forestry model is often praised for balancing wood production with environmental concerns through integrative forest management and voluntary set-asides. However, this approach has a fundamental flaw: biodiversity conservation in managed forests has primarily been developed through restrictions on forestry practices rather than through positive economic incentives. While certification systems such as PEFC and FSC exist, the potential price premiums they offer do not fully cover the increased costs of adapting forest management to meet certification requirements. As a result, forest owners continue to be financially rewarded almost exclusively for timber production, while biodiversity conservation remains largely an uncompensated burden.Without a viable market for nature conservation, biodiversity protection will continue to be deprioritized in commercial forestry.

The lack of a biodiversity market stands in stark contrast to the well-established market for wood. If biodiversity credits were introduced as a complementary financing mechanism, they could enable forest owners to integrate conservation into their management practices without sacrificing economic viability. The key finding of this thesis is that production forests already incorporate conservation values to some extent, but financial constraints limit their full potential. Future research should explore how biodiversity credits could unlock greater biodiversity gains within production forests, providing a market-driven solution to halt biodiversity decline and evaluate the trade-offs between biodiversity conservation, carbon sequestration, and timber production while maintaining productive forestry landscapes.

The design of biodiversity credit mechanisms must not only deliver measurable ecological benefits but also ensure financial viability for landowners and investors. Policymakers play a crucial role in providing regulatory clarity, fostering investor confidence, and establishing transparent monitoring, reporting, and verification (MRV) frameworks to ensure the long-term credibility of biodiversity credit markets. The evolving regulatory landscape in the EU underscores the need for scalable, voluntary biodiversity credit markets. Although recent changes to the Corporate Sustainability Reporting Directive (CSRD) through the new European Commission Omnibus Bill (European Commission 2025) have reduced the number of

companies required to disclose biodiversity-related risks, they have also reinforced the importance of voluntary market-driven nature investments. The confirmation of the double materiality principle ensures that large corporations must continue to assess both their impacts on biodiversity and the financial risks associated with ecosystem degradation. Moreover, limitations on supply chain due diligence requirements may incentivize companies to adopt nature-based risk mitigation strategies, particularly in forestry and land-use sectors. These regulatory shifts present both challenges and opportunities for biodiversity finance. On one hand, delayed mandatory reporting may slow the adoption of compliance-driven biodiversity credit purchases. On the other, the increasing role of stakeholder-driven ESG commitments is likely to bolster voluntary biodiversity investments. Institutional investors, particularly in the EU, will continue to demand transparency and nature-positive strategies from corporations, reinforcing the need for high-integrity biodiversity credit mechanisms.

The current geopolitical landscape poses significant challenges to increasing government funding for biodiversity conservation. Recent international efforts, such as the United Nations biodiversity conference (COP16) held in Rome, have aimed to address the biodiversity financing gap, which is estimated to require between USD 722 billion to USD 967 billion annually. At COP16, over 140 countries agreed on a plan to mobilize only USD 200 billion annually by 2030 to protect nature. However, the establishment of a dedicated biodiversity fund has been postponed until 2028, reflecting ongoing disagreements between wealthier and developing nations regarding funding mechanisms (Euronews 2025). Additionally, the dismantling of agencies like the U.S. Agency for International Development (USAID) under recent administrative changes has led to the cessation of various conservation projects in regions such as South America. This shift raises concerns about the continuity of funding for biodiversity initiatives, particularly those supporting vulnerable communities (Maisonnave 2025). These developments underscore the diminishing likelihood of increased government funding for biodiversity conservation in the near term. Consequently, there is an urgent need to explore alternative financing mechanisms, including the mobilization of private capital, to bridge the substantial biodiversity financing gap and ensure the implementation of effective conservation strategies.

Sweden, despite its strong environmental commitments, risks falling behind in biodiversity credit market development. Without clear regulatory support and stronger incentives for private sector engagement, Sweden and other EU nations could miss a critical opportunity to lead the global transition toward nature-positive forestry as well as finance. The emergence of biodiversity credits as a scalable market solution presents a major investment opportunity that should be actively supported by policymakers to bridge the biodiversity financing gap and drive large-scale ecological restoration. By fostering a well-structured and transparent biodiversity credit market, Sweden and the EU can position themselves as pioneers in integrating economic growth with nature conservation, ensuring that sustainable land management becomes a cornerstone of future forestry practices. Government intervention should focus on enabling private investment by establishing clear guidelines for biodiversity credit markets, creating risk-sharing mechanisms, and ensuring the long-term viability of nature-based financial instruments.

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Popular science summary

Biodiversity is declining at an alarming rate worldwide, threatening ecosystems that support food production, clean water, and a stable climate. Although much focus is placed on fighting climate change, the loss of species and habitats is an equally pressing crisis. A major challenge is that nature conservation lacks sufficient funding—governments alone cannot cover the costs. Biodiversity credits offer an innovative financial tool to involve private investors and businesses in conservation efforts. Biodiversity credits function as a market-based solution that allows companies to invest in projects that enhance and restore ecosystems. Similar to carbon credits, they provide a way to finance conservation efforts while offering businesses an opportunity to demonstrate their commitment to sustainability. By purchasing biodiversity credits, companies can fund initiatives such as forest restoration, habitat protection, and species conservation.

Forests used for timber production cover about 30% of the global land area. In Sweden and other European countries, these forests are vital to the economy, but they also play an important role in maintaining biodiversity. The Swedish forest management model aims to balance wood production with environmental goals, but a fundamental flaw exists: forest owners are only financially rewarded for wood production, not for conserving nature. This creates a system in which conservation is often deprioritized in favor of logging. Current conservation measures, such as forest certification and voluntary set-asides, do not fully compensate landowners for income lost when prioritizing biodiversity. Without a market for biodiversity conservation, the decline in species and habitats will likely continue. Biodiversity credits offer a potential solution by providing financial incentives for forest owners to integrate conservation into their management practices.

Many international policies, including the EU Biodiversity Strategy for 2030 and the Nature Restoration Law, emphasize the need for private sector involvement in conservation. Despite this, Sweden lacks a structured biodiversity credit market, putting it at risk of falling behind in the global transition toward nature-positive finance. With global biodiversity funding gaps ranging from USD 36 billion to 7 trillion annually, private capital must step in where government funding falls short. The recent geopolitical landscape makes it unlikely that governments will significantly increase

conservation funding in the near future. Biodiversity credits represent a major investment opportunity by aligning financial incentives with ecological restoration.

For biodiversity credits to succeed, clear regulatory frameworks and trustworthy verification systems are essential. Further research is needed to explore how biodiversity credits can be best designed to benefit both nature and landowners while balancing conservation, carbon sequestration, and timber production.

By creating a well-structured market for biodiversity credits, Sweden and the EU can lead the way in making nature conservation a financially viable and scalable solution, ensuring that forests remain both productive and rich in biodiversity for generations to come.

Populärvetenskaplig sammanfattning

Den biologiska mångfalden minskar i alarmerande takt världen över och hotar de ekosystem som är avgörande för livsmedelsproduktion, rent vatten och ett stabilt klimat. Samtidigt som klimatförändringar får stor uppmärksamhet, är förlusten av arter och livsmiljöer en lika akut kris. En av de största utmaningarna är bristen på finansiering för naturvård - statlig finansiering kan inte ensam täcka kostnaderna. Biokrediter erbjuder ett innovativt ekonomiskt verktyg som gör det möjligt för privata investerare och företag att bidra till bevarandet av biologisk mångfald.

Biokrediter fungerar som en marknadsbaserad lösning där företag kan investera i projekt som skyddar och återställer ekosystem. Liknande koldioxidkrediter ger de möjlighet för företag att finansiera naturvårdsinsatser samtidigt som de kan visa sitt engagemang för hållbarhet. Genom att köpa biokrediter kan företag stödja initiativ såsom skogsrestaurering, skydd av livsmiljöer och bevarande av hotade arter.

Produktionsskogar täcker cirka 30 % av världens landyta. I Sverige och andra europeiska länder är dessa skogar viktiga för ekonomin, men de spelar också en central roll i att bevara den biologiska mångfalden. Den svenska skogsbruksmodellen syftar till att balansera virkesproduktion med miljömål, men en grundläggande brist i systemet är att skogsägare, generellt sett, får ekonomisk ersättning för virkesproduktion – inte för naturvård. Detta skapar ett system där bevarandeinsatser ofta prioriteras ned till förmån för avverkning. Nuvarande naturvårdsåtgärder, såsom skogscertifiering och frivilliga avsättningar, kompenserar inte skogsägare fullt ut för den inkomst de förlorar när de prioriterar biologisk mångfald. Utan en fungerande marknad för naturvård riskerar art- och habitatförluster att fortsätta. Biokrediter kan vara en lösning genom att erbjuda ekonomiska incitament för skogsägare att integrera bevarandeinsatser i sitt skogsbruk.

Många internationella policyramverk, inklusive EU:s biodiversitetsstrategi för 2030 och naturrestaureringslagen, lyfter fram behovet av privat finansiering för naturvård. Trots detta saknar Sverige en fungerande marknad för biokrediter, vilket kan leda till att vi halkar efter i den globala omställningen mot naturpositiv ekonomi. Med ett globalt finansieringsgap för biologisk mångfald på mellan 36 miljarder och 7 biljoner USD per år, måste privat kapital spela en större roll där offentliga medel inte räcker till. Den nuvarande geopolitiska situationen gör det

osannolikt att regeringar kommer att öka sin finansiering av naturvård i någon större utsträckning. Biokrediter representerar därför en betydande investeringsmöjlighet, där ekonomiska incitament kan kopplas samman med ekologisk restaurering.

För att biokrediter ska bli framgångsrika krävs tydliga regleringar och trovärdiga verifieringssystem. Vidare forskning behövs för att undersöka hur biokrediter bäst kan utformas för att gynna både naturen och markägarna, samtidigt som man balanserar bevarande, koldioxidinlagring och virkesproduktion.

Genom att skapa en välfungerande marknad för biokrediter kan Sverige och EU ta ledningen i att göra naturvård ekonomiskt hållbart och skalbart, vilket säkerställer att skogarna förblir både produktiva och artrika för kommande generationer.

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I

Voluntary biodiversity credits: emerging concepts and a European production forest perspective

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Abstract
Production forests, which balance economic productivity with ecological functions, present significant opportunities for biodiversity preservation, restoration, and sustainable management. Biodiversity credits offer a framework to compensate private forest owners for their contributions to biodiversity enhancement, addressing funding gaps and encouraging participation in conservation initiatives. This study reviewed the state-of-knowledge on biodiversity credits as a market-based mechanism to incentivize conservation and restoration efforts in production forests while aligning with global and European Union policies, including the European Union Nature Restoration Law. A salient gap remains in the understanding of an optimal balance between financial production and carbon sequestration with improved biodiversity outcomes, as well as in efficient biodiversity credit design.

Keywords
Market-based financing of biodiversity, biodiversity credits, production forests, compensation of forest owners, European nature conservation policy

1. Introduction

Human-caused losses of natural habitats have severe consequences for global biodiversity and other life-supporting ecosystem services (Pereira et al., 2012). Biodiversity experts estimate that half of the Earth's land surface has undergone such extensive alteration by human activities that it is no longer identifiable as "natural" habitat (Obura, 2023). Some estimates indicate that approximately 30% of species globally have been threatened or driven to extinction since the 1500s (Isbell et al., 2023). However, some experts argue that the true magnitude of biodiversity loss and its impacts on ecosystems may be even more substantial. The question of how to support and enhance biodiversity, ecosystem services, and the ecological functions of forests has become a central topic among policymakers and scientists (Maier et al., 2021).

Despite ongoing global and national conservation initiatives, the predominant anthropogenic drivers of biodiversity decline persist (Jaureguiberry et al., 2022), notably encompassing agriculture, aquaculture, forestry, fisheries, and the introduction of invasive alien species (IPBES, 2019). These factors can contribute to continued environmental degradation, and ultimately lead to a new ecological state (de Lima et al., 2016; Isbell et al., 2015; Martinez-Harms et al., 2017). There are consequential and substantial economic losses associated with a state that no longer provides essential ecosystem services (Kumar et al., 2024), with an estimated annual cost of about 2.7 trillion USD; this could potentially reduce the global GDP by 2.3% between 2021 and 2030 (Johnson et al., 2021).

Multilateral initiatives have been launched to address biodiversity loss, including the Convention on Biological Diversity (Convention on Biological Diversity, 2022) and the UN Sustainable Development Goals (United Nations, 2025). Efforts to conserve remaining biodiversity hotspots have used both regulated and market-based instruments. Command-and-control interventions, such as the designation of conservation areas, represent one approach through which multilateral initiatives have been used to safeguard critical ecosystems. Moreover, a growing trend involves using market-based instruments, including voluntary mechanisms like

biodiversity credits. This emerging approach shows promise by aligning conservation goals with economic incentives, potentially broadening participation and impact, which was highlighted during the UN Biodiversity Conference (COP15) in Montreal in December 2022 (Taskforce on Nature Related Markets, 2023). The need for innovative financing schemes to halt and prevent biodiversity loss was specifically addressed; in particular, biodiversity credits were emphasized (Convention on Biological Diversity, 2022).

Here, through an integrative review of literature and subsequent analyses, we aim to assess the state of knowledge and advance conceptual understandings of payments for ecosystem services (PES) in the context of biodiversity credits as a voluntary market-based tool designed to compensate private forest landowners. Implications emerging from this review focus on production forest areas designated primarily for the supply of material wood products, bioenergy, and non-wood forest products (FAO, 2010). We provide insights into the application of biodiversity credits to advance the sustainable management of production forests, while retaining their important role in wood production. In the following sections, we define voluntary biodiversity credits, critically evaluate their potential applications to mitigate and reverse biodiversity loss, and describe pivotal characteristics for a voluntary biodiversity credit system. We propose an approach for their implementation in European production forests.

2. Methods

A systematic literature review was performed to critically evaluate existing applications of PES in the context of biodiversity conservation and restoration within production forests. This study focused on synthesizing global experiences and insights to advance these approaches, with the ultimate goal of formulating potential applications aligned with the existing European Union (EU) policy framework. Therefore, an integrative review approach was employed (Snyder, 2019).

We completed six steps in the literature review (Linnenluecke et al., 2020; Sauer and Seuring, 2023) as follows:

1) *Defining the research question*: The aim of the literature review was to synthesize existing perspectives and evaluate the effectiveness of various market-based financing instruments for biodiversity conservation in production forests to facilitate the emergence of new perspectives. The literature review answered the research question: *What lessons can be drawn from existing PES models to inform the development and advancement of biodiversity credits as a market-based tool for financing biodiversity conservation within production forests?*

2) *Defining the search string and identifying the inclusion and exclusion criteria:* To identify literature on the potential of biodiversity credits as a tool for financing biodiversity conservation within production forests, we developed the following search string:

   (“Payments for forest ecosystem services” OR “biodiversity credits” OR “financing of biodiversity conservation” OR “incentives for biodiversity conservation” AND “carbon credits” AND “forestry”)

The search string consisted of terms and synonyms for PES and biodiversity credits related to forest ecosystems and forest carbon credits. Forest carbon credits were considered a proxy for biodiversity credits because of the more advanced development of voluntary forest carbon credit markets (Blanton et al., 2024; Pollination Group, 2024), which are informed by established scientific insights in the field.

3) *Retrieving a sample of potentially relevant literature:*
Using ScienceDirect, Web of Science, and CABI Digital Library, an initial search conducted on 10 August 2024 using a combined search string returned 424 results. To ensure comprehensive coverage and avoid missing relevant literature, an additional search was performed using individual terms separately rather than simultaneously. The following terms were searched independently: "payments for forest ecosystem services," "biodiversity credits," "financing of biodiversity conservation," "incentives for biodiversity conservation," and "forest carbon credits."

   This expanded search, conducted on 12 August 2024, yielded a total of 3,625 results across the same databases. After removing duplicates, all relevant publications were retained without additional screening at this stage, resulting in a final dataset of 4,095 publications, comprising the 424 results from the initial search and the 3,625 results from the independent term searches.

   Additionally, 46 publications were identified outside the search string; these publications were not captured by the search string but were deemed important for the subject area, such as reports from grey literature, the EU, World Bank, and other organizations.

4) *Selecting the pertinent literature:* The sample of the relevant literature was subsequently evaluated against the predefined selection criteria to identify the final review. We had four selection criteria for inclusion being: (a) Eligible studies included reviews, research articles, reports, and books; encyclopedia entries and editorials were excluded; (b) Relevant subject disciplines encompassed forest management, environmental sciences, and economics. Studies were excluded from unrelated fields, including energy, engineering, agricultural and biological sciences, veterinary sciences, biochemistry, genetics and molecular biology, business management and accounting, and earth and planetary sciences; (c) Only articles specifically related to market-based mechanisms supporting sustainable forest management or market-based financing of biodiversity conservation were included; (d) Only articles published in English were included.

   The selection process for relevant publications included an initial screening of titles and abstracts. Publications that met the defined selection criteria were then further evaluated for relevance and, if found to match the selection criteria, included in the literature review (Figure 1).

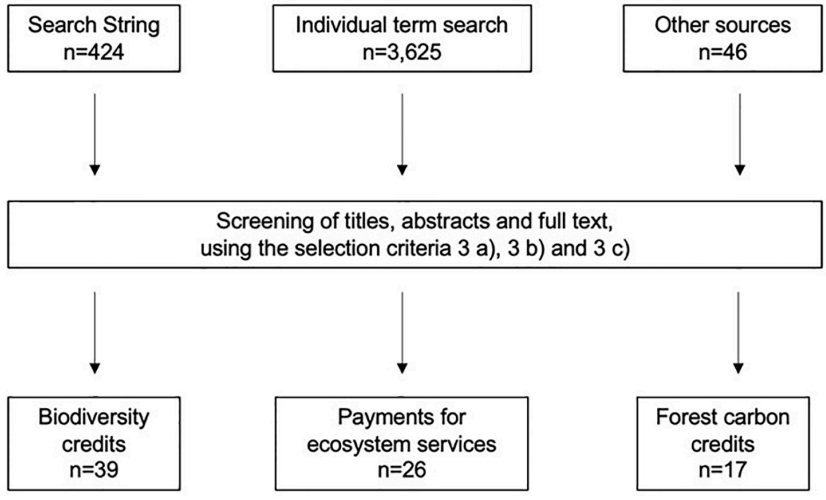

Fig. 1. Illustrative overview of the retrieval and selection process of publications included in this literature review.

The selection criteria were chosen to retrieve information relevant to applications of biodiversity credits in the context of production forests (Table 1). Focus areas included design of biodiversity credits, examples of already existing voluntary biodiversity credit initiatives, lessons from forest carbon credits, market characteristics for voluntary biodiversity credits, and voluntary biodiversity credits in the context of EU policies. Emphasis was placed on forest management applications, business adoption, and policy frameworks to ensure biodiversity credits are credible, scalable, and aligned with sustainability goals.

Table 1. Information extracted from articles that met selection criteria.

Focus area	Retrieved information
1. Design of biodiversity credits (see 3.1)	▪ Definition and conceptualization ▪ Theoretical foundations and models ▪ Important building blocks to ensure governance and credit integrity and manage risks in projects
2. Examples of voluntary biodiversity credit initiatives (see 3.2)	▪ Description of existing voluntary biodiversity credit schemes ▪ Successes, challenges, and lessons learned from past implementations (also including forest carbon credits) ▪ Examples of use in forest management and forest management applications ▪ Protocols for monitoring and reporting carbon and biodiversity credit transactions

3. Lessons from forest carbon credits (3.3)	▪ Lessons learned from past implementations of forest carbon credits
4. Market characteristics for voluntary biodiversity credits (see 3.4)	▪ Mechanisms for trading voluntary carbon and biodiversity credits in markets ▪ Economic valuation methods applied to assess the monetary value of carbon and biodiversity credits ▪ Examples and recommendations for use by businesses
5. Voluntary biodiversity credits in the context of EU policies (see 3.5)	▪ Existing EU policies governing biodiversity credits

5) *Synthesizing the literature:* The selected literature was read in-depth, the focus areas identified, and retrieved information synthesized.

6) *Reporting of results:* The results of the literature review were then reported and discussed.

3. Results

3.1 Design of forest biodiversity credits

Market-based financing instruments for biodiversity conservation are not a new concept; they have been tested and implemented since the 1990s (Bonneuil, 2015; Hrabanski, 2015). PES and PES-like schemes, including biodiversity credits, are used worldwide (Wunder et al., 2024). Biodiversity credits are frequently associated with U.S. wetland mitigation, species banking, and Australia's biodiversity offset system. These credits allow developers to compensate for biodiversity losses with the goal of achieving at least 'no net loss.' Credits represent quantifiable units denoting biodiversity improvement that are traded through offset transactions, enabling buyers to claim biodiversity gains to offset their losses. Historically, most offsets have been mandatory (Koh et al., 2019) and linked to regulatory compensation policies (Wunder et al., 2024).

Biodiversity credits, also known as “biocredits,” “biodiversity certificates,” “nature credits,” or “nature tokens” (Zynobia et al., 2023), have recently been highlighted as an innovative nature-financing instrument (Convention on Biological Diversity, 2022). Companies are increasingly seeking to achieve “nature-positive” outcomes that go beyond simply compensating for losses, setting these voluntary biodiversity credits apart from traditional offsets. Voluntary biodiversity credits aim to provide additional protection and conservation benefits that actively enhance biodiversity; this differs from offsets, which compensate for a loss elsewhere (Wunder et al., 2024). Biodiversity credits may thus be defined as “biodiversity gains that are not associated with a loss elsewhere” (NatureFinance, 2023a) and are therefore labeled as “voluntary” (Porras and Steele, 2020). Another notable definition of such voluntary biodiversity credits is “a certificate that represents a measured and evidence-based unit of positive biodiversity outcome that is durable and additional to what would have otherwise occurred” (Biodiversity Credit Alliance, 2024a). Going forward, we will focus on voluntary biodiversity credits.

PES and voluntary biodiversity credits share many similarities, and voluntary biodiversity credits are in essence a PES (Wunder et al., 2024). According to Wunder (2008), PES include five critical elements: a voluntary transaction, a well-defined environmental service, at least one buyer, at least one provider effectively controlling service provision, and conditionality requiring the environmental service provider to secure service provision. PES have been applied for conservation, restoration, and creation of new environmental services, specifically carbon sequestration, watershed management, biodiversity, and landscape beauty. PES sellers can include states, municipalities, private companies, NGOs, and the public sector and be at local, regional, or national levels (Wunder, 2008).

One key distinction between PES and voluntary biodiversity credits is that PES generally do not require functioning markets, whereas voluntary biodiversity credits are intended to be traded under true market conditions, characterized by a diverse and competitive supply and demand environment. This is feared to be difficult to achieve for voluntary biodiversity credits as biodiversity is considered too spatially specific to support true market competition (Wunder, 2008). However, there have been contemporary efforts to stimulate a worldwide market for

voluntary biodiversity credits, spearheaded by the Biodiversity Credit Alliance (Biodiversity Credit Alliance, 2023) and International Advisory Panel on Biodiversity Credits (International Advisory Panel on Biodiversity Credits, 2024).

Since 2023, voluntary biodiversity credit schemes have evolved rapidly, with increasing awareness and strong support for the development of high-integrity and technically rigorous frameworks on a global scale (International Advisory Panel on Biodiversity Credits, 2024; Pollination Group, 2023). Key trends related to scheme design (Fig. 2) have been detected and showed that components that should be considered because they produce targeted outcomes include 1) protection, 2) regeneration, 3) stewardship (i.e., maintenance of ecological value), and in some examples also 4) adaptation (e.g., in relation to climate change) (Biodiversity Credit Alliance, 2024a; Pollination Group, 2023). Existing schemes employ various approaches to inferring biodiversity metrics (Table 2) that are typically either: 1) ecosystem-level metrics, which generally involve tracking a suite of indicators for an entire ecosystem, or 2) habitat-level metrics, which are usually tailored to specific indicators relevant to particular species of flora or fauna (Biodiversity Credit Alliance, 2024a; International Advisory Panel on Biodiversity Credits, 2024; Pollination Group, 2023). Credit issuance is generally connected to verification of achieved outcomes during a defined crediting period (International Advisory Panel on Biodiversity Credits, 2024; Pollination Group, 2023).

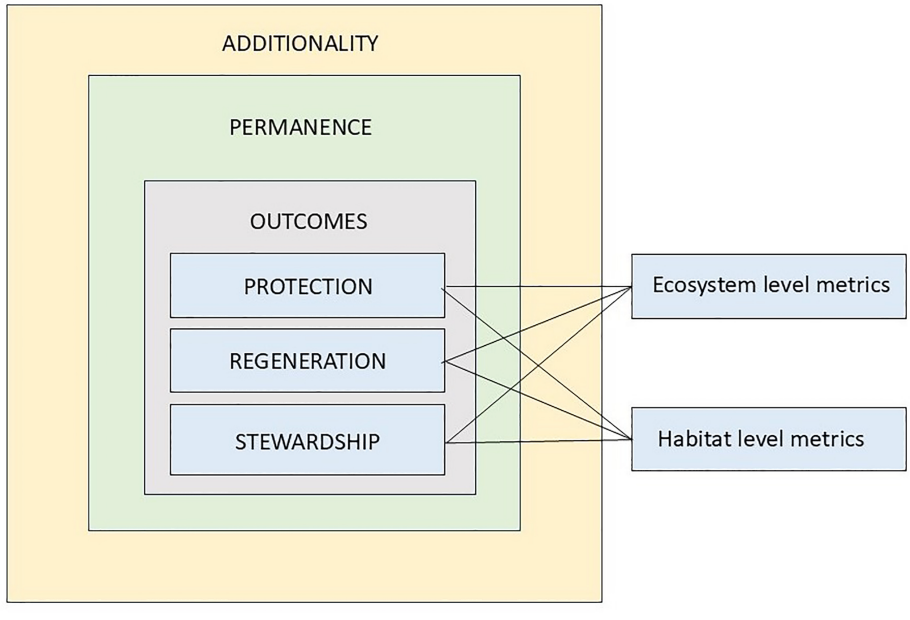

Fig. 2. Key components of a voluntary biodiversity credit scheme design.

Another key component of voluntary biodiversity schemes includes additionality and permanence considerations. Additionality means "a requirement that credits can only be assigned to biodiversity outcomes that are attributable to the project intervention, and would not have otherwise happened" (Biodiversity Credit Alliance, 2024a), and permanence addresses "the ability of a project to ensure that biodiversity outcomes on which credits are based are likely to endure for an extended period" (Biodiversity Credit Alliance, 2024a). Many biodiversity credit schemes also address benefit-sharing mechanisms, which ensure that customary rights holders and stakeholders are recognized and rewarded for their role as nature stewards (Biodiversity Credit Alliance, 2024a).

3.2 Examples of voluntary biodiversity credit initiatives

Globally, there have been several attempts to create, support, and regulate voluntary biodiversity credit markets with numerous private sector programs emerging globally, as shown in Table 2. The private sector programs are at varying stages of development and target corporations for implementation (Pollination Group, 2023). Additionally, the governments of Australia (Australian Department of Climate Change, Energy, the Environment and Water, 2025) and Niue (Niue Ocean Wide, 2024) are already at the early stages of market development, whereas New Zealand (Aotearoa New Zealand Ministry for the Environment, 2022) has taken substantial steps toward establishing a national voluntary biodiversity credit market.

There is a need to better understand beneficiaries' willingness to pay for voluntary biodiversity credits (Obeng et al., 2018). Several entities are seeking to provide market guidance on the quality and integrity of voluntary biodiversity credits as well as guidance on the appropriate use of voluntary biodiversity credits by buyers. Examples of such entities are the World Economic Forum (World Economic Forum, 2024), the Biodiversity Consultancy (The Biodiversity Consultancy, 2022), the Biodiversity Credit Alliance (Biodiversity Credit Alliance, 2024b), NatureFinance (NatureFinance, 2023b), Plan Vivo (Barisa et al., 2024), and Verra (Verra, 2024a).

Table 2. Main characteristics of emerging voluntary biodiversity credit programs, adapted from the Taskforce on Nature Related Markets (2023), Zynobia et al. (2023), and OPIS (2024).

Type (private, charity/not for profit, government, independent)	**Name**	**Country**	**Phase (development, pilot, or operational)**	**Unit of biodiversity**	**Reported price (publicly available)**
Private sector-led	Credit Nature	United Kingdom	Operational (2024)	Nature impact token; a metric that measures uplift in ecosystem integrity produced by regenerative land practices in defined areas	Price according to project cost. Existing project prices vary between 2,700 GBP/ha to 19,950 GBP/ha

	Earthly	United Kingdom	Operational (2024)	9 m^2 parcel of land abiding by Biodiversity Net Gain methodology according to the DEFRA metric	52.43 GBP/credit
	GreenCollar, NaturePlus™ Credits	Australia	Operational (2023)	Nature plus credit; 1 ha of measured and verified restoration or conservation	Information not public or available
	SouthPole, EcoAustralia™	Australia	Operational (2023)	Australian biodiversity unit (ABU); 1.5 m^2 of protected land delivering biodiversity outcomes for Australian flora and fauna species	Information not public or available
	Wilderlands	Australia	Operational (2022)	Biological diversity unit (BDU); protection of 1 m^2 of high-strategic-value conservation land	3–10 AUD/unit
	Savimbo	United States	Operational (2023)	Biodiversity credit; 60 days of presence of a designated indicator species on 1 ha	10 USD/credit (Savimbo, 2024)
	Terrasos	Colombia	Operational (2020)	10 m^2 conserved/restored for at least 20 years	25 USD/credit
	Ekos	New Zealand	Pilot (2022)	Sustainable development unit; based on UN's Sustainable Development Goal (SDG) 15, Life on Land	Information not public or available
	RePLANET and Wallacea Trust	International	Operational (2024)	Biodiversity credit; 1% uplift or avoided loss in the median value of a basket of metrics per ha	5–30 USD/credit
	ValueNature	United Kingdom	Pilot (2024)	Biodiversity credit; 1 ha of land protected for 10 years	Information not public or available

	Le Printemps des Terres	France	Operational (2024)	1 m^2 of restoration and active management of biodiversity areas of at least 30 years	6 EUR/unit
Charity-led or not-for-profit	Botanic Gardens Conservation International	United Kingdom	Operational (2023)	Biodiversity impact credit; based on number of trees in a project area	Information not public or available
	Terrain NRM	Australia	Pilot (2023)	Cassowary credit; one unit of rainforest condition improvement	Information not public or available
Government-led	Biodiversity certificates scheme (Nature Repair Market)	Australia	To be launched in 2025 (Carbon Pulse, 2024)	Not available	Information not public or available
	Ocean Conservation Commitments	Niue	Operational	Protection of 1 km^2 of Niue's ocean waters for 20 years	One unit of Ocean Conservation Commitment is 250 NZD (Niue Ocean Wide, 2024)
	Biodiversity credit system	Gabon	Information not available	Not available	Information not public or available
Independent standards	VERRA, Verified Impact Standard (SD VISta)	United States, International	Development (2023)	Nature credit; 1 ha equivalent of biodiversity uplift	Not yet operational
	Ecomarkets, The Reef Credit Scheme	Australia	Operational (2021)	Reef credit; 1 kg of dissolved inorganic nitrogen prevented from entering the Great Barrier Reef catchment (Carbon Pulse, 2023)	Information not public or available Total estimated cost 10 million AUD
	Accounting for Nature, Environmental Accounting Standard	Australia	Operational (2018)	Accounting standard	Information not public or available
	Plan Vivo Foundation, PV Nature	United Kingdom, International	Operational (2023)	Plan Vivo biodiversity certificates	Information not public or available

The biodiversity credit programs listed in Table 2 are at various stages of development and implementation; some have already issued and sold credits, whereas others are in their initial phases. There is currently no consensus on the unit of measurement for voluntary biodiversity credits among these emerging programs. Additionally, each program employs distinct project methodologies, which complicates direct comparisons between them.

A biodiversity credit project developer typically secures investment from a buyer or investor to fund conservation efforts guided by established standards and methodologies. These interventions influence land stewards to either protect biodiversity, preventing its loss ("avoided loss"), or restore it, achieving measurable improvements ("uplift") (Wunder et al., 2024). Both avoided loss and uplift are assessed relative to a counterfactual scenario, representing what would have occurred without the biodiversity credit investment, thereby demonstrating additionality. Figure 3 describes an example of a schematic biodiversity credit project:

1) Start of the project: Establishment of baseline (Wunder et al., 2024) and initial monitoring with ecosystem- and habitat-level metrics (Biodiversity Credit Alliance, 2024a; International Advisory Panel on Biodiversity Credits, 2024; Pollination Group, 2023). Outlining goals of protection and/or uplift according to a selected methodology. (see Table 2).
2) Mid-project: Ongoing monitoring and assessments of outcomes (Ford et al., 2024).
3) Verification and credit issuance: Outcome verification by a third party and issuance of credits (Wunder et al., 2024).

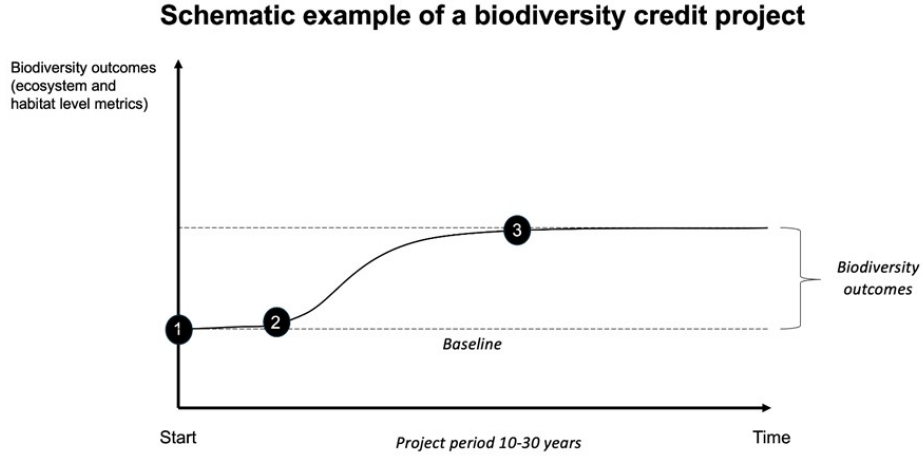

Fig. 3. Schematic example of a biodiversity credit project.

3.3 Lessons from forest carbon credits

Forest-based carbon credit projects can serve as a proxy to analyze key lessons that can be applied to the emerging voluntary biodiversity credit market (Fiegenbaum et al., 2024). Some topics that have attracted attention regarding carbon credit programs are: 1) action-based versus result-based payment systems, 2) additionality, 3) permanence, 4) leakage, 5) transparency and 6) shared stakeholder governance. These concerns highlight crucial elements of high-integrity carbon credits pertaining to the tangible impact of the carbon credit program, and these considerations may also be extrapolated to voluntary biodiversity credits as follows:

1. Some forest-based carbon projects are action-based, such as improved forest management projects where logging is deferred for a period (e.g., 20 years or longer, as in Verra methodology VM003; Verified Carbon Standard, 2023a). In such cases, carbon credits are issued based on actions (for example, by extending the rotation period of a forest) rather than results by estimating projected carbon sequestration above a baseline during the deferral period. The determination of actual carbon sequestration occurs after the project period, which introduces an inherent uncertainty in execution risk throughout the project duration. However, forest carbon projects targeting forest conservation, such as projects based on the Reducing Emissions from Deforestation and Degradation (REDD) methodology (Verified Carbon Standard, 2023c) issue carbon credits based on outcome, i.e., performed conservation. There is a proposition that transitioning from an action-based to an outcome-based payment system enhances carbon sequestration and improves the efficiency of the payment mechanism (Kim and Langpap, 2015); however, outcome-based payment systems generally require significant upfront project investments. Parisa et al. (2022) suggested that carbon sequestration on an annual basis can be efficiently traded in equivalence to one ton of permanently stored carbon. This concept of annualized carbon sequestration aims to facilitate effective trading between energy emission sources and forest carbon sinks without requiring long-term commitments from sellers and buyers.

2. Additionality, i.e., whether the project would have been undertaken without the payment arising from credits, is a main challenge connected to carbon credit schemes (Fiegenbaum, 2024; Vacchiano et al., 2018; Wunder et al., 2024). By scrutinizing each project, or by relying on secondary data, such as common practices (defining the "business as usual") in the region and sector, additionality tests can be performed (Li and Zhang, 2024; Murray et al., 2013). van Benthem and Kerr (2013) noted that it is almost always efficient to scale up programs as an entity to a political jurisdiction at the regional or national scale with one baseline. However, this is not always the case with voluntary carbon credits, where additionality is tested on project bases relative to the project methodology. Non-additionality can be managed by independent standards for which additionality tests are carried out. There are several such standards for voluntary carbon credits and several emerging ones for voluntary biodiversity credits. For example, Verra launched its Sustainable Verified Impact Standard (SD VISta; Verra, 2024b) for "nature credits" and Plan Vivo launched PV Nature Biodiversity Standard (Plan Vivo, 2025).

3. Permanence is another common issue connected to carbon credits (Wunder et al., 2024). Non-permanence results from intentional harvesting of trees and natural disturbances. Several suggestions have been provided on how to deal with permanence issues (Gren and Aklilu, 2016; Li and Zhang, 2024), such as liability in cases of carbon release, temporary credits (duration of credits), credit buffers, pooling of reversal risks, and commercial insurances. The optimal contract design was suggested to be a close to zero fixed payment and almost all upon delivery (Cordero Salas et al., 2013), which switches contractual liability from the buyer to the seller (MacKenzie et al., 2012).

4. Leakage in the context of carbon credits is a notable concern (Fiegenbaum, 2024; Haya et al., 2023), denoting the possible displacement of emissions from one location to another, either within the project area or to a different geographical area. This phenomenon has the potential to undermine the intended emissions reductions, as it involves a relocation rather than an absolute decrease in overall emissions. Wunder et al. (2024) depicted two approaches to mitigating leakage: one focuses on increasing supply or reducing demand for restricted commodities to mitigate leakage, and the other views leakage as an inevitable market force that should be measured and predicted, with initiatives scaled up to jurisdictional level, such as REDD+, offering lessons for biodiversity credits.

5. Transparency as an overarching principle for guiding private sector investments in biodiversity credits (Trouwloon et al., 2023). There needs to be understanding and clarity on the types of claims that can be accurately and credibly made when integrating carbon credits into corporate climate strategies. A general distinction between corporate climate claims is between those that signal a long-term commitment to climate mitigation, typically net-zero claims, and those claims that have already been achieved, usually carbon-neutrality claims. The latter tend to rely substantially on carbon offsetting instead of direct corporate carbon emission reductions. Similarly, a key aspect of biodiversity offset schemes is adherence to the mitigation hierarchy, which provides an outline for how no net loss of biodiversity can be achieved through the four steps to avoid, minimize, restore, and offset impact losses (Dahle, 2023). Only after achieving no net loss of biodiversity should it be advisable for a business to purchase voluntary biodiversity credits to achieve a net-positive state (Maron et al., 2023). Another important aspect is that there should be consideration of landscape context, i.e., the offset should be designed and implemented within the context of the surrounding landscape. It is possible to plan for no net loss across projects by connecting each project to regional and national biodiversity goals. This can be done by communicating conservation and restoration priorities on regional and national levels, and by doing so, providing guidance to project developers (Business and Biodiversity Offsets Programme, 2012).

6. Effective stakeholder governance is essential for equitable and successful conservation initiatives (Tedesco et al., 2023). Equity in governance involves the fair distribution of

benefits and costs, inclusive and transparent decision-making, and consideration of pre-existing conditions that influence access to resources and participation. Weak governance—marked by unequal access to information, unstable payments, and exclusion from decision-making—reduces trust and ownership, leading to poor conservation outcomes (McDermott et al., 2013). Socio-economic factors, such as governance quality and stakeholder perceptions, determine the success of incentive-based conservation programs. Transparent and inclusive governance fosters long-term engagement and positive environmental impacts (Montero-de-Oliveira et al., 2023).

Table 3 summarizes some of the major experiences reported from forest carbon credit projects and opportunities that may be used to design voluntary biodiversity credit projects.

Table 3. Essential components of credit project design and associated major experiences from forest carbon credit projects, and opportunities for voluntary biodiversity credit project design in forest landscapes.

Essential credit project design component	**Forest carbon credit project experiences**	**Voluntary biodiversity credit project opportunities in forests**
Performance/outcome-based payment system	In afforestation projects, such as Verra VM0047 (Verified Carbon Standard, 2023b), and improved forest management projects, as those described in the Verra methodology for improved forest management (Verified Carbon Standard, 2023a), carbon credits are usually issued based on performance rather than actual outcome. However, forest carbon methodologies for forest conservation, such as REDD projects, as in Verra VM0048 (Verified Carbon Standard, 2023c), apply outcome-based payments.	The payment system should be outcome-based to increase efficiency of the payment mechanism (Kim and Langpap, 2015). An annualized payment system allows projects to be developed and traded without requiring long-term commitments from sellers and buyers (Parisa et al., 2022).
Additionality	Additionality defines whether the project would have been carried out without the project financing by defining the baseline ("business as usual"), usually within a sector or a region, such as in improved forest management projects (Verified Carbon Standard,	Additionality tests and baselines should be scaled to jurisdictional level to improve efficiency (van Benthem and Kerr, 2013). Stacking of credits should be avoided as there is a risk that stacking can affect the

	2023a). However, jurisdictional baselines also exist (Verified Carbon Standard, 2023c).	perceived additionality (Torabi and Bekessy, 2015).
Permanence and risk of reversal	Permanence and risk of reversal are dealt with by reserving credit buffers (Fiegenbaum, 2024) that are kept during the duration of the project period. For example, this is illustrated by the Verra methodology for improved forest management (Verified Carbon Standard, 2023a).	The optimal contract design is suggested to be close to zero fixed payment and almost all upon delivery (Cordero Salas et al., 2013), which switches contractual liability from the buyer to the seller (MacKenzie et al., 2012).
Leakage	Leakage includes the possible displacement of carbon emissions from one location to another, as addressed in the Verra methodology for improved forest management (Verified Carbon Standard, 2023a).	There is no consensus on how leakage is best addressed (Wunder et al., 2024). The most common approach is application of a default leakage rate (Li and Zhang, 2024).
Transparency	There may be lack of transparency regarding the types of claims that can be accurately and credibly made in corporate climate strategies (Trouwloon et al., 2023).	It is necessary to understand and clarify the claims that corporations can make. Adherence to the mitigation hierarchy is imperative for engaging in voluntary biodiversity credit schemes (Maron et al., 2023).
Stakeholder governance	Active inclusion of stakeholders in carbon credit projects is crucial to address equity issues (McDermott et al., 2013).	Active inclusion of stakeholders in voluntary biodiversity credit projects is crucial to address equity issues (McDermott et al., 2013; Montero-de-Oliveira et al., 2023; Tedesco et al., 2023)

3.4 Market characteristics for voluntary biodiversity credits

According to Deutz et al. (2020), “green” financial products have the potential to turnover between approximately 30 and 90 billion USD annually in 2030. Moreover, biodiversity credits may be part of nature-based solutions projects, which are projected to turnover between approximately 25–40 billion USD annually in 2030. Collectively, the global market potential for biodiversity credits could reach 55–130 billion USD annually by 2030 and provides considerable potential to promote both biodiversity conservation and financial returns for the private sector.

However, there are several market characteristics relevant for biodiversity credits that need to be fulfilled to capture this market potential:

1. **Clear and enforceable property rights**: Property rights define the rules for accessing, using, and transferring both tangible and intangible assets, and the roles and responsibilities of parties engaged in market transactions (Alvarado-Quesada et al., 2014; Koh et al., 2019; Zhang, 2016). Ecosystem service markets vary in regulation and institutional maturity. For example, the U.S. wetland mitigation program benefits from clear legal frameworks and enforceable property rights, whereas developing countries implementing REDD+ programs (UN Climate Change, 2025) face challenges such as weak land tenure, poorly defined property rights, and limited enforcement systems (Alvarado-Quesada et al., 2014).

2. **Sufficient number of sellers and buyers producing a price mechanism**: For markets to achieve efficiency under well-defined property rights, a large number of buyers and sellers is essential (Alvarado-Quesada et al., 2014). In biodiversity offset markets, competition among buyers and sellers establishes a price mechanism to balance supply and demand. More than 100 countries have either laws or policies in place that require biodiversity offsetting or policies that support voluntary compensation measures used to compensate for negative impacts of development on biodiversity (IUCN, 2019). The data show that offsets occur where there are regulatory requirements. Mandatory markets involve developers choosing between mitigation banks or landowners, with governments defining property rights, liabilities, valuation metrics, and exchange rules (Koh et al., 2019). There is some evidence, however, that PES do not need to be highly marketized to have a measurable positive effect on environmental services (Gallemore et al., 2024).

   Land owners worldwide are positively inclined to participate in PES (Bartczak and Metelska-Szaniawska, 2015; Juutinen et al., 2021, 2022; Lee and Youn, 2023; Miller et al., 2012; Osei et al., 2023; Plevnik and Japelj, 2023). However, it has not been established if there is a corporate willingness to buy voluntary biodiversity credits because of their novelty (Pollination Group, 2024) or because they engage in other voluntary conservation actions (Reale et al., 2019). There is lack of evidence that corporate social responsibility efforts are compensated in corporate market valuations, which might deter investments in biodiversity conservation (Mollet, 2014). The absence of a universally accepted framework for corporate social responsibility evaluation and the difficulty in quantifying non-financial impacts contribute to the market's challenges in appropriately valuing companies' social and environmental responsibility initiatives. Markets tend to favor private goods such as timber, and therefore often lack sustainable financing mechanisms for public goods and services such as carbon storage, biodiversity conservation, and recreational value (Mollet, 2014).

   There is anticipation, however, that the corporate interest in voluntary biodiversity credits may increase because of environmental reporting regulations and voluntary reporting initiatives, such as those put forth by the Taskforce on Nature-related Financial Disclosures (Nabuurs et al., 2024; Seidl et al., 2024); as a result of lender requirements

(International Finance Corporation, 2012, 2023); or to improve their image and prepare for future regulation (Blanton et al., 2024). To induce corporate buyers' interest in voluntary biodiversity credits, effort must be made to connect biodiversity credit projects with corporate value chains (Seidl et al., 2024; Thompson, 2021).

3. **Information asymmetry**: Incomplete information is widely recognized as a challenge for the effective functioning of biodiversity markets (Alvarado-Quesada et al., 2014). However, in both the U.S. and Australian biodiversity schemes, adverse selection—a problem arising from asymmetrical information, where one party has better knowledge about the traded good—is uncommon. This is because credits are defined and assigned by a third party, ensuring that the quality and characteristics of the biodiversity credit area are assessed during credit creation. This process guarantees a minimum quality standard for credits in the market (Alvarado-Quesada et al., 2014).

4. **Barriers to enter biodiversity credit market**: High transaction costs are the main obstacle preventing investors and businesses from participating in PES markets (Alvarado-Quesada et al., 2014). Examples of such transaction costs are intermediary costs to connect sellers and buyers, consultant fees for project assessment, and upfront costs to landowners to establish projects and agreements.

5. **Biodiversity credit schemes and the unit of biodiversity**: A significant challenge for both voluntary and regulatory biodiversity markets is the lack of standardized methodologies for defining tradable units. Each scheme employs its own measurement system to quantify credits, baseline, and additionality (Blanton et al., 2024), making it difficult to compare credits across different programs (OPIS, 2024; Taskforce on Nature Related Markets, 2023; Zynobia et al., 2023).

3.5 Voluntary biodiversity credits in the context of EU policies

There are several EU strategies and policies related to forest biodiversity conservation and restoration. The most relevant ones are the EU Biodiversity Strategy for 2030 (European Commission, 2024a), the Habitats Directive (European Commission, 2024b), the European Green Deal (European Commission, 2024c), the Nature Restoration Law (European Commission, 2024d), the EU Forest Strategy (European Commission, 2024e), and the EU Taxonomy for Sustainable Activities (European Commission, 2024f).

The EU Biodiversity Strategy for 2030 (European Commission, 2020) is a comprehensive and long-term plan to protect nature and halt ecosystem destruction. This strategy is a core part of the European Green Deal, which is the EU's program that addresses climate change and environmental degradation. The EU Biodiversity Strategy for 2030 includes concrete actions and commitments to ensure that Europe's biodiversity starts to recover by 2030. Key goals of the strategy include expanding protected areas to 30% of the EU's land and sea and restoring nature. These goals have produced considerable concern among many European countries whose economies derive significant income from agriculture and commercial management of semi-natural forests because there are uncertainties with implications for forest owners

regarding, for example, the extent of future commercial use of forests (Swedish Forest Industries, 2022).

In June 2023, the European Parliament voted to pass a new Nature Restoration Law, despite wide opposition from farmers and forest owners in several EU countries (Canas, 2024; Hunter, 2024; Schauenberg, 2023). This is the first continent-wide, comprehensive law of its kind (European Commission, 2023a). The Nature Restoration Law is a key element of the EU Biodiversity Strategy for 2030 and combines an overarching restoration objective for the long-term recovery of nature within the EU with a binding restoration target of at least 20% of the EU's land and sea by 2030, and ultimately all ecosystems in need of restoration by 2050 (European Commission, 2022a). With respect to forestry, the following restoration measures were discussed in the Nature Restoration Law (European Commission, 2022b), all of which may be incorporated into a voluntary biodiversity credit scheme:

1. Restore wetlands by rewetting drained peatlands, removing peatland drainage structures

2. Remove unwanted scrub encroachment or non-native plantations on grasslands, wetlands, forests, and sparsely vegetated land;

3. Increase ecological features in forests, such as habitat trees and amounts of lying and standing dead wood;

4. Work toward a diversified forest structure to enable natural regeneration and succession of tree species;

5. Enhance the development of old-growth native forests and mature stands (e.g., by abandoning harvesting);

6. Improve connectivity across habitats;

7. Allow ecosystems to develop their own natural dynamics, such as by abandoning harvesting and promoting natural wilderness.

The EU Forest Strategy (European Commission, 2024e) is another important initiative of the European Green Deal and builds on the EU Biodiversity Strategy for 2030 (European Commission, 2024a). This strategy contributes to achieving the EU biodiversity objectives and greenhouse gas emission reduction target of at least 55% by 2030 and climate neutrality by 2050. Some of the measures proposed in this strategy promote sustainable forest management; provide financial incentives for forest owners and managers to adopt environmentally friendly practices, such as those linked to carbon storage and sequestration; and improve forest size and biodiversity.

The EU Taxonomy Regulation for Sustainable Activities (European Commission, 2024f) is a classification system that defines criteria for economic activities that are aligned with a net zero trajectory by 2050 and for which there are broader environmental goals than just climate. The aim of this system is to help scale sustainable investments and create security for investors by setting out conditions that an economic activity has to meet to qualify as environmentally sustainable (European Parliament, 2020). Protection and restoration of biodiversity and ecosystems are outlined (Articles 9, 10, and 15), and activities are mentioned that are thought to substantially contribute to the protection and restoration of biodiversity and ecosystems. It was specifically mentioned that only net biodiversity gains (and not offsets) are able to be accounted for as a sustainable activity, and are therefore potentially able to be used as voluntary biodiversity credits (European Commission, 2023b). The taxonomy regulation acknowledges the initiation, development, and execution, either independently or on a contractual basis, of conservation activities; this encompasses restoration efforts, with the goal of sustaining or enhancing the condition and trajectories of terrestrial, freshwater, and marine habitats, ecosystems, and associated populations of fauna and flora species. Additionally, it provides guidance on critical components of a voluntary biodiversity credit scheme, such as: initial biodiversity assessment, management plan requirement, stakeholder consultation, monitoring scheme, permanence, transparency, third-party audit, and verification. This is important because recognition of nature conservation and restoration as a "green investment" may reveal important capital and corporate willingness to invest in such activities.

Another EU directive to likely have a direct impact on businesses and potentially on willingness to invest in biodiversity conservation and restoration is the Corporate Sustainability Reporting Directive (European Parliament and Council of the European Union, 2022), which took effect in January 2023. This directive defines the rules concerning the social and environmental information that must be reported by companies. The sustainability reporting standard specifies the information to be disclosed regarding climate change mitigation, climate change adaptation, water and marine resources, resource use and the circular economy, pollution, and biodiversity and ecosystems. Companies will have to apply the new rules for the first time in the 2024 financial year for reports to be published in 2025. Therefore, the first step for companies is to report on their climate and natural resource footprint. Once companies are aware of their footprint, the next step will be to mitigate the footprint. This exercise may then lead to ambitious businesses aiming for no-net-loss or even nature-positive states, which may entail financing of nature restoration projects or purchase of voluntary biodiversity credits or similar instruments (European Parliament and Council of the European Union, 2022).

Although all the abovementioned regulations and strategies provide guidance and opportunities to create new flows of private finance for nature conservation and restoration, PES and PES-like schemes are scarce in Europe (Hernández-Morcillo et al., 2022). Research showed that, to attract investors to invest in voluntary biodiversity credits, there needs to be a clear policy signaling that there will be a demand for credits (zu Ermgassen and Löfqvist, 2024).

The EU Forest Strategy encourages the establishment of payment schemes for ecosystem services and, in particular, the roll out of carbon farming practices. The European Commission

proposed an EU voluntary framework for certifying carbon removals (European Commission, 2022a); this framework includes critical building blocks for a voluntary scheme that could also potentially be adopted for a voluntary biodiversity scheme. A staff working document (European Commission, 2023c) primarily discusses public financing schemes and includes some ideas on combining public and private financing schemes to create synergies for financing, but provides no guidance on privately financed schemes for biodiversity conservation or restoration. However, President von der Leyen stated in September 2024 that "we can create a market for restoring our planet," specifically mentioning "nature credits" (European Commission, 2024g); this shows ambition and a direction for action within the EU.

4. Discussion

Roughly 30% of the total global land area, equivalent to approximately 4 billion hectares, is comprised of production forests (FAO and UNEP, 2020; World Resources Institute, 2024). In the EU alone, out of the total forest area of 160 million ha, only 4% has not been modified by human intervention (European Parliament, 2023); i.e., most of the forest area has been subject to forest management. The production forests in Europe, in particular in the Nordic countries, are of local and international economic importance because they produce a large amount of industrial wood and are often intensively managed for commercial wood production (Eggers et al., 2022; Rytter et al., 2016). The biodiversity of these forests has decreased because of historical habitat fragmentation and logging, and significant long-term impacts of ongoing environmental change have been predicted for mid- and high-latitude European forests in the future (Pussinen et al., 2009). Forest production landscapes will continue to be of significant importance for wood production, which is an integral part of a circular bioeconomy (Salvador et al., 2023). Liang et al. (2016) found that biodiversity loss adversely impacts forest productivity, with a 10% decrease in biodiversity resulting in a 3% decline in forest productivity. Moreover, Liang et al. (2016) estimated that the economic value of biodiversity for maintaining forest productivity is 166–490 billion USD annually, which surpasses global conservation costs of all terrestrial ecosystems at a global scale; this underscores the need to reassess forest management and conservation strategies worldwide.

A vast amount of financing is needed to stop global biodiversity decline. Recent estimates of the global biodiversity financing gap range between 36 billion to 7 trillion USD per year (Anyago-van Zwieten, 2021; Deutz et al., 2020). It is estimated that over 80% of funding for nature restoration originates from public sources that are primarily distributed through government expenditures (Deutz et al., 2020; zu Ermgassen and Löfqvist, 2024). Involving the private sector in biodiversity conservation efforts is essential, as private investment decisions are key contributors to ecosystem degradation, and public sector funding alone is insufficient to address the financial demands of restoration (zu Ermgassen and Löfqvist, 2024). For private forest owners, inadequate funding from states has proven to be a problem for implementing conservation programs (Li and Zhang, 2024). European forest owners and policymakers are seeking innovative governance solutions that create economic opportunities while safeguarding the long-term provision of forest ecosystem services (Maier et al., 2021). There are multiple positive effects of PES apart from biodiversity conservation, such as support to local economy and increase of social well-being at different levels (Schirpke et al., 2018). However, despite

existing policy support, few PES have been implemented in the EU as of 2019 (Sarvašová et al., 2019).

Creating a market for PES offers an opportunity to effectively capture the value of ecosystem assets, thereby incentivizing conservation efforts (Daily and Ellison, 2002). Lessons learned from carbon credits can be used to inform the design of biodiversity credits (Table 3). There are several studies illustrating how externalities, such as carbon sequestration, can be quantified (Mei, 2023a) and traded (Lee et al., 2018), and that they can bring a premium to the forest owner (Mei, 2023b). By diversifying income opportunities to the forest owner, there is an economic incentive to change how forests are being managed (Mei, 2023b; Satake et al., 2008).

However, there is skepticism about using capitalist mechanisms for conservation, as capitalism is often seen as a driver of environmental degradation. Ethical concerns arise over monetizing nature through market-based models, which are criticized for the inherent conflicts of interest associated with balancing ecological goals with investor demands for returns, efficiency, and scalability (Kedward et al., 2022). Alternatively, Coqueret et al. (2023) showed that there is a biodiversity risk premium on expected returns in sectors exposed to the double materiality of biodiversity risks, suggesting that these companies may have a monetary incentive to reduce their biodiversity footprint.

Ultimately, little is known about the actual effectiveness of PES (Lewis et al., 2011). For example, despite two-thirds of the world's biodiversity offsets being applied in forested ecosystems, none have shown successful no-net-loss outcomes for forested habitats or species (zu Ermgassen et al., 2019). Furthermore, it is difficult to evaluate various biodiversity offset programs because there is a lack of adequate long-term monitoring programs with standardized monitoring approaches, such as randomized design and baseline data (Josefsson et al., 2021).

Concerns associated with PES have been connected to the risk of new externalities, concern that market-based systems will crowd out altruistic motivations, burden of monitoring to curb cheating, difficulties in applying PES where property rights are unclear, and one-size-fits-all programs (Chan et al., 2017). A potential new externality in production forest landscapes resulting from PES may be a reduction in commercial wood production, leading to decreased wood supply for industries. This may subsequently lower the use of wood, an environmentally friendly and circular material, affecting its contribution to environmentally responsible applications. Moreover, solely focusing on biodiversity may result in lower carbon sequestration due to decreased tree growth resulting from altered forest management (Capparos and Jacquemont, 2003).

Approximately 60% of European forest area is privately owned and managed for commercial forest production (Weiss et al., 2021). Because most existing income streams to forest owners come from producing and selling wood (Lovrić et al., 2025), efforts should be made to provide income streams to forest owners aside from wood production to reward outcomes that yield greater forest biodiversity. Our literature review demonstrated that voluntary biodiversity credits show promise for implementation in production forests. While European production

forests have not been thoroughly explored in terms of these credits, there are various ways in which they can actively contribute to enhancing and uplifting biodiversity qualities, beyond merely focusing on protection.

Production forests offer significant opportunities for biodiversity conservation and restoration that align with global and EU conservation policies, such as the EU Nature Restoration Law. However, none of the existing biodiversity credit schemes address biodiversity conservation and restoration from the perspective of production forests. In fact, some prohibit occurrence of monocultures within project areas (e.g., as in the Verra SD Nature Framework; Verra, 2023), even in situations where such projects demonstrate good examples of responsible biodiversity-friendly management. This is an oversight, as there is abundant evidence that production forests can provide valuable habitat even for some threatened and endangered species, and may contribute to conservation and restoration of biodiversity by various mechanisms (Brockerhoff et al., 2008). Key opportunities include preserving high-value ecological areas; integrating biodiversity restoration into forest management through tree species diversification and creation of habitat, such as dead wood (Asplund et al., 2024); and improving forest management by combining sustainable forestry with conservation measures to benefit both biodiversity and economic viability of production forests.

5. Final remarks and recommendations

Integrating biodiversity conservation into the management of production forests enhances their capacity to maintain ecological processes, while also ensuring that economic benefits are realized in a sustainable manner (Nabuurs et al., 2024). As shown in this paper, existing EU policies advocate for a shift towards multifunctional forest landscapes that deliver diverse ecosystem and landscape services, including biodiversity conservation, climate adaptation, and carbon storage. The transition to such a system, however, requires significant regulatory or market-based pressure entailing forest managers to evolve into ecosystem stewards, prioritizing functional green infrastructures that support adaptation to climate change, corporate sustainability goals, and biodiversity challenges (Angelstam et al., 2022). This paper has summarized learnings from existing PES models, including forest carbon projects, and suggested opportunities for biodiversity credit project design in line with EU policies. One major opportunity for European forest owners would be establishment of jurisdictional level additionality tests and baseline recommendations (van Benthem and Kerr, 2013) within the European Union.

Future studies should explore various scenarios with different levels of conservation and restoration efforts in a production forest context. Such investigations are essential to achieve an optimal balance between wood production outputs and carbon sequestration with improved biodiversity outcomes. More research is also needed to recommend efficient biodiversity credit design, payment, and financing schemes to both satisfy marketability and optimize biodiversity outcomes.

CRediT authorship contribution statement

Aleksandra Holmlund: Conceptualization, formal analyses, writing. **Francisco X. Aguilar**: Supervision, writing – review and editing; **Anneli M. Ågren**: Writing – review and editing; **Tomas Lundmark:** Writing – review and editing.

Declaration of competing interest

The authors declare that there are no conflicts of interest or financial interests beyond the fact that Aleksandra Holmlund is employed by Qarlbo Biodiversity, which could use the findings of this paper in their business model.

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Biodiversity is declining globally, and current funding for conservation is insufficient. Production forests, covering 30% of global land, offer opportunities for biodiversity restoration if viable incentives exist. Biodiversity credits can compensate forest owners for enhancing biodiversity, encouraging private-sector investment. This thesis explores their potential in European production forests, aligning with policies like the EU Nature Restoration Law. Success depends on clear regulation and robust verification, with further refinement needed to balance biodiversity, carbon, and timber production.

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