

Review Paper

Voluntary biodiversity credits: A review of concepts and a perspective on their application in European production forests

Aleksandra Holmlund^a, Francisco X. Aguilar^{b,*}, Anneli M. Ågren^c, Tomas Lundmark^c

^a Qarlbo Biodiversity, Mäster Samuelsgatan 45, 111 57 Stockholm, Sweden

^b Swedish University of Agricultural Sciences, Department of Forest Bioeconomy and Technology, Skogmarksgränd 17, 907 36 Umeå, Sweden

^c Swedish University of Agricultural Sciences, Department of Forest Ecology and Management, Skogmarksgränd 17, 907 36 Umeå, Sweden

ARTICLE INFO

Keywords:

Biodiversity credits
Production forests
Compensation
Forest owners
European nature conservation policy

ABSTRACT

Forestlands suitable for timber production also have a significant role supporting biodiversity. Here, we synthesized the current state of knowledge on voluntary biodiversity credits as a market-based mechanism designed to incentivize conservation and restoration efforts in production forests. We compared these mechanisms with features common to carbon credits and assessed their consistency and alignment with existing European Union policies. Attributes particular to production forests, including well-defined tenure rights and the common use of forest management plans, poise them for the implementation of biodiversity credits. Among EU policies, the Taxonomy Regulation for Sustainable Activities and the Directive on Corporate Sustainability Reporting lay a framework that supports emerging biodiversity credit markets, and the EU Restoration Law provides a pathway for adoption across European production forests. Converging ecological opportunities, and policy and financial frameworks, may unlock voluntary biodiversity credits in production forests as a scalable pathway for private capital to support biodiversity conservation and restoration in Europe.

1. Introduction

Anthropogenic losses of natural habitats have severe consequences on global biodiversity and other life-supporting ecosystem services (Pereira et al., 2012). Some estimates indicate that approximately 30% of species globally have been threatened or driven to extinction since the 1500s (Isbell et al., 2023). Despite global and national conservation initiatives, the predominant anthropogenic drivers of biodiversity decline persist (Jauregui et al., 2022) including unsustainable forms of agriculture, aquaculture, forestry, and fisheries (IPBES, 2019). The loss of ecosystem services, including provisioning biodiversity, has substantial economic consequences with an estimated annual cost of about US\$ 2.7 trillion (Kumar et al., 2024). Losses in the flow of biodiversity-centered ecosystem services could potentially reduce global gross domestic product by 2.3% between 2021 and 2030 (Johnson et al., 2021).

Multilateral initiatives addressing biodiversity losses include the Convention on Biological Diversity (Convention on Biological Diversity, 2022) and the UN Sustainable Development Goals (United Nations, 2025). Efforts to conserve biodiversity have relied on both command-and control and market-based instruments with an increased interest

in the latter, including voluntary mechanisms. Voluntary tools aim to align and balance conservation goals with economic incentives, potentially broadening participation and impact (TNFD, 2023). The need for innovative financing schemes to halt biodiversity loss and promote restoration were emphasized during COP15 of the CBD (Convention on Biological Diversity, 2022).

Here, we aim to advance the conceptual understanding of voluntary biodiversity credits applied in production forests through an integrative systematic literature review. Our focus on production forests – forestland meeting productivity thresholds that can be actively managed to produce wood, fiber, bioenergy and/or non-wood forest products, and not precluded by law or regulation from commercial harvesting that comprise about 30% of global forestlands (FAO, 2018; FAO, UNEP, 2020; McGinley et al., 2023) – is motivated by several reasons. Among them are (1) the large share and geographic distribution of production forests worldwide, (2) an existing legal framework categorizing these forests for lawful active management, including restoration; (3) clear ownership (whether public or private), defined tenure rights and allowable uses that facilitate the implementation and enforcement of legally-binding contracts, (4) the ability to estimate any forgone net income from timber production to calculate minimum financial

* Corresponding author.

E-mail address: francisco.aguilar@slu.se (F.X. Aguilar).

<https://doi.org/10.1016/j.ecoser.2026.101828>

Received 17 June 2025; Received in revised form 26 January 2026; Accepted 2 February 2026

Available online 17 February 2026

2212-0416/© 2026 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

compensation needed to promote conservation or restoration, (5) in a European Union (EU) context, the prevalence of private ownership across production forests presents an opportunity for voluntary adoption over coercive interventions to foster biodiversity conservation and restoration. These attributes can facilitate the scalability of biodiversity restoration in forestlands, particularly European production forests.

In the next section, we present a summary of key concepts underpinning payments for non-market ecosystem services and for biodiversity credits specifically. It is followed by a description of our methods to conduct a systematic review of the scientific literature. Our integrative systematic review complements other recent efforts synthesizing information on the design of payments for ecosystem services (Clifton and Schwerdtner Manez, 2025) by focusing on biodiversity credits, key elements that distinguish them as a category within PESs, lessons drawn from voluntary carbon trading, and how voluntary biodiversity conservation as a private initiative fits within the extant EU policy regulating forests and biodiversity. We discuss potential applications to mitigate and reverse biodiversity losses, describe pivotal characteristics for a voluntary biodiversity credit system, and describe a rationale for their implementation in European production forests with Sweden as a case in point.

2. Forest ecosystem services and their internalization into financial values

In an early definition, Daily (1997) described ecosystem services as the conditions and processes through which natural ecosystems “sustain and fulfill human life”. The 2005 *Millennium Ecosystem Assessment (2005)* advanced the conceptual categorization of the tangible and intangible contributions of ecosystems to human wellbeing via provisioning (e.g., food and fresh water), regulating (e.g., water purification), cultural (e.g., recreation and aesthetics), and supporting (e.g., soil formation) services. A link to human wellbeing acknowledged, subsequent efforts have been made to assign monetary values to the ecosystem services that directly benefit human wellbeing (Boyd and Banzhaf, 2007). Monetization of the flow of ecosystem services can allow decision makers to account for market and non-market values including conservation, improvements, and deterioration or losses of ecosystem services. Subsequent multilateral efforts to value and account for ecosystem services in national economies include *The Economics of Ecosystems and Biodiversity (2009)* and more recently the System of Environmental-Economic Accounting (United Nations, Department of Economic and Social Affairs 2024).

Among the numerous forest ecosystem services, timber supply is one that is valued in wood product markets constituting the financial backbone to the silvicultural management of production forests. Nevertheless, in contexts with weak property rights and non-enforceable legal frameworks, timber value can be a major driver behind human-driven forest degradation (Lapola et al., 2023). The non-monetary nature of many other forest ecosystem services creates a market imperfection that can result in the inefficient allocation between forestland areas classified for production and strict conservation, and between forests and non-forest land uses including illegal deforestation (Barbier and Burgess, 2001). Interventions aimed at correcting non-market externalities of ecosystem services are often classified under either command-and-control or market-based actions (Angelsen, 2010). Command-and-control interventions commonly try to define forest areas for strict conservation and their restoration, or to ascribe allowable uses such as when setting timber concessions on public lands and when assigning land tenure and titling rights (Blackman et al., 2017). Market-oriented actions such as the third-party certification of sound forest management are partly motivated by the expectation that markets will pay a premium for the sustainable supply of forest products (Aguilar and Vlosky, 2007). Other market-based interventions include financial payments for avoided deforestation, degradation, and improvements in the supply of selected ecosystem services (Engel et al., 2008). Schemes

setting up payment for ecosystem services (PES) attempt to internalize the value of services external to financial transactions (Börner and Vosti, 2013).

A system of payments for ecosystem services (PES) can be described as a voluntary agreement between buyers and sellers for a clearly specified environmental service, in which at least one buyer compensates at least one provider who has effective control over service delivery, and payment is conditional upon verified provision of that service. (Wunder, 2008). PES schemes have been implemented to finance forest conservation, restoration, and support of ecosystem services such as carbon sequestration, watershed restoration, and landscape scenery conservation (Obeng et al., 2018). PES levels are commonly set via different mechanisms under the premise that financial compensation should reach a minimum point where the net present value of targeted land after an intervention equals or exceeds that of alternative uses (Engel et al., 2008; Angelsen, 2010). In some cases, payment is informed by land prioritization guidelines based on deforestation and degradation pressures as it was the case of the Socio Bosque program in Ecuador or Mexico’s Pago por Servicios Ambientales (Mohebalian and Aguilar 2016; Alix-Garcia et al., 2012). In others, as in the case of avoided emissions from deforestation and degradation, payments can be based on the social cost of carbon emissions (Marcos-Martinez et al. 2019). Efficiency in offsetting impacts is sought via the value in-trade between buyers and sellers of credits. Efficiencies sought via trading are illustrated by compensatory mitigation for unavoidable losses as in the US wetland mitigation banking under the Clean Water Act of 1972 (Academies et al., 2001), and the original premise for Clean Development Mechanisms under Article 12 of the Kyoto Protocol to allow nations to offset emissions via saleable certified reduction credits (UNFCCC, 1998).

In the EU efforts to conserve biodiversity have been consistently directed towards the biodiversity-rich habitats and protected species. The lion’s share efforts at the EU level have occurred via the designation of protected areas under the Habitats Directive 1992/43/ECC). This effort toward improvement of the provision of biodiversity habitat in Europe aligns with command-and-control interventions for conservation. Incentive-based instruments in the EU to support biodiversity, among other objectives, have been structured under the Common Agricultural Policy’s agri-environmental measures that target farmlands but not forestlands (Uthes and Matzdorf, 2013). There are outstanding opportunities for the use of market-based interventions, including PES to promote biodiversity on EU private forestlands (Maes et al., 2012; Blicharska et al., 2022).

3. Systematic scientific literature review

We conducted an integrative systematic review of the scientific literature (Snyder, 2019) to evaluate the extant state-of-knowledge on applications of PES in the context of biodiversity conservation and restoration within production forests under five focal areas: Design of biodiversity credits; examples of voluntary biodiversity credit initiatives; lessons from forest carbon credits; market characteristics for voluntary biodiversity credits; voluntary biodiversity credits in the context of EU policies. These focal areas stem from the need for information syntaxes that provide specific recommendations to reconcile the complexity of ecosystem services with on-the-ground practical advice (Olander et al., 2017) as illustrated by lessons drawn from forest-based carbon credit projects to advise emerging voluntary biodiversity credit schemes (Fiegenbaum, 2024).

Our systematic review consisted of the following six steps (Linnenluecke et al., 2020; Sauer and Seuring, 2023):

- 1) *Defining the research question:* Our review was structured to answer the research question: *What lessons can be drawn from existing PES models and voluntary carbon credit experiences to inform the development and advancement of biodiversity credits across production forests?*

- 2) *Defining the search string, and identifying inclusion and exclusion criteria:* To identify relevant scientific literature, we implemented the combined 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 included terms and synonyms for PES and biodiversity credits related to forest ecosystems and forest carbon credits. Forest carbon credits were included in this step as a proxy for biodiversity credits because of the more advanced development of voluntary forest carbon credit markets and relevance to production forests (Blanton et al., 2024; Waterford et al., 2024).
- 3) *Retrieving a sample of potentially relevant literature:* An initial search of the scientific databases ScienceDirect, Web of Science, and CABI Digital Library, completed on 10 August 2024 using our combined search string returned 424 results. To ensure comprehensive coverage and avoid missing relevant literature, an additional search was performed using the following individual terms rather than as a combined search: “payments for forest ecosystem services,” “biodiversity credits,” “financing of biodiversity conservation,” “incentives for biodiversity conservation,” and “forest carbon credits.” This expanded search, completed on 12 August 2024, yielded a total of 3,625 results across selected databases. After removing duplicates, all relevant publications were retained without additional screening, 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, 68 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 multi-lateral organizations.
- 4) *Selecting final sample of the relevant literature:* The retrieved sample was evaluated against the predefined research question by using four inclusion criteria. These were: (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 fields not directly specific to biodiversity credits, such as energy, engineering, agricultural and fundamental biological sciences, veterinary sciences, biochemistry, genetics and molecular biology, business management and accounting, and earth and planetary sciences; (c) only articles specific 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. A comprehensive list of the literature included in this study is provided in Appendix 1. In total, 165 references are documented in this paper, of which 124 were incorporated into our literature review in sections 4, 5 and 6. (Fig. 1). The appendix also indicates the specific sections in this paper where each reference is cited. The selected literature was content-reviewed for relevance to selected focal areas (Table 1).

Table 1
Content focus areas and key information retrieved from the final sample of the relevant published literature.

Focus areas for content evaluation	Retrieved information
1. Concept and design of biodiversity credits	<ul style="list-style-type: none"> ■ Definition and conceptualization ■ Theoretical foundations and models ■ Building blocks and principles to ensure governance and credit integrity and manage risks ■ Commonalities and distinction from PES
2. Examples of voluntary biodiversity credit initiatives	<ul style="list-style-type: none"> ■ Description of existing voluntary biodiversity credit schemes ■ Successes, challenges, and lessons learned from past implementations ■ Examples of use in forest management and forest management applications
3. Relevant lessons for forest-based biodiversity credits from carbon markets	<ul style="list-style-type: none"> ■ Action-based implementation ■ Additionality from credit payments ■ Permanence of carbon credit additionality ■ Leakage of outcomes ■ Transparency of investment claims ■ Effective stakeholder governance
4. Market characteristics for voluntary biodiversity credits	<ul style="list-style-type: none"> ■ Characteristics for biodiversity credits markets ■ Economic valuation methods applied to assess the monetary value of carbon and biodiversity credits ■ Examples and practical recommendations
5. Voluntary biodiversity credits in the context of EU policies	<ul style="list-style-type: none"> ■ Existing EU policies governing and regulating biodiversity and biodiversity habitat conservation and restoration ■ Existing EU policies governing and prospectively affecting biodiversity credits

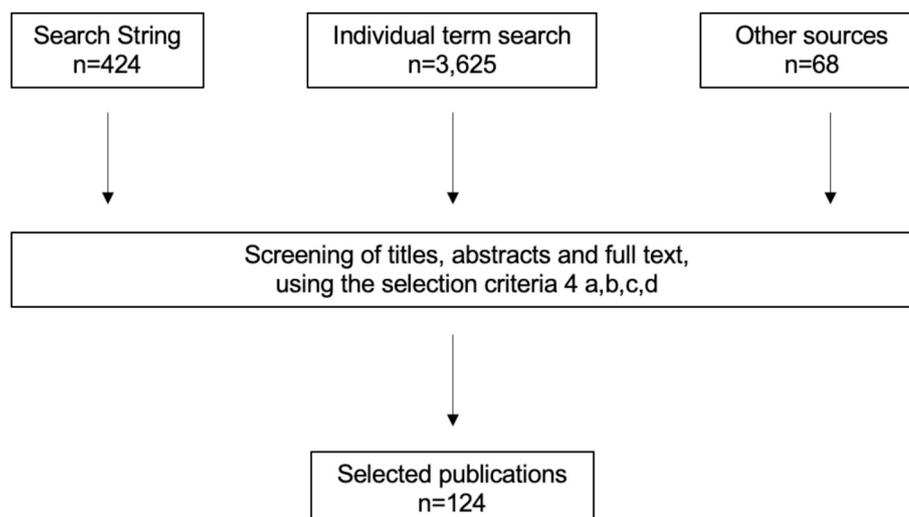


Fig. 1. Outline of systematically selected publications included in the integrative literature review.

- 5) *Synthesizing knowledge*: All the selected literature was read in-depth, the focus areas identified, and retrieved content information was synthesized.
- 6) *Reporting*: In the following sections we report and discuss the results of the literature review.

4. Results

4.1. Concept and design of forest biodiversity credits

Market-based financing for biodiversity conservation is not a new concept. PES and PES-like schemes have been tested and implemented in various forms since the 1990s (Bonneuil, 2015; Hrabanski, 2015; Wunder et al., 2025). Some of the earlier applications of biodiversity credits include the US wetland mitigation and species banking, and Australia's biodiversity offset system where credits offer a tool for developers to compensate for unavoidable biodiversity losses due to land use changes. These programs created biodiversity offsets as quantifiable units denoting improvements in biodiversity habitat that are transacted to offset potential losses elsewhere. Historically, most offsets have been mandatory actions regulated by environmental policies with the goal of achieving 'no net loss' in environmental quality (Koh et al., 2019; Wunder et al., 2025). Biodiversity credits are also referred to in the scientific literature as 'biocredits', 'biodiversity certificates', 'nature credits', or 'nature tokens' (Zynobia et al., 2023).

At the outset, biodiversity credits may be classified as a type of PES (Wunder et al., 2025). But a key distinction between PES and voluntary biodiversity credits is that PESs generally are not conditional on functioning trading of credits, whereas voluntary biodiversity credits are intended to be traded. An example is the use of PES to compensate for land practices that protect soil quality or watershed functions that are transacted in cost-share contracts but are not openly traded. However, the uniqueness and spatial specificity of biodiversity provision (Boyd and Banzhaf 2007) can make related credits harder to trade and meet competitive market conditions (Wunder, 2008), as compared to avoided carbon emissions that could be commoditized and traded to lower overall greenhouse gas levels. There is no consistency in how credits units are measured and what they represent, whether referring to biodiversity habitat or specific individual or multiple species. We offer a number of examples to illustrate this issue in the next section.

Biodiversity credits have been defined as "biodiversity gains that are not associated with a loss elsewhere" (NatureFinance, 2023a, Porras and Steele, 2020). Another common definition of 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). Recently, the literature (e.g., Wunder et al., 2025; Schwerdtner Manes and Clifton, 2025) suggests distinguishing between voluntary biodiversity credits and biodiversity offsets. Distinctive features include that biodiversity credits (1) by definition are voluntary and may not be created or mandated by regulations, (2) aim at delivered net positive improvements, (3) their jurisdiction is not limited to national boundaries, (4) and strive for biodiversity conservation at multiple scales (e.g. locale, landscape, regional). In contrast, offsets are coerced by regulation, aim at no net-loss biodiversity outcomes, commonly operate within a single nation, and target expected habitat losses at a particular locality risking to overlook conservation at larger geographic scales.

Voluntary biodiversity credit schemes have evolved rapidly since 2023 with a focus on principles and standards that ensure the environmental integrity of claimed benefits and due-diligence frameworks (IAPB, 2024b; Waterford et al., 2023). Key metrics (Fig. 2) include those for outcomes regarding (1) protection, (2) regeneration, (3) stewardship (i.e., maintenance of ecological value), and (4) adaptation (e.g., in relation to climate change) to a lesser extent (Biodiversity Credit Alliance, 2024a; Waterford et al., 2023). Existing schemes employ various approaches to inferring biodiversity typically gauged at either

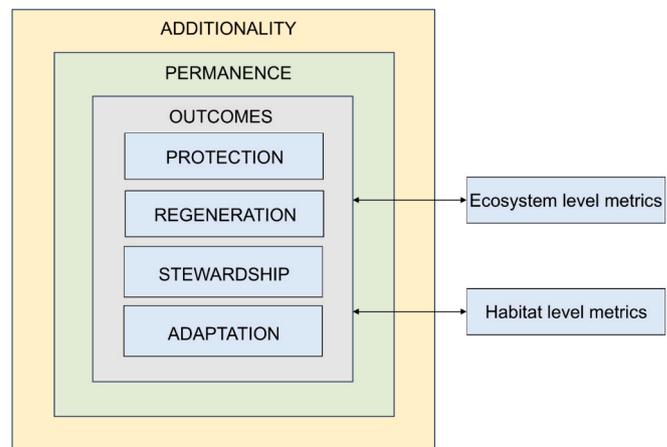


Fig. 2. Depiction of key elements of biodiversity credits and selected outcome metrics.

ecosystem- or habitat-levels to, respectively, track a suite of indicators for an entire ecosystem, or tailored to particular species of flora and/or fauna (Biodiversity Credit Alliance, 2024a; IAPB, 2024a; Waterford et al., 2023). Credit issuance is generally conditional to the verification of achieved outcomes during a defined crediting period (IAPB, 2024a; Waterford et al., 2023).

Other key integrity metrics of voluntary biodiversity schemes include additionality and permanence (Wunder et al., 2025), (IAPB, 2024b). 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).

4.2. Examples of voluntary biodiversity credit initiatives

Globally, numerous programs have attempted to create, support, and regulate voluntary biodiversity credit markets. Private sector programs are at varying stages of development (Waterford et al., 2023). For example, 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. Several entities including the World Economic Forum (2024), the Biodiversity Consultancy (2022), the Biodiversity Credit Alliance (2024b), NatureFinance (2023b), Plan Vivo (Barisa et al., 2024), and Verra (2024a) have offered guidance on the use of voluntary biodiversity credits to observe and deliver key integrity metrics. Wunder et al. (2025) report 34 ongoing biodiversity credit initiatives worldwide, Zynobia et al. (2023) mention 11 biodiversity credit schemes and Bloom Labs database (2025) list 53 biodiversity credit schemes. In Table 2 we offer a non-comprehensive list to illustrate main characteristics of some emerging voluntary biodiversity credit schemes.

Notably, there is no current consensus among biodiversity credit schemes regarding the unit of measurement for voluntary biodiversity credits. The metrics employed are typically area-based—ranging from square meters to hectares—and often incorporate a temporal dimension reflecting project duration (e.g., one hectare of land protected over ten years, as exemplified by ValueNature). Lack of standardization in

Table 2
Main characteristics of selected emerging voluntary biodiversity credit schemes, and

Type	Name	Country	Phase	Unit of biodiversity	Reported price
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 publicly 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 publicly 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 publicly 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 publicly available
Charity-led or non-profit	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
	Botanic Gardens Conservation International Terrain NRM	United Kingdom	Operational (2023)	Biodiversity impact credit; based on number of trees in a project area	Information not publicly available
Government-led	Terrain NRM	Australia	Pilot (2023)	Cassowary credit; one unit of rainforest condition improvement	Information not publicly available
	Biodiversity certificates scheme (Nature Repair Market)	Australia	To be launched in 2025 (Carbon Pulse, 2024)	Not available	Information not publicly 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)
Independent standards	Biodiversity credit system	Gabon	Information not available	Not available	Information not public or available
	VERRA, Verified Impact Standard (SD VISTA)	United States, International	Under 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 publicly 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 publicly available

Adapted from the [Taskforce on Nature Related Markets \(2023\)](#), [Zynobia et al. \(2023\)](#) and [OPIS \(2024\)](#).

measurement units, coupled with the diversity of methodological approaches, hinders the establishment and scalability of a coherent voluntary biodiversity credit market (IAPB, 2024b). Nevertheless, this represents a fundamental distinction from carbon credit systems where a relatively standardized unit (TCO₂e) allows for comparability, tradability, and fungibility across markets.

Beyond apparent measurement inconsistencies, biodiversity credit programs differ substantially in how they operationalize these methodologies in project design and credit issuance. In practice, biodiversity credit developers secure investment from buyers or investors to finance conservation activities structured according to specific standards. These activities incentivize land stewards either to protect existing biodiversity—preventing its loss (“avoided loss”)—or to restore it (“uplift”) through measurable ecological improvements (Wunder et al., 2025). Both avoided loss and uplift are evaluated relative to a counterfactual

scenario representing what would have occurred in the absence of the biodiversity credit intervention, thereby enabling the assessment of additionality.

Currently, no biodiversity credit schemes seem to target biodiversity conservation and restoration in production forests. As discussed by Oettel and Lapin (2020), 44 biodiversity indicators and 32 forest management practices have been identified that link forest management practices with biodiversity outcomes. These indicators present opportunities for integration into biodiversity credit schemes, supporting greater consistency and methodological rigor. Examples of most common biodiversity indicators are arthropods, birds, plants and habitats which in turn are referring to tree microhabitats, deadwood, forest structure, habitat at landscape level and protected habitats. With regards to forest management indicators most common are stand structure and size and management intensity.

Our examination of past initiatives shows the common inclusion of milestones when measuring key project outcomes in support to the issuance of credits which we depict in Fig. 3. Commonly, at the start of a project poised to be a source of credits, a baseline and initial monitoring with ecosystem- and habitat-level metrics are established outlining goals of protection and/or uplift according to a selected methodology. Monitoring and assessments of outcomes are completed approximately mid-way through a project with a common 10–30 year period. Following verified outcomes by a third-party auditor, credits can be issued as a final milestone.

4.3. Lessons for voluntary forest-based biodiversity credits from carbon markets

Experiences from carbon credit schemes offer useful conceptual insights for developing biodiversity credit frameworks. The lessons drawn here highlight relevant considerations in existing carbon markets such as transparency, permanence, leakage, and additionality. We identify seven features particularly relevant to the development of principles that can ensure the environmental and social integrity of biodiversity credits (Table 3).

The first feature relates to the measurement of project outcomes based on actions or performance of improved forest management. Carbon credits can be issued based on actions such as extending the rotation period of a forest to enhance carbon sequestration above a baseline during the deferral period (e.g., 20 years or longer, as in Verra VM003; Verified Carbon Standard, 2023a). The determination of actual carbon sequestration occurs after the project period, which introduces inherent uncertainty and risk in execution. However, projects targeting forest conservation such as those under the Reducing Emissions from Deforestation and Degradation Methodology (Verified Carbon Standard, 2023c) issue carbon credits based on performance outcomes, i.e. if the forest is protected. There is a proposition that transitioning from an action-based to an outcome-based payment system improves the efficiency of payment mechanisms (Kim and Langpap, 2015). However, outcome-based payment systems generally require significant upfront project investments with revenues only taking place at the end of the project. Parisa et al. (2022) suggested that outcome-based 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 emission emitters and forest carbon sinks without requiring long-term commitments and this principle may be useful also in biodiversity credit projects.

Second, is the challenge to measuring additionality to assess whether a project would have been undertaken without the payment arising from

credits (Fiegenbaum, 2024; Vacchiano et al., 2018; Wunder et al., 2024). Additionality can be evaluated by examining each project, or by relying on secondary data to define business-as-usual assumptions (Li and Zhang, 2024; Murray et al., 2013). Van Benthem and Kerr (2013) noted that it is common to efficiently scale-up programs as an entity to a political jurisdiction at the regional or national scale with a single baseline. However, this is not always the case with voluntary carbon credits, where additionality is tested relative to the project methodology defining a particular baseline. Non-additionality can be managed by independent standards for which additionality tests are carried out. There are several standards for voluntary carbon credits and for emerging voluntary biodiversity credits such as Verra's Sustainable Verified Impact Standard (SD VISta; Verra, 2024b) for "nature credits" and Plan Vivo launched PV Nature Biodiversity Standard (Plan Vivo, 2025).

A third feature revolves around the permanence of carbon credits (Wunder et al., 2025). Non-permanence arises 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 insurance. An optimal contract design has been 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).

A fourth feature relates to leakage of outcomes including the possible displacement of emissions from one location to another, either within the project area or to a different geography, consequently undermining intended emissions reduction (Fiegenbaum, 2024; Haya et al., 2023). Wunder et al. (2025) outlined two approaches to mitigating leakage: one focused on increasing supply or reducing demand for restricted commodities to mitigate leakage; the other to view 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 to apply a jurisdictional default leakage rate to projects (Li and Zhang, 2024).

Fifth, capital investments can be challenged by a lack of transparency in the type of claims that can be made (Trouwloon et al., 2023). A general distinction made among corporate climate claims is that for signaling a long-term commitment to climate mitigation (e.g., net-zero claims) and those claims that have already been achieved (e.g., carbon-neutrality). The latter tend to rely substantially on carbon offsetting instead of direct 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 avoidance, minimization, restoration, and

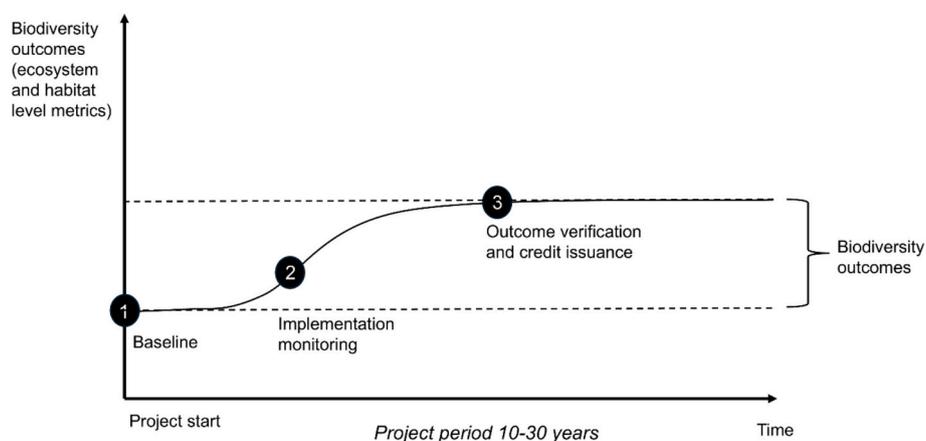


Fig. 3. Schematic of biodiversity credit project with milestones at project (1) starting baseline, (2) implementation monitoring, (3) outcome verification and credit issuance.

Table 3
Seven essential features of forest-based carbon credit projects, and conceptual insights for voluntary biodiversity credit projects.

Credit project design components	Forest carbon credit project experiences	Conceptual insights for voluntary forest biodiversity credit projects
Action-based payments	In afforestation projects, such as Verra VM0047 (Verified Carbon Standard, 2023b), and improved forest management projects (e.g., Verified Carbon Standard, 2023a), carbon credits are usually issued based on actions, for example extended rotation period, rather than actual carbon sequestration outcome.	The payment system should be outcome-based to increase efficiency of the payment mechanism (Kim and Langpap, 2015). However, an annualized payment system allows projects to be developed and traded without requiring long-term commitments from sellers and buyers, while also addressing cash flow challenges that arise when revenues are only realized upon performance assessment at the end of the project proving the outcome of the project. (Parisa et al., 2022).
Outcome-based payments	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).
Additionality	Additionality defines whether the project and its benefits would have been accrued without its financing by defining a baseline (“business as usual”), usually within a sector or a region, such as in improved forest management projects (Verified Carbon Standard, 2023a). Jurisdictional baselines exist (Verified Carbon Standard, 2023c).	Additionality tests and baselines should be scaled to jurisdictional level to improve efficiency (van Benthem and Kerr, 2013). There is a risk that stacking can affect the perceived additionality of carbon plantings, which has the potential to erode the integrity of carbon markets (Torabi and Bekessy, 2015).
Permanence and risk of reversal	Permanence and risk of reversal are commonly dealt with by reserving credit buffers (Fiegenbaum, 2024) which are kept during the entire project period. This is illustrated by the Verra methodology for improved forest management (Verified Carbon Standard, 2023a).	The optimal contract design has been 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). An annualized payment system allows projects to be developed and traded without requiring long-term commitments from sellers and buyers (Parisa et al., 2022).
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., 2025). A common approach is application of a default leakage rate because leakage is often unavoidable (Li and Zhang, 2024).
Transparency	There might be a lack of transparency in 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).

Table 3 (continued)

Credit project design components	Forest carbon credit project experiences	Conceptual insights for voluntary forest biodiversity credit projects
Inclusive stakeholder governance	Active inclusion of stakeholders in carbon credit projects is crucial to address equity and inclusiveness 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)

offsetting impact losses (Ghijselinck et al., 2025). Net-positive conservation investments may only be advisable after credits have met a threshold of no net biodiversity losses (Maron et al., 2023). Another important aspect is the consideration of landscape-level effects, 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 linking each project to regional and national biodiversity goals (Business and Biodiversity Offsets Programme, 2012).

Lastly, the review of carbon markets points to inclusive stakeholder governance as being essential for successful, equitable and inclusive conservation (Tedesco et al., 2023). Equity in governance involves a fair distribution of benefits and costs, inclusive and transparent decision-making processes, and consideration of pre-existing conditions that can influence access to resources and participation. Weak governance—as evidenced by unequal access to information, unstable payments, and exclusion from decision-making processes—reduces trust and ownership, leading to poor conservation outcomes (McDermott et al., 2013). Socio-economic factors, such as governance quality and stakeholder perceptions, can 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).

4.4. Market characteristics for voluntary biodiversity credits

Financial capital will be needed to support investments in biodiversity credits. Some suggest that issuance of green financial conservation products has the potential to attract 30–90 billion USD annually by 2030 (Deutz et al., 2020). Nature-based solution projects, which biodiversity credits may be part of, are projected to reach an annual value of 25–40 billion USD by 2030 (Deutz et al., 2020). Our review suggests several market characteristics needed to help meet market expectations, including:

- **Clear and enforceable property rights:** Property rights define the rules establishing the demand, access, use, and transferability of traded assets, and the roles and responsibilities of parties engaged in market transactions (Alvarado-Quesada et al., 2014; Koh et al., 2019; Zhang, 2016). The US wetland mitigation banking program offers an example of a clear legal framework for the use of wetland credits to compensate for unavoidable impacts by establishing enforceable property rights that support active trading. In the case of developing countries implementing REDD + programs (UN Climate Change, 2025) to mitigate greenhouse gas emissions, many face challenges such as weak land tenure, poorly defined property rights, and limited enforcement systems that can call into question the environmental and social integrity of credits (Palmer, 2011).
- **Sufficient number of buyers and sellers to support pricing mechanisms:** A large number of buyers and sellers is essential to achieve market efficiency (Alvarado-Quesada et al., 2014), although the inclusion of many participants can substantially increase transaction costs of tradable credits (Stavins, 1995). In biodiversity offset markets, competition among buyers and sellers establishes a price

mechanism to balance supply and demand. Data from more than 100 countries where laws or policies require biodiversity offsetting or voluntary measures to compensate for negative impacts of development on biodiversity (IUCN, 2019), suggest that offsets tend to occur where there are clear regulatory requirements. Regulated markets, with governments defining property rights, liabilities, valuation metrics, and exchange rules, encompass those demanding credits (e.g., land developers) who can choose the most efficient credit suppliers via mitigation banks or by transacting directly with landowners (Koh et al., 2019).

- **Information symmetry:** Incomplete information is widely recognized as a challenge to the effective functioning of biodiversity markets (Alvarado-Quesada et al., 2014). In examples from U.S. and Australian biodiversity schemes, adverse selection—a problem arising from asymmetrical information, where one party has better knowledge about the traded good—seems uncommon. This is because credits are defined and assigned by a third party, ensuring that the characteristics of biodiversity credits is assessed during credit issuance and trading. This process guarantees a minimum quality standard for credits in the market (Elton and Fitzsimons, 2023). Some, like Clifton and Schwerdtner Manez (2025), suggest that disclosing social integrity information, including local community rights where credits originate, could not only improve asymmetries but also lead to associated price premiums.
- **Barriers to entry:** High transaction costs are a major 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. Transactions costs can be prohibitive for small-scale participants to bear and may undermine the economic viability of PES initiatives without policy or institutional mechanisms to reduce them (Huber-Stearns et al., 2013). Another barrier to entry can be the ability and willingness to participate, particularly among landowners. While financial limitations are frequently highlighted, participation is also shaped by broader factors such as education, social networks, access to physical and natural resources, and cultural preferences for non-monetary exchanges. Willingness is further influenced by perceived fairness, social motivations, environmental values, and risk reduction potential—underscoring that successful participation depends on both material and non-material conditions (Clifton and Schwerdtner Manez, 2025).
- **Standardized methods to define and measure a unit of biodiversity and credit:** A significant challenge for both voluntary and regulatory-based biodiversity markets is the lack of standardized methodologies defining tradable units of biodiversity. Often, schemes employ their own measurement system to quantify credits, and define a baseline and additionality (Blanton et al., 2024) making it difficult to compare credits and facilitate tradeable biodiversity credits (OPIS, 2024; Taskforce on Nature Related Markets, 2023; Zynobia et al., 2023).

4.5. Voluntary biodiversity credits and EU forest policy

There are several EU strategies and policies addressing forest biodiversity conservation and restoration. Under an overarching European Green Deal (European Commission, 2024a) the most relevant policies at the EU level are the Biodiversity Strategy for 2030, the Council Directive 1992/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, commonly referred to as the ‘Habitats Directive’, the Regulation 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation 2022/869, commonly referred to as the ‘Nature Restoration Law’, the Forest Strategy (European Commission, 2024b) and the Regulation of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable

investments, commonly referred to as the ‘EU Taxonomy Regulation for Sustainable Activities’. Evidence of how implementation of conservation directives on productive lands can lead to financial compensation already exists. The Court of Justice of the European Union (2022) has ruled that “support is to be granted annually per hectare of agricultural area or per hectare of forest in order to compensate beneficiaries, in the areas concerned, for additional costs and income foregone resulting from disadvantages”, related to the implementation of the Habitats Directive 1992/43/ECC, the Directive of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds commonly referred to as the ‘Birds Directive’ and the Directive of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, commonly referred to as the ‘Water Framework’. That ruling clarified that a system of compensation under this Directive can be based on land opportunity costs to meet conservation goals on agricultural and forestry lands including procedures, preconditions, priorities, quality standards, technical specifications, among other considerations. Nevertheless, it makes no explicit mention to market-based incentives nor private initiatives.

The EU Biodiversity Strategy for 2030 is a comprehensive and long-term plan to protect nature and halt ecosystem destruction. The Strategy is a core element of the European Green Deal, which is the EU’s program that addresses climate change and environmental degradation. Key goals of the strategy include expanding protected areas to 30% of the EU’s land and sea and restoring nature by 2030. These goals have spurred considerable concern among many European countries whose economies derive significant income from agriculture and commercial forest management because of uncertain implications for forest owners in national compliance (Swedish Forest Industries, 2022).

In June 2023, the European Parliament voted to pass a new Nature Restoration Law, 2024/1991, despite concerns from many EU farmers and forest owners (Canas, 2024; Hunter, 2024; Schauenberg, 2023). The Nature Restoration Law 2024/1991, 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. With respect to forestry, the following restoration measures are discussed in the Nature Restoration Law, 2024/1991, all of which could 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 is another initiative central to the European Green Deal and builds on the EU Biodiversity Strategy for 2030. The Forest Strategy aims to contribute to the EU biodiversity objectives and greenhouse gas emission reduction targets of at least 55% from 1990 levels 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 2020/852 is

a classification system that defines criteria for economic activities that are aligned with a net zero trajectory by 2050 and environmental goals broader than climate. A goal is to help scale sustainable investments and create security for investors by setting out conditions for economic activities to be qualified as environmentally sustainable. Protection and restoration of biodiversity and ecosystems are outlined in Articles 9, 10, and 15; along activities poised to substantially contribute to the protection and restoration of biodiversity and ecosystems. Under the EU Taxonomy Regulation for Sustainable Activities 2020/852, only activities that yield net biodiversity gains (i.e., not offsets) can be accounted for as a sustainable, hence, eligible as voluntary biodiversity credits. The EU Taxonomy Regulation for Sustainable Activities 2020/852 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, including initial biodiversity assessment, management plan requirement, stakeholder consultation, monitoring scheme, permanence, transparency, third-party audit, and verification. Guidelines and criteria that acknowledge nature conservation and restoration as a form of sustainable investment can encourage corporate willingness to invest related activities, thus, help mobilize necessary capital.

The Directive of the European Parliament and of the Council of 14 December 2022 regarding corporate sustainability reporting, commonly referred to as the ‘Corporate Sustainability Reporting Directive’ which took effect in January 2023, is likely to have a direct impact on businesses’ willingness to invest in biodiversity conservation and restoration. This Directive defines corporate reporting rules concerning social and environmental disclosures. It 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 lead to businesses aiming for no-net-loss or even net nature-positive outcomes, which may entail financing of nature restoration projects or purchase of voluntary biodiversity credits or similar instruments).

In summary, forest biodiversity conservation and restoration in the EU are guided by an integrated policy framework under the European Green Deal, including the Biodiversity Strategy for 2030, Nature Restoration Law 2024/1991, Forest Strategy, Habitats Directive 1992/43/ECC, and EU Taxonomy Regulation for Sustainable Activities 2020/852. These policy instruments establish binding targets for protection and restoration, strive to promote sustainable forest management, and increasingly recognize financial compensation and investment mechanisms for conservation measures on productive lands. Legal clarification by the Court of Justice of the EU confirms that opportunity-cost-based compensation schemes for landowners can be established, although market-based instruments are not yet explicitly embedded in legislation. Complementary regulatory frameworks such as the EU Taxonomy Regulation for Sustainable Activities 2020/852 and the Corporate Sustainability Reporting Directive 2022/2464 have the potential to further incentivize private capital flows toward biodiversity-positive activities by defining eligibility criteria, reporting obligations, and standards for credible investment in nature.

5. Discussion

5.1. Prospects for the implementation of voluntary biodiversity credits in production forests

About 1.15 billion ha accounting for some 30% of the world’s forestlands are classified as production forests (FAO and UNEP, 2025). Such a large share of forests where active management is legally permitted seems poised for the adoption of biodiversity credits. Categorization as productive forest reflects knowledge of minimum land productivity thresholds that often underpin quality of biodiversity habitat. Greater levels of productivity are closely correlated with financial profitability that can challenge the allocation of these forestlands to active conservation because of large opportunity costs (Lovrić et al., 2025). On the other hand, knowledge of productivity thresholds and market values can facilitate the establishment of baselines, measurable outcomes, and gauge land use change pressures to assess the performance, additionality and permanence of biodiversity conservation payments (Mönkkönen et al., 2014). Extant legal structures enveloping production forests can improve the governance, equality and inclusiveness of voluntary biodiversity credit markets. Here, we recognize that other non-production forests such as those under strict conservation can also be part of a market of biodiversity conservation credits, but the clear identification of owners and/or users along relevant stakeholders of production forests can lead to a transparent system of biodiversity credits where due diligence of credits, buyers and sellers and support environmental integrity and inclusive governance. For instance, a common definition for production forests within a particular jurisdiction can support leakage assessments particularly if production forests are certified for sustainable forest management as stewardship certifications have mechanisms to gauge and handle leakage (FSC Controlled Wood, 2025). By extension, the ability to assess opportunity costs of foregone timber management offers shadow prices to estimate what payment levels would be necessary to trigger conservation. The adoption of management plans across many production forests and their common participation in timber markets can lower transaction costs in the creation, monitoring, and issuance of credits. A combination of clarity and enforceability of property rights, inferable opportunity conservation costs, and low transaction costs can help the success of biodiversity investments within a voluntary framework and via transfer payments (Langpap and Wu, 2017).

Financial payments that internalize non-market forest ecosystem values can bring a premium to forest owners (Mei, 2023). Diversification of income opportunities creates economic incentives for forest management other than single-species even-age silvicultural management within production forests (Mei, 2023; Satake et al., 2008). Conditions have been conceptually derived to promote the effectiveness of payments to promote endangered species conservation (Langpap and Wu, 2017), but there is limited empirical evidence to-date (Lewis et al., 2011). Despite two-thirds of the world’s biodiversity offsets being found in forested ecosystems, none have shown successful no-net-loss outcomes for forested habitats or species (zu Ermgassen et al., 2019). A lack of adequate long-term monitoring programs with standardized monitoring approaches, such as randomized design and baseline data, makes it difficult to evaluate biodiversity offset programs (Josefsson et al., 2021).

Evidence consistently shows that biodiversity outcomes are closely linked to forest management practices, and that measurable associations exist between indicators of forest management and biodiversity (Chaudhary et al., 2016; Dieler et al., 2017; Oettel and Lapin, 2020). Commonly cited indicators of biodiversity in production forests include:

- Habitat structure, e. g. standing and lying dead wood, old and veteran trees relating to many species including fungi, lichens, arthropods, birds, bats and bryophytes (Asplund et al., 2024; Floren et al., 2014; Lassauce et al., 2011; Parisi et al., 2016),

- Canopy and stand structural diversity, e. g. basal area, canopy cover and diversity, tree species diversity, diameter distribution, tree age and height etc. relating especially to vascular plants, birds and ground dwelling species (Larrieu et al., 2018; Winter et al., 2015; Sever and Nagel, 2019), and
- Reduced harvesting intensity or even a “no-management” approach, e. g. lowering of harvesting intensity, adaptation of forest management methods and creation of areas with no forest management, relating to especially various bird species. These indicators may therefore be particularly relevant for the monitoring of biodiversity credit projects in production forests. Many species benefit from or even require active management measures for their conservation and development (Augustynczyk et al., 2019; Cistrone et al., 2015; Hlásny et al., 2017). For example, there is evidence of higher bat foraging activity in sustainably managed forests relative to unmanaged stands (Cistrone et al., 2015). Moreover, greater vascular plant species richness has shown a positive association with shifts in tree species composition in forests previously dominated by monocultural spruce (Hlásny et al., 2017).

Single-species conservation frameworks, including keystone, flagship, and umbrella species, have been widely applied to guide habitat management, based on the assumption that protecting habitat for selected species confers broader biodiversity benefits. Although umbrella species approaches can be cost- and time-efficient, they are also criticized for taxonomic bias and limited reliability as comprehensive biodiversity indicators, particularly in forest ecosystems (Oettel and Lapin, 2020). In a biodiversity credit application context, the demonstrated sensitivity of species responses to silvicultural measures may support the use of linkages between forest management and biodiversity outcomes to design a streamlined, pragmatic system that prioritizes monitoring of ecological structures shaped by management, rather than relying on single-species assessments. Examples of management interventions that promote structural diversity include reducing stem density, promoting mixed-species stands, extending rotation periods, and creating both horizontal and vertical heterogeneity within stands.

Attaining and sustaining old-growth conditions in the long term is often associated with a loss of financial profitability for forest owners (Sever and Nagel, 2019). Compensation via voluntary biodiversity credits can help ameliorate trade-offs between wood production revenues and biodiversity protection (Naumov et al., 2018; Mönkkönen et al., 2014; Triviño et al., 2016; Angelstam et al., 2018). Modest reductions in timber revenues can substantially increase landscape multifunctionality, particularly biodiversity indicators.

5.2. Voluntary biodiversity credit adoption across production forests to advance EU policy goals

Total forest area in the EU spans over 160 million ha but only 4% has not been impacted by human intervention (European Parliament, 2023). Forest production landscapes will be instrumental to supporting the circular bioeconomy via wood production and other ecosystem services (Salvador et al., 2023). Production forests in Europe, in particular those in Nordic countries, are of national and international economic importance because they produce large amounts of industrial wood traded worldwide and are often managed intensively for commercial wood production (Eggers et al., 2022; Rytter et al., 2016). The prevalence of private ownership across EU production forests presents an opportunity for voluntary adoption and income diversification to support the advancement of EU policy goals.

In response to the escalating biodiversity crisis of the 21st century, international, regional, and local policy frameworks have increasingly emphasized the role of forest biodiversity in achieving broader conservation objectives (Bayrak and Marafa, 2016). Opportunities to voluntarily incorporate conservation credits as part of the management of production forests align with extant EU policies. President von der Leyen

stated in September 2024 that “we can create a market for restoring our planet”, specifically mentioning “nature credits” (European Commission, 2024c); this shows ambition and a direction for action within the EU. Our examination of European policy relevant to production forest landscapes shows that the EU Nature Restoration Law creates favorable policy conditions for financing biodiversity restoration measures through credit mechanisms, as restoration targets under this framework align directly with biodiversity credit objectives. The adoption of voluntary biodiversity credits in European forests will partly hinge on the development of standardizing methodologies to define and measure, among others, biodiversity units and impacts to gauge additionality and permanence. In Europe, and in line with monitoring processes, the establishment of jurisdictional level baseline recommendations with corresponding additionality tests can offer an opportunity to support claims of net social and environmental benefits.

All aforementioned EU regulations and strategies provide guidance and opportunities to create new flows of private finance to invest in nature conservation and restoration, but PES and PES-like schemes within forestlands are scarce in Europe (Hernández-Morcillo et al., 2022) specifically productive forests, although there are some relevant experiences elsewhere as with agri-environmental programmes. Zu Ermgassen and Löfqvist (2024) stress that to attract capital to be invested in voluntary biodiversity credits, there needs to be a clear policy signaling a sustained demand for credits. The EU Forest Strategy already encourages the establishment of PES schemes and, in particular, the roll out of carbon farming practices. The European Commission has proposed an EU voluntary framework for certifying carbon removals (European Commission, 2025); this framework includes critical building blocks for a voluntary scheme that could also potentially be adopted for a voluntary biodiversity scheme. Integrating biodiversity credits into certified carbon removal credits would entail a degree of stacking of these two forest ESs (which we mentioned could challenge measurements of additionality, leakage and permanence), but it could also lower transaction costs for participation in credits markets and enhance accessibility to both suppliers and buyers. A staff working document (European Commission, 2023) 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.

In a scenario where biodiversity credits are widely adopted across European production forests, there will be discernible trade-offs from lower timber supplies and consequential economic effects that could challenge the advancement of a circular bioeconomy. Future studies should explore scenarios where long-term biodiversity conservation and restoration efforts impact the wood products sector, particularly where the wood products industry is a central component of rural economies. Potential trade-offs might be starker on particular private forests owners and their ownerships for which asymmetric effects should be assessed (Tiebel et al., 2021). Such investigations are essential to informing public policy and to the design of biodiversity credits in a quest to reach a more optimal balance between wood production and improved biodiversity outcomes. In line, more research is also needed to recommend efficient biodiversity credit design, payment mechanisms, and financing schemes tailored to European contexts to both satisfy marketability and improve biodiversity outcomes.

Sweden, with 83 percent of its nearly 18 million ha of forestland classified as productive forests (Riksskogstaxeringen (Swedish National Forest Inventory Program), 2025), provides an example regarding the prospects for adopting voluntary biodiversity credits. EU Natura 2000 sites in Sweden expand over 808,400 ha of production forests, and 898,400 ha of non-productive forests (Sweden Statistical Database, 2025b). Across production forests in Sweden 1.44 million ha constitute formally protected land and 1.39 ha correspond to voluntary set-asides, totaling about 12.2 percent of all Swedish production forests (Sweden Statistical Database 2025a). Albeit a relatively small share, it equates to

about all forests in Austria. Opportunities remain for voluntary actions to efficiently compensate private forest owners to promote less-intensive and diverse management systems across a larger share of production forests (Lovrić et al., 2025).

Swedish forests are particularly relevant to the EU Biodiversity Strategy because its implementation will likely heighten timber management pressures on Nordic boreal forests as a result of less management elsewhere (Di Fulvio et al., 2025). According to Triviño et al (2016), maximizing timber revenues has precluded achieving high levels of either carbon storage or biodiversity in boreal forests. Market-oriented interventions under Swedish law already support domestic forest biodiversity including nature conservation agreements (where landowners are compensated for the forgone value of commercial timber amortized over multi-year agreements), and set-asides within management units as required under third-party forest certification (Länsstyrelserna (Swedish County Administrative Board), 2025). Nevertheless, not all conservation actions involve financial payments as it is the case when key biotopes are identified and the Swedish Forest Agency could require mandatory set-asides without financial compensation (Blicharska et al., 2022).

In Sweden the EU Birds Directive 2009/147/EC and Habitats Directive 1992/43/ECC are implemented under the Species Protection Ordinance, although interpretation of legal requirements is often debated in the Courts (Naturvårdsverket, 2025). General guidance has been issued regarding select species in Sweden such as in the case of habitat quality for *Picoides tridactylus* L. (Roberge et al., Diarién 2024), but species-specific criteria and considerations that can affect forest management are set on a case-by-case basis (Skogsstyrelsen, 2025). Such a context creates a degree of uncertainty from potential regulatory actions faced by forest owners. The high transaction costs stemming from regulated case-by-case management interventions that can be litigated with uncertain consequences can create an incentive for voluntary market-oriented conservation measures to emerge (Langpap and Wu, 2017).

6. Conclusions

Our findings suggest that production forests are well-positioned for the implementation of biodiversity credits for conservation and restoration. Past experiences with carbon credits in the forest sector offer strong guidance to develop and support the design of voluntary biodiversity credit schemes. Specifically, we point to the ability to gauge additionality, permanence, and leakage from biodiversity credits

Appendix 1

Final sample of scholarly literature selected for knowledge synthesis.

No.	Section	Reference	Citation
1	4.4	Alvarado-Quesada et al., 2014	Alvarado-Quesada, I., Hein, L., Weikard, H. P., 2014. Market-based mechanisms for biodiversity conservation: A review of existing schemes and an outline for a global mechanism. <i>Biodivers. Conserv.</i> 23, 1–21. https://doi.org/10.1007/s10531-013-0598-x .
2	5.1	Angelstam et al., 2018	Angelstam, P., Naumov, V., Elbakidze, M., Manton, M., Priednieks, J., Rendenieks, Z., 2018. Wood production and biodiversity conservation are rival forestry objectives in Europe's Baltic Sea Region. <i>Ecosphere</i> 9(3):e02119. https://doi.org/10.1002/ecs2.2119
3	4.2	Aotearoa New Zealand Ministry for the Environment, 2022	Aotearoa New Zealand Ministry for the Environment, 2022. Investigating the use of biodiversity markets to scale financing of nature-based solutions in Aotearoa New Zealand. https://consult.environment.govt.nz/biodiversity/nz-biodiversity-credit-system/supporting_documents/20230905_Pollination_NZ_MfE_Summary_Report.pdf .
4	5.1	Asplund et al., 2024	Asplund, J., Nordén, J., Kjønaas, O. J., Madsen, R.L., Lunde, L. F., Birkemoe, T., Ronold, E. K., Norkute, M., Jansson, K. U., Karlson, D. P., Sverdrup-Thygeson, A., 2024. Long term effects of forest management on forest structure and dead wood in mature boreal forests. <i>For. Ecol. Manag.</i> 572, 122315. https://doi.org/10.1016/j.foreco.2024.122315 .
5	5.1	Augustynczyk et al., 2019	Augustynczyk, A. L., Asbeck, T., Basile, M., Bauhus, J., Storch, I., Mikusinski, G., Yousefpour, R., Hanewinkel, M., 2019. Diversification of forest management regimes secures tree microhabitats and bird abundance under

(continued on next page)

implemented in production forests. Defined ownership and users' forestland rights, the capacity to gauge land opportunity cost and in many cases the existence of management plans make such assessments possible across production forests – also reducing transaction costs – as compared to other forest categories. Further, defined tenure and user rights within production forests can support the inclusiveness of different stakeholders in the governance of voluntary biodiversity credits systems. By extension, measurable outcomes and identifiable responsible parties can support the transparency and integrity of biodiversity credits. Our analyses of the literature suggest that for voluntary biodiversity credit markets to emerge these will require clear government policy signals and legal frameworks to create demand signals and regulatory certainty to foster private investments. European production forests and extant EU policy framing biodiversity conservation and restoration seem to already offer fundamental conditions to support the adoption and scalability of voluntary biodiversity credit systems.

CRediT authorship contribution statement

Aleksandra Holmlund: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **Francisco X. Aguilar:** Writing – review & editing, Supervision, Conceptualization. **Anneli M. Ågren:** Writing – review & editing, Supervision. **Tomas Lundmark:** Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We thank Mallory Eckstut, Ph.D., of Synergy Scientifics LLC for editorial assistance and proofreading an earlier draft of this article. This work was partially funded by The Swedish Research Council (Formas: 2025-00213) to FA, and (Formas: 2021-00713, 2021-00115) and the Knut and Alice Wallenberg Foundation (Future Silviculture: 2018.0259) to AÅ. Funding sources were not involved in study design, collection, analysis and interpretation of data, nor in the writing of this article. Any errors are the authors' responsibility.

(continued)

No.	Section	Reference	Citation
			climate change. <i>Science of The Total Environment</i> , 650, Part 2, 2717–2730. https://doi.org/10.1016/j.scitotenv.2018.09.366
6	4.2	Australian Department of Climate Change, Energy, the Environment and Water, 2025	Australian Department of Climate Change, Energy, the Environment and Water, 2025. Nature Repair Market. https://www.dcceew.gov.au/environment/environmental-markets/nature-repair-market (accessed 9 March 2025).
7	4.2	Barisa et al., 2024	Barisa, K., Millington Drake, M., Shah, T., Susarla, R., Rodewald, N., 2024. Credit wheredit's due: Identifying the core principles for a high integrity biodiversity credit market. https://www.planvivo.org/news/new-report-credit-where-credits-due (accessed 14 December 2024).
8	5.2	Bayrak and Marafa, 2016	Bayrak, M. M., and Marafa L. M., 2016. Ten years of REDD+: A Critical Review of the Impact of REDD + on Forest-Dependent Communities. <i>Sustainability</i> . 8, 620. https://doi.org/10.3390/su8070620
9	4.2	Biodiversity Consultancy, 2022	Biodiversity Consultancy, 2022. Biodiversity credits: Design Principles for High Integrity Outcomes, 2022. https://www.thebiodiversityconsultancy.com/insights/biodiversity-credits-design-principles-for-high-integrity-outcomes/ (accessed 25 October 2025)
10	4.1	Biodiversity Credit Alliance, 2024a	Biodiversity Credit Alliance, 2024a. Definition of a biodiversity credit. Issue paper. https://www.biodiversitycreditalliance.org/wp-content/uploads/2024/05/Definition-of-a-Biodiversity-Credit-Rev-220524.pdf (accessed 14 December 2024).
11	4.2	Biodiversity Credit Alliance, 2024b	Biodiversity Credit Alliance, 2024b. High level principles to guide the biodiversity credit market. Working paper. https://www.biodiversitycreditalliance.org/wp-content/uploads/2024/11/BCA_High-level-Principles-to-Guide-the-Biodiversity-Market-working-paper-EN_ES_FR.pdf (accessed 14 December 2024).
12	4.4	Blanton et al., 2024	Blanton, A., Mohan, M., Galgamuwa, G. P., Watt, M. S., Montenegro, J. F., Mills, F., Carlsen, S. C. H., Velasquez-Camacho, L., Bomfim, B., Pons, J., Broadbent, E. N., 2024. The status of forest carbon markets in Latin America. <i>J. Environ. Manag.</i> 352, 119921. https://doi.org/10.1016/j.jenvman.2023.119921 .
13	5.2	Blicharska et al., 2022	Blicharska, M., Hedblom, M., Josefsson, J., Widenfalk, O., Ranius, T., Öckinger, E. and Widenfalk, L.A., 2022. Operationalisation of ecological compensation—Obstacles and ways forward. <i>Journal of Environmental Management</i> , 304, 114277. https://doi.org/10.1016/j.jenvman.2021.114277
14	4.2	Bloom Labs database, 2025	Bloom Labs database, 2025. https://app.bloomlabs.earth/schemes (accessed 11 October 2025)
15	4.1	Bonneuil, 2015	Bonneuil, C., 2015. Tell me where you come from, I will tell you who you are: A genealogy of biodiversity offsetting mechanisms in historical context. <i>Biol. Conserv.</i> 192, 485–491. https://doi.org/10.1016/j.biocon.2015.09.022 .
16	4.3	Business and Biodiversity Offsets Programme, 2012	Business and Biodiversity Offsets Programme, 2012. Standard on biodiversity offsets. https://www.forest-trends.org/wp-content/uploads/bbop/bbop_standard_on_biodiversity_offsets_1_feb_2013-pdf.pdf (accessed 14 December 2024).
17	4.5	Canas, 2024	Canas, N., 2024. Contested Nature Restoration Law passes EU Parliament, despite last-minute revolt. https://www.euractiv.com/section/biodiversity/news/contested-nature-restoration-law-passes-eu-parliament-despite-last-minute-revolt/ (accessed 14 September 2024).
18	4.2	Carbon Pulse, 2023	Carbon Pulse, 2023. Queensland govt issues A\$10 mln reef credit purchase guarantee. https://carbon-pulse.com/223785/ (accessed 14 September 2024).
19	4.2	Carbon Pulse, 2024	Carbon Pulse, 2024. Australia issues tender to develop first methodologies under Nature Repair Market. https://carbon-pulse.com/308148/ (accessed 17 October 2024).
20	5.1	Chaudhary et al., 2016	Chaudhary, A., Burivalova, Z., Koh, L. et al., 2016. Impact of Forest Management on Species Richness: Global Meta-Analysis and Economic Trade-Offs. <i>Sci Rep</i> 6, 23954. https://doi.org/10.1038/srep23954
21	5.1	Cistrone et al., 2015	Cistrone, L., Altea, T., Matteucci, G., Posillico, M., De Cinti, B., Russo, D., 2015. The effect of thinning on bat activity in Italian high forests: the LIFE+ “ManFor C. BD:” experience. <i>Hystrix It. J. Mamm.</i> 26(2), 125–131. https://doi.org/10.4404/hystrix-26.2-11477
22	1;4.1	Convention on Biological Diversity, 2022	Convention on Biological Diversity, 2022. COP15: Nations adopt four goals, 23 targets for 2030 in landmark UN biodiversity agreement. https://www.cbd.int/article/cop15-cbd-press-release-final-19dec2022 (accessed 9 January 2023).
23	4.3	Cordero Salas et al., 2013	Cordero Salas, P., Roe, B. E., Sohngen, B., 2013. Addressing additionality in REDD contracts when formal enforcement is absent. World Bank Policy Research Working Paper No. 6502. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/415971468326187886/addressing-additionality-in-redd-contracts-when-formal-enforcement-is-absent (accessed 14 December 2024).
24	4.5	Court of Justice of the European Union, 2022	Court of Justice of the European Union, 2022. Press release No 17/22. Luxembourg, 27 January 2022. https://curia.europa.eu/jcms/upload/docs/application/pdf/2022-01/cp220017en.pdf (accessed 26 October 2025).
25	4.4; 5	Deutz et al., 2020	Deutz, A., Heal, G.M., Niu, R., Swanson, E., Townshend, T., Zhu, L., Delmar, A., Meghji, A.Sethi, S.A., Tobin-de la Puente, J., 2020. Financing nature: Closing the global biodiversity financing gap. The Paulson Institute, The Nature Conservancy, and the Cornell Atkinson Center for Sustainability.
26	5.1	Dieler et al., 2017	Dieler, J., Uhl E., Biber P., Müller J., Rötzer T., Pretzsch H., 2017. Effect of forest stand management on species composition, structural diversity, and productivity in the temperate zone of Europe. <i>Eur J Forest Res</i> 136, 739–766 (2017). https://doi.org/10.1007/s10342-017-1056-1
27	5.2	Di Fulvio et al., 2025	Di Fulvio, F., Snäll, T., Lauri, P., Forsell, N., Mönkkönen, M., Burgas, D., Blattter, C., Eyvindson, K., Caicoya, A.T., Vergarechea, M. and Antón-Fernández, C., 2025. Impact of the EU biodiversity strategy for 2030 on the EU wood-based bioeconomy. <i>Global Environmental Change</i> , 92, 102986. https://doi.org/10.1016/j.gloenvcha.2025.102986
28	5.2	Eggers et al., 2022	Eggers, J., Lundström, J., Snäll, T., Öhman, K., 2022. Balancing wood production and biodiversity in intensively managed boreal forest. <i>Scand. J. For. Res.</i> 37, 213–225. https://doi.org/10.1080/02827581.2022.2066170 .
29	4.4	Elton and Fitzsimons, 2023	Elton, P., Fitzsimons J. A., 2023. Framework features enabling faster establishment and better management of privately protected areas in New South Wales, Australia. <i>Front. Conserv. Sci.</i> 4:1277254. https://doi.org/10.3389/fcosc.2023.1277254
30	5.2	European Commission, 2023	European Commission, 2023. Commission staff working document: Guidance on the development of public and private payment schemes for forest ecosystem services. https://agriculture.ec.europa.eu/system/files/2023-07/guidance-dev-public-private-payment-schemes-forest_en.pdf (accessed 27 February 2025).
31	4.5	European Commission, 2024a	European Commission, 2024a. The European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (accessed 27 February 2025).
32	4.5	European Commission, 2024b	European Commission, 2024b. New EU forest strategy for 2030. https://environment.ec.europa.eu/strategy/forest-strategy_en (accessed 27 February 2025).

(continued on next page)

(continued)

No.	Section	Reference	Citation
33	5.2	European Commission, 2024c	European Commission, 2024c. Keynote speech by President von der Leyen at the DLD NatureConference. https://ec.europa.eu/commission/presscorner/detail/en/speech_24_4668/ (accessed 14 September 2024).
34	5.2	European Parliament, 2023	European Parliament, 2023. The European Union and forests. https://www.europarl.europa.eu/erpl-app-public/factsheets/pdf/en/FTU_3.2.10.pdf (accessed on 27 February 2025)
35	5.1	FAO, UNEP, 2020	FAO, UNEP, 2020. The state of the world's forests 2020: Forest, biodiversity, and people. FAO and UNEP, Rome. https://www.fao.org/documents/card/en/c/ca8642en (accessed 27 February 2025).
36	4.3	Fiegenbaum, 2024	Fiegenbaum, H., 2024. Complementing carbon credits from forest-related activities with biodiversity insurance and resilience value. https://doi.org/10.48550/arXiv.2411.08452
37	5.1	Floren et al., 2014	Floren A., Müller T., Sittrich M., Weiss M., Linsenmair K. E., 2014. The influence of tree species, stratum and forest management on beetle assemblages responding to deadwood enrichment. <i>For. Ecol. Manage.</i> , 323, 57–64. https://doi.org/10.1016/j.foreco.2014.03.028
38	3	Footnote 1	European Council Directive 1992/43/EEC. Link: https://eur-lex.europa.eu/eli/dir/1992/43/oj
39	4.5	Footnote 2	Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: EU Biodiversity Strategy for 2030, Bringing Nature Back into our Lives. European Commission, Brussels. Link: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380
40	4.5	Footnote 3	Council Directive 1992/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Link: https://eur-lex.europa.eu/eli/dir/1992/43/oj
41	4.5	Footnote 4	Regulation 024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation 2022/869. Link: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1991&qid=1722240349976
42	4.5	Footnote 5	Regulation 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation 2019/2088. Link: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852
43	4.5	Footnote 6	Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (Codified version). Link: OJ L 20, 26.1.2010, pp. 7–25. Current consolidated version: 26/06/2019. https://eur-lex.europa.eu/eli/dir/2009/147/oj/eng
44	4.5	Footnote 7	Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. OJ L 327, 22. 12. 2000, pp. 1–73. Current consolidated version: 20/11/2014. Link: https://eur-lex.europa.eu/eli/dir/2000/60/oj/eng (accessed on 26 October 2025).
	5	Footnote 8	Directive 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting. Link: https://eur-lex.europa.eu/eli/dir/2022/2464/oj
45	5.1	FSC Controlled Wood, 2025	FSC Controlled Wood, 2025. https://us.fsc.org/en-us/certification/controlled-wood (accessed 12 October 2025)
46	4.3	Ghijssels et al., 2025	Ghijssels, D., Matthysen, E., Honnay, O., 2025. Mitigation Without Biodiversity Loss? Strengthening the Mitigation Hierarchy in Environmental Impact Assessment. Available at SSRN: https://ssrn.com/abstract=5290546 or http://dx.doi.org/10.2139/ssrn.5290546
47	4.3	Gren and Aklilu, 2016	Gren, I.-M., Aklilu, A. Z., 2016. Policy design for forest carbon sequestration: A review of the literature. <i>For. Policy Econ.</i> 70, 128–136. http://dx.doi.org/10.1016/j.forpol.2016.06.008 .
48	4.3	Haya et al., 2023	Haya, B. K., Evans, S., Brown, L., Bukoski, J., Butsic, V., Cabiyo, B., Jacobson, R., Kerr, A., Potts, M., Sanchez, D. L., 2023. Comprehensive review of carbon quantification by improved forest management offset protocols. <i>Front. For. Glob. Change</i> 6, 958879. https://doi.org/10.3389/fgc.2023.958879 .
49	5.2	Hernández-Morcillo et al., 2022	Hernández-Morcillo, M., Torralba, M., Baiges, T., Bernasconi, A., Bottaro, G., Brogaard, S., Bussola, F., Díaz-Varela, E., Geneletti, D., Grossmann, C.M., Kister, J., 2022. Scanning the solutions for the sustainable supply of forest ecosystem services in Europe. <i>Sustain. Sci.</i> 17, 2013–2029. https://doi.org/10.1007/s11625-022-01111-4 .
50	5.1	Hlásny et al., 2017	Hlásny, T., Barka, I., Kulla, L., Bucha, T., Sedmák, R., Trombik, J., 2017. Sustainable forest management in a mountain region in the Central Western Carpathians, northeastern Slovakia: the role of climate change. <i>Reg Environ Change</i> 17, 65–77. https://doi.org/10.1007/s10113-015-0894-y
51	4.4	Huber-Stearns et al., 2013	Huber-Stearns H. R., Goldstein J. H., Duke E. A., 2013. Intermediary roles and payments for ecosystem services: A typology and program feasibility application in Panama. <i>Ecosyst. Serv.</i> 6, 104–116. https://doi.org/10.1016/j.ecoser.2013.09.006
52	4.1	Hrabanski, 2015	Hrabanski, M., 2015. The biodiversity offsets as market-based instruments in global governance: Origins, success and controversies. <i>Ecosyst. Serv.</i> 15, 143–151. https://doi.org/10.1016/j.ecoser.2014.12.010 .
53	4.5	Hunter, 2024	Hunter, L., 2024. EU fights back opposition to pass landmark Nature Restoration Law. https://cphpost.dk/2024-06-18/news/climate/eu-fights-back-opposition-to-pass-landmark-nature-restoration-law/ (accessed 14 September 2024).
54	4.1	IAPB, 2024a	International Advisory Panel on Biodiversity Credits, 2024. Landscape analysis of biodiversity credits projects: Results from the Supply Working Group project developers' survey. https://drive.google.com/file/d/1feQT1WWUZbjpLQGOoHPduScaJE36I85U/view (accessed 14 September 2024).
55	4.1	IAPB, 2024b	International Advisory Panel on Biodiversity Credits, 2024. Framework for high integrity biodiversity credit markets. https://www.iapbiocredits.org/framework (accessed 11 October 2025)
56	4.4	IUCN, 2019	IUCN, 2019. Global Inventory of Biodiversity Offset Policies (GIBOP). https://portals.iucn.org/offsetpolicy/ (accessed 25 February 2025).
57	5.1	Josefsson et al., 2021	Josefsson, J., Ahlbäck Widenfalk, L., Blicharska, M., Hedblom, M., Pärt, T., Ranius, T., Öckinger, E., 2021. Compensating for lost nature values through biodiversity offsetting—Where is the evidence? <i>Biol. Conserv.</i> 257, 109117. https://doi.org/10.1016/j.biocon.2021.109117 .
58	4.3	Kim and Langpap, 2015	Kim, I., Langpap, C., 2015. Incentives for carbon sequestration using forest management. <i>Environ. Resour. Econ.</i> 62, 491–520. https://doi.org/10.1007/s10640-014-9827-3
59	4.1; 4.4	Koh et al., 2019	Koh, N. S., Hahn, T., Boonstra, W. J., 2019. How much of a market is involved in biodiversity offset? A typology of biodiversity offset policies. <i>J. Environ. Manage.</i> 232, 679–691. https://doi.org/10.1016/j.jenvman.2018.11.080 .

(continued on next page)

(continued)

No.	Section	Reference	Citation
60	5.1	Langpap and Wu, 2017	Langpap, C., Wu, J., 2017. Thresholds, perverse incentives, and preemptive conservation of endangered species. <i>Journal of the Association of Environmental and Resource Economists</i> , Vol. 4, S1. https://doi.org/10.1086/6920
61	5.1	Larrieu et al., 2018	Larrieu, L., Paillet, Y., Winter, S., Büttler, R., Kraus, D., Krumm, F., Lachat, T., Michel, A. K., Regnery, B., Vandekerckhove, K., 2018. Tree related microhabitats in temperate and Mediterranean European forests: A hierarchical typology for inventory standardization. <i>Ecological Indicators</i> , Vol. 84, 194–207. https://doi.org/10.1016/j.ecolind.2017.08.051
62	5.1	Lassauce et al., 2011	Lassauce, A., Paillet, Y., Jactel, H., Boughet C., 2011. Deadwood as a surrogate for forest biodiversity: Meta-analysis of correlations between deadwood volume and species richness of saproxylic organisms. <i>Ecological Indicators</i> , Vol 11, 1027–1039. https://doi.org/10.1016/j.ecolind.2011.02.004
63	5.1	Lewis et al., 2011	Lewis, D. J., Plantinga, A. J., Nelson, E., Polasky, S., 2011. The efficiency of voluntary incentive policies for preventing biodiversity loss. <i>Resour. Energy Econ.</i> 33, 192–211. https://doi.org/10.1016/j.reseneeco.2010.04.012 .
64	4.3	Li and Zhang, 2024	Li, L., Zhang, D., 2024. Forest carbon offset protocols in compliance carbon markets. <i>For. Policy Econ.</i> 165, 103253. https://doi.org/10.1016/j.forpol.2024.103253 .
65	5.2	Lovrić et al., 2025	Lovrić, M., Torralba, M., Orsi, F., Pettenella, D., Mann, C., Geneletti, D., Plieninger, T., Primmer, E., Hernandez-Morcillo, M., Thorsen, B. J., Lundhede, T., 2025. Mind the income gap: Income from wood production exceed income from providing diverse ecosystem services from Europe's forests. <i>Ecosyst. Serv.</i> 71, 101689. https://doi.org/10.1016/j.ecoser.2024.101689 .
66	5.2	Länsstyrelserna (Swedish County Administrative Board), 2025	Länsstyrelserna (Swedish County Administrative Board). 2025. Protected Nature. https://www.lansstyrelsen.se/english/nature-and-rural-areas/protected-nature.html (accessed 30 September 2025)
67	4.3	MacKenzie et al., 2012	MacKenzie, I. A., Ohndorf, M., Palmer, C., 2012. Enforcement-proof contracts with moralhazard in precaution: Ensuring 'permanence' in carbon sequestration. <i>Oxf. Econ. Pap.</i> 64, 350–374. https://doi.org/10.1093/oxep/gpr057 .
68	4.3	Maron et al., 2023	Maron, M., Quétiér, F., Sarmiento, M., ten Kate, K., & Evans, M. C., 2023. 'Nature positive' must incorporate, not undermine, the mitigation hierarchy. <i>Nature Ecology & Evolution</i> , 7(9), 1224–1226. https://doi.org/10.1038/s41559-023-02164-4
69	4.3	McDermott et al., 2013	McDermott, M., Mahanty, S., Schreckenber, K., 2013. Examining equity: A multidimensional framework for assessing equity in payments for ecosystem services. <i>Environ. Sci. Policy</i> 33, 416–427. https://doi.org/10.1016/j.envsci.2012.10.006 .
70	5.1	Mei, 2023	Mei, B., 2023. Carbon offset as another driver of timberland investment returns in United States. <i>J. For. Bus. Res.</i> 2, 1–19. https://doi.org/10.62320/jfbr.v2i1.20 .
71	4.3	Montero-de-Oliveira et al., 2023	Montero-de-Oliveira, F. E., Blundo-Canto, G., Ezzine-de-Blas, D., 2023. Under what conditions do payments for environmental services enable forest conservation in the Amazon? A realist synthesis. <i>Ecol. Econ.</i> 205, 107697. https://doi.org/10.1016/j.ecolecon.2022.107697 .
72	4.3	Murray et al., 2013	Murray, B. C., Busch, J., Woodward, R. T., Jenkins, A., 2013. Designing cap and trade to correctfor non-additional offsets (September 2013). <i>Duke Environmental and Energy Economics Working Paper EE 13-05</i> . https://doi.org/10.2139/ssrn.2467670 .
73	5.1	Mönkkönen et al., 2014	Mönkkönen, M., Juutinen, A., Mazziotta, A., Miettinen, K., Podkopaev, D., Reunanen, P., Salminen, H., Tikkanen, O-P., 2014. Spatially dynamic forest management to sustain biodiversity and economic returns. <i>Journal of Environmental Management</i> , 134, 80–89. https://doi.org/10.1016/j.jenvman.2013.12.021
74	4.1	NatureFinance, 2023a	NatureFinance, 2023a. Biodiversity credit markets: The role of law, regulation and policy. https://uploads-ssl.webflow.com/623a362e6b1a3e2eb749839c/643f2790f52d9172d6aa8e6_BiodiversityCreditMarkets.pdf (accessed 14 December 2024).
75	4.2	NatureFinance, 2023b	NatureFinance, 2023b. Harnessing biodiversity credits for people and planet. https://www.naturefinance.net/wp-content/uploads/2023/06/HarnessingBiodiversityCreditsForPeopleAndPlanet.pdf (accessed 14 December 2024).
76	5.2	Naturvårdsverket, 2025	Naturvårdsverket, 2025. Species protection ordinance. https://www.naturvardsverket.se/en/guidance/species-protection/species-protection-ordinance/ (assessed 26 October 2025).
77	5.1	Naumov et al., 2018	Naumov, V., Manton, M., Elbakidze, M., Rendenieks, Z., Priednieks, J., Uhljanets, S., Yamelnyets, T., Zhivotov, A., Angelstam, P., 2018. <i>Journal of Environmental Management</i> . 218, 1–13. https://doi.org/10.1016/j.jenvman.2018.03.095
78	4.2	Niue Ocean Wide, 2024	Niue Ocean Wide, 2024. Overview of Ocean Conservation Commitments. https://niueoceanwide.com/ocean-conservation-commitments/ (accessed 14 September 2024).
79	4.2	Obeng et al., 2018	Obeng, E. A., Aguilar, F. X., Mccann, L. M., 2018. Payments for forest ecosystem services: a look at neglected existence values, the free-rider problem and beneficiaries' willingness to pay. <i>Int. For. Rev.</i> 20, 206–219. https://doi.org/10.1505/146554818823767528 .
80	4.2; 5.1	Oettel and Lapin, 2020	Oettel, J., and Lapin, K., 2020. Linking forest management and biodiversity indicators to strenghten sustainable forest management in Europe. <i>Ecological Indicators</i> , 122, 107275. https://doi.org/10.1016/j.ecolind.2020.10.7275
81	4.2; 4.4	OPIS, 2024	OPIS, 2024. Biodiversity market report. https://www.opisnet.com/product/pricing/spot/biodiversity-market-report/ (accessed 7 November 2024).
82	4.4	Palmer, 2011	Palmer, C. 2011. Property rights and liability for deforestation under REDD+: Implications for 'permanence' in policy design. <i>Ecological Economics</i> 70, 571–576. https://doi.org/10.1016/j.ecolecon.2010.10.011
83	4.3	Parisa et al., 2022	Parisa, Z., Marland, E., Sohngen, B., Marland, G., Jenkins, J., 2022. The time value of carbon storage. <i>For. Policy Econ.</i> 144, 102840. https://doi.org/10.1016/j.forpol.2022.102840 .
84	5.1	Parisi et al., 2016	Parisi, F., Lombardi, F., Sciarretta, A., Tagnetti, R., Campanaro, A., Marchetti, M., Trematerra, P., 2016. Spatial patterns of saroxylic beetles in a relic silver fir forest (Central Italy), relationships with forest structure and biodiversity indicators. <i>Forest ecology and management</i> , Vol. 381, 217–234. https://doi.org/10.1016/j.foreco.2016.09.041
85	4.3	Plan Vivo, 2025	Plan Vivo, 2025. PV Nature – Documentation. https://www.planvivo.org/pv-nature-documentation (accessed 27 February 2025).
86	4.1	Porras and Steele, 2020	Porras, I., Steele, P., 2020. Making the market work for nature: How biocredits can protect biodiversity and reduce poverty. IIED, London. https://www.iied.org/16664iied (accessed 27 February 2025).
87	5.2	Riksskogstaxeringen (Swedish National Forest Inventory Program), 2025	Riksskogstaxeringen (Swedish National Forest Inventory Program). 2025. Land area by land use class according to the Swedish Forestry Act. https://skogsstatistik.slu.se/pxweb/en/OffStat/ (accessed on 30 September 2025).

(continued on next page)

(continued)

No.	Section	Reference	Citation
88	5.2	Roberge and Olsson, 2024	Roberge, J.-M., and Olsson, J. Skogsstyrelsen, vägledning: Metod för klassning av ett skogsområdes livsmiljövärde för tretåig hackspett. Version 2.2. Diariern 2024/3935. https://www.skogsstyrelsen.se/globalassets/aga-skog/miljohansyn/vagledning—metod-for-klassning-av-ett-skogsomrades-livsmiljovarde-for-tretajg-hackspett_tillganglighetsanpassad.pdf
89	5.2	Rytter et al., 2016	Rytter, L., Ingerslev, M., Kilpeläinen, A., Torssonen, P., Lazdina, D., Löf, M., Madsen, P., Muiste, P., Stener, L. G., 2016. Increased forest biomass production in the Nordic and Baltic countries—a review on current and future opportunities. <i>Silva Fenn.</i> 50, 1660. https://doi.org/10.14214/sf.1660 .
90	5.2	Salvador et al., 2023	Salvador, R., Barros, V. M., Pieroni, M., Silva, A. D., Freire, F., Francisco, C. A., 2023. Overarching business models for a circular bioeconomy: Systematising archetypes. <i>Sustain. Prod. Consum.</i> 43, 349v362. https://doi.org/10.1016/j.spc.2023.11.010 .
91	5.1	Satake et al., 2008	Satake, A., Rudel, T. K., Onuma, A., 2008. Scale mismatches and their ecological and economic effects on landscapes: A spatially explicit model. <i>Glob. Environ. Change</i> 18, 768–775. https://doi.org/10.1016/j.gloenvch.2008.07.007 .
92	4.2	Savimbo, 2024	Savimbo, 2024. Fair Trade Biodiversity Credits. https://www.savimbo.com/biodiversity?srsltid=AfmBOoQOt0ZawUsFXize1SrGRVuPk_foFX94uVUWiszc3VieoMz1WDhd (accessed 17 October 2024).
93	4.5	Schauenberg, 2023	Schauenberg, T., 2023. Farmers revolt against EU's historic nature restoration law. https://www.dw.com/en/farmers-revolt-against-eus-historic-nature-restoration-law/a-65735393 (accessed 14 September 2024).
94	4.1	Schwerdtner Manez and Clifton, 2025	Schwerdtner Manez, K., Clifton, J., 2025. Biodiversity credits: a new currency to support nature conservation? <i>Oryx</i> , Firest View, 1–6. https://doi.org/10.1017/S0030605324001467
95	5.1	Sever and Nagel, 2019	Sever, K., and Nagel, T., A., 2019. Patterns of tree microhabitats across a gradient of managed to old-growth conditions: a case study from beech dominated forests of South-Eastern Slovenia. <i>Acta Silvae et Ligni.</i> 118, 29–40. https://doi.org/10.20315/ASetL.118.3
96	5.2	Skogsstyrelsen, 2025	Skogsstyrelsen, 2025. Vägledningar och kunskapsstöd artskydd. https://www.skogsstyrelsen.se/aga-skog/han-syn-till-miljo-och-skyddade-arter/vagledningar-och-kunskapsstod-artskydd/ (accessed 26 October 2025)
97	5.2	Sweden Statistical Database, 2025a	Sweden Statistical Database. 2025a. Formally protected forest land, voluntary set-asides, consideration patches and unproductive forest land. https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START_MI_MI0605/SkyddSkogFrivillig/ (accessed on 30 September 2025).
98	5.2	Sweden Statistical Database, 2025b	Sweden Statistical Database. 2025b. Natura 2000 areas by type of nature. Year 2022 – 2024. https://www.statistikdatabasen.scb.se/ (accessed on 30 September 2025).
99	4.5	Swedish Forest Industries, 2022	Swedish Forest Industries, 2022. EU-förslag om återställande av natur kan påverka jobben. https://www.skogsindustrierna.se/aktuellt/nyheter/2022/11/eu-forslag-om-aterstallande-av-natur-paverkar-ekonomi-och-jobb/ (accessed 8 January 2024).
100	4.4	Stavins, 1995	Stavins, R. N., 1995. Transaction costs and tradeable permits. <i>J. Env. Economics and Management.</i> 29(2), 133–148. https://doi.org/10.1006/jeem.1995.1036 .
101	4.2; 4.4	Taskforce on Nature Related Markets, 2023	Taskforce on Nature Related Markets, 2023. Biodiversity Credit Markets: The role of law, regulation and policy. https://assets-global.website-files.com/623a362e6b1a3e2eb749839c/6452340b9bcb3ef3f82e6b6_BiodiversityCreditMarkets.pdf (accessed 27 February 2025).
102	4.3	Tedesco et al., 2023	Tedesco, A. M., Brancalion, P. H., Hepburn, M. L. H., Walji, K., Wilson, K. A., Possingham, H. P., Dean, A. J., Nugent, N., Elias-Trostmann, K., Perez-Hammerle, K. V., Rhodes, J. R., 2023. The role of incentive mechanisms in promoting forest restoration. <i>Philos. Trans. R. Soc. B</i> 378, 20210088. https://doi.org/10.1098/rstb.2021.0088 .
103	5.2	Tiebel et al. 2021	Tiebel, M., Mölder, A., Plieninger, T., 2021. <i>Ambio</i> . Vol 51, 836–848. https://doi.org/10.1007/s13280-021-01615-w
104	4.3	Torabi and Bekessy, 2015	Torabi, N., Bekessy, S. A., 2015. Bundling and stacking in bio-sequestration schemes: Opportunities and risks identified by Australian stakeholders. <i>Ecosyst. Serv.</i> 15, 84–92. https://doi.org/10.1016/j.ecoser.2015.08.001 .
105	5.1	Triviño et al., 2016	Triviño, M., Pohjanmies, T., Mazziotta, A., Juutinen, A., Podkopaev, D., Le Tortorec, E., Mönkkönen, M., 2016. Optimizing management to enhance multifunctionality in a boreal forest landscape. <i>Journal of Applied Ecology.</i> 54, 61–70. https://doi.org/10.1111/1365-2664.12790
106	4.3	Trouwloon et al., 2023	Trouwloon, D., Streck, C., Chagas, T., Martinus, G., 2023. Understanding the use of carbon credits by companies: a review of the defining elements of corporate climate claims. <i>Global Chall.</i> 7, 2200158. https://doi.org/10.1002/gch2.202200158 .
107	4.4	UN Climate Change, 2025	UN Climate Change, 2025. What is REDD+? https://unfccc.int/topics/land-use/workstreams/redd/what-is-redd (accessed 2 January 2025).
108	4.3	Vacchiano et al., 2018	Vacchiano, G., Berretti, R., Romano, R., Motta, R., 2018. Voluntary carbon credits from improved forest management: Policy guidelines and case study. <i>iForest</i> 11, 1–10. https://doi.org/10.3832/ifor2431-010 .
109		Uthes and Matzdorf, 2013	Uthes, S., Matzdorf, B., 2013. Studies on Agri-environmental Measures: A Survey of the Literature. <i>Environmental Management</i> 51, 251–266. https://doi.org/10.1007/s00267-012-9959-6
110	4.3; 5	van Benthem and Kerr, 2013	van Benthem, A., Kerr, S., 2013. Scale and transfers in international emissions offsets programs. <i>J. Public Econ.</i> 107, 31–46. https://doi.org/10.1016/j.jpubeco.2013.08.004 .
111	4.3	Verified Carbon Standard, 2023a	Verified Carbon Standard, 2023a. Methodology for improved forest management through extension of rotation age, v1.3. https://verra.org/methodologies/vm0003-methodology-for-improved-forest-management-through-extension-of-rotation-age-v1-3/ .
112	4.3	Verified Carbon Standard, 2023b	Verified Carbon Standard, 2023b. Afforestation, reforestation, and revegetation, v1.0. https://verra.org/methodologies/vm0047-afforestation-reforestation-and-revegetation-v1-0/ .
113	4.3	Verified Carbon Standard, 2023c	Verified Carbon Standard, 2023c. Reducing emissions from deforestation and forest degradation, v1.0. https://verra.org/methodologies/vm0048-reducing-emissions-from-deforestation-and-forest-degradation-v1-0/ .
114	4.2	Verra, 2024a	Verra, 2024a. Verra Launches Nature Framework. https://verra.org/verra-launches-nature-framework/ (accessed 14 December 2024).
115	4.3	Verra, 2024b	Verra, 2024b. Sustainable Development Verified Impact Standard. https://verra.org/programs/sd-verified-impact-standard/ (accessed 15 September 2024).
116	4.1	Waterford et al., 2023	Waterford, L., FitzSimons, V., Back, O., 2023. State of voluntary biodiversity credit markets: A global review of biodiversity credit schemes. <i>Pollination Group</i> . 42p. https://pollinationgroup.com/wp-content/uploads/2023/10/Global-Review-of-Biodiversity-Credit-Schemes-Pollination-October-2023.pdf (accessed 27 February 2025).
117	5.1	Winter et al., 2015	Winter, S., Höfler, J., Michel, A. K., Böck, A., Ankerst, D. P., 2015. Association of tree and plot characteristics with microhabitat formation in European beech and Douglas-fir forests. <i>Eur J Forest Res</i> 134, 335–347. https://doi.org/10.1007/s10342-014-0855-x

(continued on next page)

(continued)

No.	Section	Reference	Citation
118	4.2	World Economic Forum, 2024	World Economic Forum, 2024. Nature finance and biodiversity credits: A private sector roadmap to finance and act on nature. World Economic Forum in collaboration with McKinsey & Company. https://www3.weforum.org/docs/WEF_Nature_Finance_and_Biodiversity_Credits_2024.pdf (accessed 27 February 2025).
119	4.1	Wunder, 2008	Wunder, S., 2008. Necessary conditions for ecosystem service payments. https://www.conservation-strategy.org/sites/default/files/field-file/Tropics_Conference_Wunder_PES_markets.pdf (accessed on 27 October 2025)
120	4.1; 4.2; 4.3	Wunder et al., 2025	Economics and Conservation in the Tropics: A Strategic Dialogue. Conference paper. Wunder, S., Fraccaroli, C., Bull, J. W., Dutta, T., Eyres, A., Evans, M. C., Jellesmark Thorsen, B., Jones, J. P. G., Maron, M., Muys, B., Pacheco, A., Strange-Olesen, A., Swinfield, T., Tegegne, Y. T., White, T. B., Zhang, H., zu Ermgassen, O. S. E., 2025. Biodiversity credits: An overview of the Current State, Future Opportunities, and Potential Pitfalls. Business Strategy and the Environment. https://doi.org/10.1002/bse.70018
121	4.4	Zhang, 2016	Zhang, D., 2016. Payments for forest-based environmental services: A close look. For. PolicyEcon. 72, 78–84. https://doi.org/10.1016/j.forpol.2016.06.017 .
122	5.1	zu Ermgassen et al., 2019	zu Ermgassen, S. O., Baker, J., Griffiths, R. A., Strange, N., Matthew, S. J., Bull, J. W., 2019. The ecological outcomes of biodiversity offsets under “no net loss” policies: A global review. Conserv. Lett. 12, e12664. https://doi.org/10.1111/conl.12664 .
123	5.2	Zu Ermgassen and Löfqvist, 2024	zu Ermgassen, S. O., Löfqvist, S., 2024. Financing ecosystem restoration. Curr. Biol. 34,R412–R417. https://doi.org/10.1016/j.cub.2024.02.031
124	4.1; 4.4	Zynobia et al., 2023	Zynobia, E., Steele, P. Ducros, A., 2023. Biocredit catalogue: A collection of biocredit developers and schemes. IIED, London. https://www.iied.org/22201iied.pdf (accessed 27 February 2025).

¹ European Council Directive 1992/43/EEC. Link: <https://eur-lex.europa.eu/eli/dir/1992/43/oj>.

² Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: EU Biodiversity Strategy for 2030, Bringing Nature Back into our Lives. Link: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380>.

³ Council Directive 1992/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Link: <https://eur-lex.europa.eu/eli/dir/1992/43/oj>.

⁴ Regulation 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation 2022/869. Link: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1991&qid=1722240349976>.

⁵ Regulation 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation 2019/2088. Link: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852>.

⁶ Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds. Link: OJ L 20, 26.1.2010, pp. 7–25. Current consolidated version: 26/06/2019. <https://eur-lex.europa.eu/eli/dir/2009/147/oj/eng>.

⁷ Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Link: <https://eur-lex.europa.eu/eli/dir/2000/60/oj/eng>.

⁸ Directive 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting. Link: <https://eur-lex.europa.eu/eli/dir/2022/2464/oj>.

Data availability

Data will be made available on request.

References

- Aguilar, F.X., Vlosky, R.P., 2007. Consumer willingness to pay price premiums for environmentally certified wood products in the US. Forest Policy Econ. 9 (8), 1100–1112. <https://doi.org/10.1016/j.forpol.2006.12.001>.
- Alix-Garcia, J.M., Shapiro, E.N., Sims, K.R.E., 2012. Forest conservation and slippage: evidence from Mexico's national payments for ecosystem services program. Land Econ. 88 (4), 613–638. <https://doi.org/10.3368/le.88.4.613>.
- Alvarado-Quesada, I., Hein, L., Weikard, H.P., 2014. Market-based mechanisms for biodiversity conservation: A review of existing schemes and an outline for a global mechanism. Biodivers. Conserv. 23, 1–21. <https://doi.org/10.1007/s10531-013-0598-x>.
- Angelsen, A., 2010. Policies for reduced deforestation and their impact on agricultural production. PNAS 107 (46), 19639–19644. <https://doi.org/10.1073/pnas.0912014107>.
- Angelstam, P., Naumov, V., Elbakidze, M., Manton, M., Priednieks, J., Rendenieks, Z., 2018. Wood production and biodiversity conservation are rival forestry objectives in Europe's Baltic Sea Region. Ecosphere 9 (3). <https://doi.org/10.1002/ecs2.2119>.
- Aotearoa New Zealand Ministry for the Environment, 2022. Investigating the use of biodiversity markets to scale financing of nature-based solutions in Aotearoa New Zealand. https://consult.environment.govt.nz/biodiversity/nz-biodiversity-credit-system/supporting_documents/20230905_Pollination_NZ_MfE_Summary_Report.pdf.
- Asplund, J., Nordén, J., Kjønaas, O.J., Madsen, R.L., Lunde, L.F., Birkemoe, T., Ronold, E. K., Norkute, M., Jansson, K.U., Karlsen, D.P., Sverdrup-Thygeson, A., 2024. Long term effects of forest management on forest structure and dead wood in mature boreal forests. For. Ecol. Manag. 572, 122315. <https://doi.org/10.1016/j.foreco.2024.122315>.
- Augustynczyk, A.L., Asbeck, T., Basile, M., Bauhus, J., Storch, I., Mikusinski, G., Yousefpour, R., Hanewinkel, M., 2019. Diversification of forest management regimes secures tree microhabitats and bird abundance under climate change. Sci. Total Environ. 650 (Part 2), 2717–2730. <https://doi.org/10.1016/j.scitotenv.2018.09.366>.
- Australian Department of Climate Change, Energy, the Environment and Water, 2025. Nature Repair Market. <https://www.dcceew.gov.au/environment/environmental-markets/nature-repair-market> (accessed 9 March 2025).
- Barbier, E.B., Burgess, J.C., 2001. The economics of tropical deforestation. J. Econ. Surv. 15 (3), 413–433. <https://doi.org/10.1111/1467-6419.00144>.
- Barisa, K., Millington Drake, M., Shah, T., Susarla, R., Rodewald, N., 2024. Credit where credit's due: Identifying the core principles for a high integrity biodiversity credit market. <https://www.planvivo.org/news/new-report-credit-where-credits-due> (accessed 14 December 2024).
- Bayrak, M.M., Marafa, L.M., 2016. Ten years of REDD+: A critical Review of the impact of REDD+ on forest-dependent communities. Sustainability 8, 620. <https://doi.org/10.3390/su8070620>.
- Biodiversity Consultancy, 2022. Biodiversity credits: Design Principles for High Integrity Outcomes. <https://www.thebiodiversityconsultancy.com/insights/biodiversity-credits-design-principles-for-high-integrity-outcomes/> (accessed 25 October 2025).
- Biodiversity Credit Alliance, 2024a. Definition of a biodiversity credit. Issue Paper. <https://www.biodiversitycreditalliance.org/wp-content/uploads/2024/05/Definition-of-a-Biodiversity-Credit-Rev-220524.pdf> (accessed 14 December 2024).
- Biodiversity Credit Alliance, 2024b. High level principles to guide the biodiversity credit market. Working Paper. https://www.biodiversitycreditalliance.org/wp-content/uploads/2024/11/BCA_High-level-Principles-to-Guide-the-Biodiversity-Market-working-paper-EN_ES_FR.pdf (accessed 14 December 2024).
- Blackman, A., Corral, L., Lima, E., Asner, G., 2017. Titling indigenous communities protects forests in the Peruvian Amazon. Proc. Natl. Acad. Sci. U.S.A. 114 (16), 4123–4128. <https://doi.org/10.1073/pnas.1603290114>.
- Blanton, A., Mohan, M., Galgamuwa, G.P., Watt, M.S., Montenegro, J.F., Mills, F., Carlsen, S.C.H., Velasquez-Camacho, L., Bomfim, B., Pons, J., Broadbent, E.N., 2024. The status of forest carbon markets in Latin America. J. Environ. Manag. 352, 119921. <https://doi.org/10.1016/j.jenvman.2023.119921>.
- Blicharska, M., Hedblom, M., Josefsson, J., Widenfalk, O., Ranius, T., Öckinger, E., Widenfalk, L.A., 2022. Operationalisation of ecological compensation—Obstacles and ways forward. J. Environ. Manag. 304, 114277. <https://doi.org/10.1016/j.jenvman.2021.114277>.
- Bloom Labs database, 2025. <https://app.bloomlabs.earth/schemes> (accessed 11 October 2025).
- Bonneuil, C., 2015. Tell me where you come from, I will tell you who you are: A genealogy of biodiversity offsetting mechanisms in historical context. Biol. Conserv. 192, 485–491. <https://doi.org/10.1016/j.biocon.2015.09.022>.
- Boyd, J., Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecol. Econ. 63 (2–3), 616–626. <https://doi.org/10.1016/j.ecolecon.2007.01.002>.

- Börner, J., Vosti, S., 2013. Chapter 2. Managing Tropical Forest Ecosystem Services: An Overview of Options. In: Muradian, R., Rival, L. (Eds.), *Governing the Provision of Ecosystem Services, Studies in Ecological Economics* 4. https://doi.org/10.1007/978-94-007-5176-7_2.
- Business and Biodiversity Offsets Programme, 2012. Standard on biodiversity offsets. https://www.forest-trends.org/wp-content/uploads/bbop/bbop_standard_on_biodiversity_offsets_1_feb_2013.pdf (accessed 14 December 2024).
- Canas, N., 2024. Contested Nature Restoration Law passes EU Parliament, despite last-minute revolt. <https://www.euractiv.com/section/biodiversity/news/contested-nature-restoration-law-passes-eu-parliament-despite-last-minute-revolt/> (accessed 14 September 2024).
- Pulse, C., 2024. Australia issues tender to develop first methodologies under Nature Repair Market. <https://carbon-pulse.com/308148/> (accessed 17 October 2024).
- Chaudhary, A., Burivalova, Z., Koh, L., et al., 2016. Impact of forest management on species richness: global meta-analysis and economic trade-offs. *Sci. Rep.* 6, 23954. <https://doi.org/10.1038/srep23954>.
- Cistrone, L., Altea, T., Matteucci, G., Posillico, M., De Cinti, B., Russo, D., 2015. The effect of thinning on bat activity in Italian high forests: the LIFE+ “ManFor C. BD.” Experience. *Hystrix It. J. Mamm.* 26 (2), 125–131. <https://doi.org/10.4404/hystrix-26.2-11477>.
- Clifton, J., Schwerdtner Manek, K., 2025. A framework based on payments for ecosystem services to support the delivery of high integrity carbon and biodiversity credits. *Ecosyst. Serv.* 73, 101724. <https://doi.org/10.1016/j.ecoser.2025.101724>.
- Convention on Biological Diversity, 2022. COP15: Nations adopt four goals, 23 targets for 2030 in landmark UN biodiversity agreement. <https://www.cbd.int/article/cop15-cbd-press-release-final-19dec2022> (accessed 9 January 2023).
- Cordero Salas, P., Roe, B.E., Sohngen, B., 2013. Addressing additionality in REDD contracts when formal enforcement is absent. *World Bank Policy Research Working Paper No. 6502*. <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/415971468326187886/addressing-additionality-in-redd-contracts-when-formal-enforcement-is-absent> (accessed 14 December 2024).
- Carbon Pulse, 2023. Queensland govt issues A\$10 mln reef credit purchase guarantee. <https://carbon-pulse.com/223785/> (accessed 14 September 2024).
- Court of Justice of the European Union, 2022. Press release No 17/22. Luxembourg, 27 January 2022. <https://curia.europa.eu/jcms/upload/docs/application/pdf/2022-01/cp220017en.pdf> (accessed 26 October 2025).
- Daily, G.C., 1997. Chapter 1. What are ecosystem services? Nature's services. In: *Societal Dependence on Natural Ecosystems*. Island Press, pp. 1–10.
- Deutz, A., Heal, G.M., Niu, R., Swanson, E., Townshend, T., Zhu, L., Delmar, A., Meghji, A., Sethi, S.A., Tobin-de la Puente, J., 2020. Financing nature: Closing the global biodiversity financing gap. The Paulson Institute, The Nature Conservancy, and the Cornell Atkinson Center for Sustainability. <https://doi.org/10.13140/RG.2.2.26226.32968>.
- Dieler, J., Uhl, E., Biber, P., Müller, J., Rötzer, T., Pretzsch, H., 2017. Effect of forest stand management on species composition, structural diversity, and productivity in the temperate zone of Europe. *Eur. J. Forest Res.* 136, 739–766. <https://doi.org/10.1007/s10342-017-1056-1>.
- Di Fulvio, F., Snäll, T., Lauri, P., Forsell, N., Mönkkönen, M., Burgas, D., Blattert, C., Eyvindson, K., Caicoya, A.T., Vergarechea, M., Antón-Fernández, C., 2025. Impact of the EU biodiversity strategy for 2030 on the EU wood-based bioeconomy. *Global Environ. Chang.* 92, 102986. <https://doi.org/10.1016/j.gloenvcha.2025.102986>.
- Eggers, J., Lundström, J., Snäll, T., Öhman, K., 2022. Balancing wood production and biodiversity in intensively managed boreal forest. *Scand. J. for. Res.* 37, 213–225. <https://doi.org/10.1080/02827581.2022.2066170>.
- Elton, P., Fitzsimons, J.A., 2023. Framework features enabling faster establishment and better management of privately protected areas in New South Wales, Australia. *Front. Conserv. Sci.* 4, 1277254. <https://doi.org/10.3389/fcsc.2023.1277254>.
- Engel, S., Pagiola, S., Wunder, S., 2008. Designing payments for environmental services in theory and practice: An overview of the issues. *Ecol. Econ.* 65 (4), 663–674. <https://doi.org/10.1016/j.ecolecon.2008.03.011>.
- European Commission, 2023. Commission staff working document: Guidance on the development of public and private payment schemes for forest ecosystem services. https://agriculture.ec.europa.eu/system/files/2023-07/guidance-dev-public-private-payment-schemes-forest_en.pdf (accessed 27 February 2025).
- European Commission, 2024a. The European green deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (accessed 27 February 2025).
- European Commission, 2024b. New EU forest strategy for 2030. https://environment.ec.europa.eu/strategy/forest-strategy_en (accessed 27 February 2025).
- European Commission, 2024c. Keynote speech by president von der Leyen at the DLD nature conference. https://ec.europa.eu/commission/presscorner/detail/en/speech_24_4668/ (accessed 14 September 2024).
- European Commission, 2025. Carbon Removals and Carbon Farming. https://nam11.safelinks.protection.outlook.com/?url=https%3A%2Fclimate.ec.europa.eu%2Ffeu-action%2Fcarbon-removals-and-carbon-farming_en&data=05%7C02%7Cp.das%40elsevier.com%7C3e65e3c57c14489318f0e8de6a2d0b3c%7C9274ee3f94254109a27f9fb15c10675d%7C0%7C639064938880376991%7CUnknown%7CTWFPbGZsb3d8eyJFbXB0eU1hcGkiOnRydWUslYiOilwLjAuMDAwMCIslAIoiJXaW4zMiIsIkFOIjoiTWFpbCIsIldUjoiYjQ%3D%3D%7C0%7C7C%7C7C&sdata=LUIAmlAwRIQ77KHw4VAMyYt6nSujl58LgVee6ArPm0%3D&reserved=0 (accessed 26 October 2025).
- European Parliament, 2023. The European union and forests. https://www.europarl.europa.eu/erpl-app-public/factsheets/pdf/en/FTU_3.2.10.pdf (accessed on 27 February 2025).
- FAO, 2018. Global forest resources assessment 2020: Terms and definitions. <https://openknowledge.fao.org/server/api/core/bitstreams/531a9e1b-596d-4b07-b9fd-3103fb4d0e72/content>.
- FAO, UNEP, 2020. The state of the world's forests 2020: Forest, biodiversity, and people. <https://openknowledge.fao.org/server/api/core/bitstreams/dfb12960-44ee-4ddc-95f7-bec93fb141e/content> (accessed 27 February 2025).
- FAO and UNEP, Rome. <https://www.fao.org/documents/card/en/c/ca8642en> (accessed 27 February 2025).
- Fiengenbaum, H., 2024. Complementing carbon credits from forest-related activities with biodiversity insurance and resilience value. arXiv. <https://nam11.safelinks.protection.outlook.com/?url=https%3A%2Fdoi.org%2F10.48550%2FarXiv.2411.08452&data=05%7C02%7Cp.das%40elsevier.com%7C3e65e3c57c14489318f0e8de6a2d0b3c%7C9274ee3f94254109a27f9fb15c10675d%7C0%7C639064938880325435%7CUnknown%7CTWFPbGZsb3d8eyJFbXB0eU1hcGkiOnRydWUslYiOilwLjAuMDAwMCIslAIoiJXaW4zMiIsIkFOIjoiTWFpbCIsIldUjoiYjQ%3D%3D%7C0%7C7C%7C7C&sdata=NpVJgzfScfpUN6NpYuNXI2IMP0PZK%2BRkaP12rtMY%3D&reserved=0>.
- Floren, A., Müller, T., Sittrich, M., Weiss, M., Linsenmair, K.E., 2014. The influence of tree species, stratum and forest management on beetle assemblages responding to deadwood enrichment. *For. Ecol. Manage.* 323, 57–64. <https://doi.org/10.1016/j.foreco.2014.03.028>.
- FSC Controlled Wood, 2025. <https://nam11.safelinks.protection.outlook.com/?url=https%3A%2Ffsc.fsc.org%2Fen-us%2Fcertification%2Fcontrolled-wood&data=05%7C02%7Cp.das%40elsevier.com%7C3e65e3c57c14489318f0e8de6a2d0b3c%7C9274ee3f94254109a27f9fb15c10675d%7C0%7C639064938880351299%7CUnknown%7CTWFPbGZsb3d8eyJFbXB0eU1hcGkiOnRydWUslYiOilwLjAuMDAwMCIslAIoiJXaW4zMiIsIkFOIjoiTWFpbCIsIldUjoiYjQ%3D%3D%7C0%7C7C%7C7C&sdata=kmj3UZH%2F9pP17pWKLHwoeb9VafCFJZgieRwJESi%3D&reserved=0> (accessed 12 October 2025).
- Ghijssels, D., Matthysen, E., Honnay, O., 2025. Mitigation Without Biodiversity Loss? Strengthening the Mitigation Hierarchy in Environmental Impact Assessment. <https://doi.org/10.2139/ssrn.5290546>.
- Gren, I.-M., Akilu, A.Z., 2016. Policy design for forest carbon sequestration: A review of the literature. *For. Policy Econ.* 70, 128–136. <https://doi.org/10.1016/j.forpol.2016.06.008>.
- Haya, B.K., Evans, S., Brown, L., Bukoski, J., Butsic, V., Cabiyo, B., Jacobson, R., Kerr, A., Potts, M., Sanchez, D.L., 2023. Comprehensive review of carbon quantification by improved forest management offset protocols. *Front. For. Glob. Change* 6, 958879. <https://doi.org/10.3389/ffgc.2023.958879>.
- Hernández-Morcillo, M., Torralba, M., Baiges, T., Bernasconi, A., Bottaro, G., Brogaard, S., Bussola, F., Díaz-Varela, E., Geneletti, D., Grossmann, C.M., Kister, J., 2022. Scanning the solutions for the sustainable supply of forest ecosystem services in Europe. *Sustain. Sci.* 17, 2013–2029. <https://doi.org/10.1007/s11625-022-01111-4>.
- Hlásny, T., Barka, I., Kulla, L., Bucha, T., Sedmák, R., Trombik, J., 2017. Sustainable forest management in a mountain region in the Central Western Carpathians, northeastern Slovakia: the role of climate change. *Reg. Environ. Change* 17, 65–77. <https://doi.org/10.1007/s10113-015-0894-y>.
- Huber-Stearns, H.R., Goldstein, J.H., Duke, E.A., 2013. Intermediary roles and payments for ecosystem services: A typology and program feasibility application in Panama. *Ecosyst. Serv.* 6, 104–116. <https://doi.org/10.1016/j.ecoser.2013.09.006>.
- Hunter, L., 2024. EU fights back opposition to pass landmark Nature Restoration Law. <https://cphpost.dk/2024-06-18/news/climate/eu-fights-back-opposition-to-pass-landmark-nature-restoration-law/> (accessed 14 September 2024).
- Hrabanski, M., 2015. The biodiversity offsets as market-based instruments in global governance: Origins, success and controversies. *Ecosyst. Serv.* 15, 143–151. <https://doi.org/10.1016/j.ecoser.2014.12.010>.
- IAPB, International Advisory Panel on Biodiversity Credits, 2024a. Landscape analysis of biodiversity credits projects: Results from the Supply Working Group project developers' survey. <https://drive.google.com/file/d/1feQT1WWUZbjpLQGOoHPdUSeAJ3E6185U/view> (accessed 14 September 2024).
- IAPB, International Advisory Panel on Biodiversity Credits, 2024b. Framework for high integrity biodiversity credit markets. <https://www.iapbiocredits.org/framework> (accessed 1 October 2025).
- IPBES, 2019. Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (Eds.). IPBES Secretariat, Bonn. <https://doi.org/10.5281/zenodo.3831673>.
- Isbell, F., Balvanera, P., Mori, A.S., He, J.S., Bullock, J.M., Regmi, G.R., Seabloom, E.W., Ferrier, S., Sala, O.E., Guerrero-Ramírez, N.R., Tavella, J., 2023. Expert perspectives on global biodiversity loss and its drivers and impacts on people. *Front. Ecol. Environ.* 21, 94–103. <https://doi.org/10.1002/fee.2536>.
- Iucn, 2019. Global inventory of biodiversity offset policies (GIBOP). accessed 25 February 2025. <https://portals.iucn.org/offsetpolicy/>.
- Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D.E., Coscieme, L., Golden, A.S., Guerra, C.A., Jacob, U., Takahashi, Y., Settele, J., Díaz, S., 2022. The direct drivers of recent global anthropogenic biodiversity loss. *Sci. Adv.* 8. <https://doi.org/10.1016/j.ecomglob.2026.107478>.
- Johnson, J.A., Ruta, G., Baldos, U., Cervigni, R., Chonabayashi, S., Corong, E., Gerber, J., Ruta, G., Polasky, S., 2021. The economic case for nature: A global earth-economy model to assess development policy pathways. *World Bank, Washington*. <https://doi.org/10.1596/35882>.
- Joseffson, J., Ahlback Widenfalk, L., Blicharska, M., Hedblom, M., Pärt, T., Ranius, T., Öckinger, E., 2021. Compensating for lost nature values through biodiversity offsetting—where is the evidence? *Biol. Conserv.* 257, 109117. <https://doi.org/10.1016/j.biocon.2021.109117>.

- Snyder, H., 2019. Literature review as a research methodology: An overview and guidelines. *J. Bus. Res.* 104, 333–339. <https://doi.org/10.1016/j.jbusres.2019.07.039>.
- Stavins, R.N., 1995. Transaction costs and tradeable permits. *J. Environ. Econ. Manage.* 29 (2), 133–148. <https://doi.org/10.1006/jeem.1995.1036>.
- Sweden Statistical Database, 2025a. Formally protected forest land, voluntary set-asides, consideration patches and unproductive forest land. https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START_MI_MI0605/SkyddSkogFrivillig/ (accessed on 30 September 2025).
- Sweden Statistical Database, 2025b. Natura 2000 areas by type of nature Year 2022–2024. <https://www.statistikdatabasen.scb.se/> (accessed on 30 September 2025).
- Swedish Forest Industries, 2022. EU-förslag om återställande av natur kan påverka jobben. <https://www.skogsindustrierna.se/aktuellt/nyheter/2022/11/eu-forslag-om-aterstallande-av-natur-paverkar-ekonomi-och-jobb/> (accessed 8 January 2024).
- Taskforce on Nature Related Markets, 2023. Biodiversity credit markets: the role of law, regulation and policy. https://assets-global.website-files.com/623a362e6b1a3e2eb749839c/6452340b9bcb3ef3f82e6b6_BiodiversityCreditMarkets.pdf (accessed 27 February 2025).
- Tedesco, A.M., Brancalion, P.H., Hepburn, M.L.H., Walji, K., Wilson, K.A., Possingham, H.P., Dean, A.J., Nugent, N., Elias-Trostmann, K., Perez-Hammerle, K. V., Rhodes, J.R., 2023. The role of incentive mechanisms in promoting forest restoration. *Philos. Trans. R. Soc. B* 378, 20210088. <https://doi.org/10.1098/rstb.2021.0088>.
- The Economics of Ecosystems and Biodiversity, 2009. The Economics of Ecosystems and Biodiversity for National and International Policy Makers - Summary: responding to the Value of Nature. <https://digitallibrary.un.org/record/786349?ln=en&v=pdf> (accessed on 30 September 2025).
- Tiebel, M., Mölder, A., Plieninger, T. 51, 836–848. <https://doi.org/10.1007/s13280-021-01615-w>.
- TNFD, Taskforce on Nature-related Financial Disclosures, 2023. Recommendations of the Taskforce on Nature-related Financial Disclosures. https://tnfd.global/wp-content/uploads/2023/08/Recommendations_of_the_Taskforce_on_Nature-related_Financial_Disclosures_September_2023.pdf (accessed 26 October 2025).
- Torabi, N., Bekessy, S.A., 2015. Bundling and stacking in bio-sequestration schemes: Opportunities and risks identified by Australian stakeholders. *Ecosyst. Serv.* 15, 84–92. <https://doi.org/10.1016/j.ecoser.2015.08.001>.
- Triviño, M., Pohjanmies, T., Mazziotta, A., Juutinen, A., Podkopaev, D., Le Tortorec, E., Mönkkönen, M., 2016. Optimizing management to enhance multifunctionality in a boreal forest landscape. *J. Appl. Ecol.* 54, 61–70. <https://doi.org/10.1111/1365-2664.12790>.
- Trouwloon, D., Streck, C., Chagas, T., Martinus, G., 2023. Understanding the use of carbon credits by companies: a review of the defining elements of corporate climate claims. *Glob. Chall.* 7, 2200158. <https://doi.org/10.1002/gch2.202200158>.
- UN Climate Change, 2025. What is REDD+? <https://unfccc.int/topics/land-use/worksheets/redd/what-is-redd> (accessed 2 January 2025).
- United Nations, 2025. The 17 goals. <https://sdgs.un.org/goals> (accessed 24 February 2025).
- United Nations, Department of Economic and Social Affairs, 2024. System of Environmental Economic Accounting – Ecosystem Accounting. United Nations, New York ST/ESA/STAT/SER.F/124. 409 p. https://seea.un.org/sites/seea.un.org/files/documents/EA/seea_ea_f124_web_12dec24.pdf (accessed on 30 September 2025).
- Uthes, S., Matzdorf, B., 2013. Studies on Agri-environmental measures: A Survey of the Literature. *Environ. Manage.* 51, 251–266. <https://doi.org/10.1007/s00267-012-9959-6>.
- Vacchiano, G., Berretti, R., Romano, R., Motta, R., 2018. Voluntary Carbon Credits from Improved Forest Management: Policy Guidelines and Case Study 11, 1–10. <https://doi.org/10.3832/ifer2431-010>.
- van Benthem, A., Kerr, S., 2013. Scale and transfers in international emissions offsets programs. *J. Public Econ.* 107, 31–46. <https://doi.org/10.1016/j.jpubeco.2013.08.004>.
- UNFCCC, United Nations Framework Convention on Climate change, 1998. Kyoto Protocol, Article 12 (a clean development mechanism). <https://unfccc.int/resource/docs/convkp/kpeng.pdf#page=12> (accessed on 30 September 2025).
- Verified Carbon Standard, 2023a. Methodology for improved forest management through extension of rotation age, v1.3. <https://verra.org/methodologies/vm0003-methodology-for-improved-forest-management-through-extension-of-rotation-age-v1-3/>.
- Verified Carbon Standard, 2023b. Afforestation, reforestation, and revegetation, v1.0. <https://verra.org/methodologies/vm0047-afforestation-reforestation-and-revegetation-v1-0/>.
- Verified Carbon Standard, 2023c. Reducing emissions from deforestation and forest degradation, v1.0. <https://verra.org/methodologies/vm0048-reducing-emissions-from-deforestation-and-forest-degradation-v1-0/>.
- Verra, 2024a. Verra Launches Nature Framework. <https://verra.org/verra-launches-nature-framework/> (accessed 14 December 2024).
- Verra, 2024b. Sustainable Development Verified Impact Standard. <https://verra.org/prgrams/sd-verified-impact-standard/> (accessed 15 September 2024).
- Waterford, L., FitzSimons, V., Back, O., 2023. State of voluntary biodiversity credit markets: A global review of biodiversity credit schemes. *Pollination*. Group. 42, p. <https://pollinationgroup.com/wp-content/uploads/2023/10/Global-Review-of-> (accessed 27 February 2025).
- Waterford, L., FitzSimons, V., Back, O., Martin, M., Ingram, C., Chessman, J., Swann, E., 2024. State of voluntary biodiversity credit markets: current supply and demand dynamics. *Pollination*. Group. 43, p. <https://pollinationgroup.com/global-perspectives/state-of-voluntary-biodiversity-credit-markets/> (accessed 27 February 2025).
- Winter, S., Höfler, J., Michel, A.K., Böck, A., Ankerst, D.P., 2015. Association of tree and plot characteristics with microhabitat formation in European beech and Douglas-fir forests. *Eur. J. Forest Res.* 134, 335–347. <https://doi.org/10.1007/s10342-014-0855-x>.
- World Economic Forum, 2024. Nature finance and biodiversity credits: A private sector roadmap to finance and act on nature. World Economic Forum in collaboration with McKinsey & Company. https://www3.weforum.org/docs/WEF_Nature_Finance_and_Biodiversity_Credits_2024.pdf (accessed 27 February 2025).
- Wunder, S., Necessary conditions for ecosystem service payments. *Economics and Conservation in the Tropics: A Strategic Dialogue*. Conference Paper. https://www.researchgate.net/publication/239924635_Necessary_Conditions_for_Ecosystem_Service_Payments.
- Wunder, S., Fraccaroli, C., Bull, J.W., Dutta, T., Eyres, A., Evans, M.C., Jellesmark Thorsen, B., Jones, J.P.G., Maron, M., Muys, B., Pacheco, A., Strange-Olesen, A., Swinfield, T., Tegegne, Y.T., White, T.B., Zhang, H., Zu Ermgassen, O.S.E., 2025. Biodiversity credits: An overview of the current state, future opportunities, and potential pitfalls. *Bus. Strategy Environ.* <https://doi.org/10.1002/bse.70018>.
- Zhang, D., 2016. Payments for forest-based environmental services: A close look. *Forest Policy Econ.* 72, 78–84. <https://doi.org/10.1016/j.forpol.2016.06.017>.
- zu Ermgassen, S.O., Baker, J., Griffiths, R.A., Strange, N., Matthew, S.J., Bull, J.W., 2019. The ecological outcomes of biodiversity offsets under “no net loss” policies: A global review. *Conserv. Lett.* 12, e12664. <https://doi.org/10.1111/conl.12664>.
- Zu Ermgassen, S.O., Löfqvist, S., 2024. Financing ecosystem restoration. *Curr. Biol.* 34, R412–R417. <https://doi.org/10.1016/j.cub.2024.02.031>.
- Zynobia, E., Steele, P., Ducros, A., 2023. Biocredit catalogue: A collection of biocredit developers and schemes. IIED, London. <https://www.iied.org/22201iied> (accessed 27 February 2025).