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Article title: A financial framework for nature must that recognise that ecosystems have local temporal and spatial dynamics

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Abstract

Decades of research and politics have led to a coherent set of biodiversity metrics and strong evidence that biodiversity supports human well-being. So why do we not have a financial system that encourages conservation and restoration of nature? We argue that a central reason is that the financing used has not been aligned with the spatial and temporal structure of biodiversity. Ecosystems are 'local': strongly shaped by the propagating consequences of interactions through time and across space, such that measuring or predicting biodiversity in any one region requires context from nearby regions and prior ecological processes. Not all financing methods are local, and joint biodiversity-finance approaches that do not account for ecosystems' locality cannot succeed. This mismatch helps explain why biodiversity crediting markets face persistent design problems, and why advances in monitoring or AI, while valuable, cannot by themselves resolve the challenge. We therefore argue for coupled ecological-financing methods that respect ecological locality, non-fungibility, and time-horizons. Drawing on case studies of finance-based interventions, we outline modifications to existing frameworks and argue that biodiversity finance is likely to require new intermediary institutions, potentially including nested global and regional systems of financial institutions.

Impact statement

Despite the well-established financial and societal impacts of global biodiversity loss, we have yet to develop financial architectures capable of prioritising nature conservation and recovery at scale. We argue that an important reason is a mismatch between the spatial and temporal structure of ecological systems and the way biodiversity finance is often structured. This implies that global crediting approaches, while potentially useful in limited settings, are unlikely to be sufficient unless they are embedded in frameworks that preserve ecological context, avoid excessive aggregation, and rely on institutions capable of mediating between global finance and local ecosystems.

Main text

Biodiversity is essential for people and economies, with strong evidence that it underpins key ecosystem services that we rely on, providing food, water, and health (Dasgupta, 2021; Díaz et al., 2019; IPBES, 2024; Kumar, 2012; Pimentel et al., 1997). This makes the ongoing loss of biodiversity a global crisis (Díaz et al., 2019). In response, the creation of organisations and frameworks to address the challenge of biodiversity loss (*e.g.*, IPBES; see Díaz et al., 2015) has led to the development of targeted road-maps and plans (*e.g.*, the Kunming-Montreal Global Biodiversity Framework, reviewed by Hughes & Grumbine, 2023) and a coherent set of biodiversity metrics that can be applied in almost any ecosystem (*e.g.*, Pereira et al., 2013). These impressive efforts have achieved a great deal, but there are still concerns that the pace of change is insufficient to stop, yet alone reverse, current biodiversity loss (Leclère et al., 2020).

Governments have been quick to identify the importance of biodiversity (and in particular 'natural capital'; Dasgupta, 2021), but many, particularly those with large regions of intact ecosystems, lack the resources to preserve nature in the short-term. Given current national budget deficits and debts (International Monetary Fund, 2024), ongoing external stressors such as wars, and growing impacts from climate change (Pörtner et al., 2023), it seems unlikely that governments will have greater resources to spend on biodiversity in the near-term. Financial frameworks, by leveraging private resources, are seen as a potential solution to these issues (Flammer et al., 2025b; Karolyi & Tobin-de la Puente, 2023a). Financial instruments (summarised in table 1) and institutions offer alternative, potentially faster-paced, ways to preserve biodiversity in comparison with traditional, governmental conservation actions.

To incorporate biodiversity into financial decision-making, frameworks such as the Taskforce on Nature-related Financial Disclosures (TNFD; reviewed by Irvine-Broque & Dempsey, 2023) have been developed to provide guidance on assessing and reporting nature-related dependencies and impacts. The uptake and enforcement of these frameworks is beginning to be recognised but remains limited (Nedopil, 2023). This is partly because, unlike carbon, biodiversity lacks established markets and universal pricing strategies or regulations, restricting financial incentives for its protection (Tedersoo et al., 2024). A key barrier has been the question of how to measure biodiversity: on the one hand, biodiversity researchers have long argued that there is no one metric of biodiversity (Magurran, 2021) and so there should never be a single policy metric (Purvis, 2025). As a result, they have instead provided a suite of potential metrics to be used in concert (Pereira et al., 2013). On the other hand, financial actors need a universal, reliable, and trusted method of biodiversity measurement to form the backbone of a market (Lucey et al., 2025).

Here, we argue that current approaches to integrating ecology and finance have a fundamental, conceptual flaw: they do not recognise that they operate across distinct spatio-temporal scales. The search for a single (set of) biodiversity metric(s) that work for global financing is one, of many, problems that results from this flaw. We begin by describing the fundamental issues, and then consider whether simple fixes to existing reporting schemes would be capable of addressing this issue. We then outline the issues associated with spatial, and then temporal, scale variation for coupled biodiversity-financing methods. We conclude by outlining a new, more radical, approach to integrating biodiversity into finance, that is grounded in the current global financial situation and approaches that have proven successful in the past. Our claim is not that biodiversity lacks metrics, nor that finance lacks interest, but that the dominant financial architectures currently being proposed are poorly matched to the scale structure of ecological processes.

Ecosystems are locally bounded within time and space and financing must account for this

Biodiversity scientists are rarely interested in the absolute value of an observed biodiversity sample at a single place and time. Rather, they are interested in how biodiversity varies across time and space, and how that variation can be used to understand underlying ecosystem processes and states (Chave, 2013; Levin, 1992). Different biological processes—interactions among individuals, environmental forcing factors, and evolution—are expected to be detectable at different spatio-temporal scales (figure 1; Cavender-Bares et al., 2009; Weiher & Keddy, 1995). Importantly, this spatio-temporal mapping is not controversial in biodiversity science, and it is expected that processes that operate across broader spatial scales will also operate across broader temporal ones. Entire sub-fields, such as eco-evolutionary dynamics, have been created for the fascinating edge cases of this relationship, such as when evolutionary processes traditionally thought of as operating across broad spatio-temporal scales are detected at finer ones (Pelletier et al., 2009).

Recognising this spatio-temporal framework allows the biodiversity researcher to make intuitive decisions about the data required to understand their study system. To forecast the biodiversity of a $1m^2$ patch of grass at Silwood Park (UK) in a year's time, we would hope to have data on nearby (within $100m$) sites from which seeds could disperse, the biodiversity and climate of the last two years (to establish a baseline), and climate forecasts for next year (to inform prediction). It is perhaps intuitive that to forecast a million years into the future would require data from greater distances away (as there is more time for dispersal of distant species), from further in the past (to establish a greater baseline of expected variation), and of different kinds (*e.g.*, genetic data, to account for possible evolution). What is less intuitive to the non-specialist, and that this framework shows us, is that modelling biodiversity across broader spatial scales also requires broader temporal scales. As we move across space, we move across lineages (species) that have been isolated for longer periods of time and so have accumulated deeper evolutionary differences.

This need for spatio-temporal context reveals that, even if AI and other technological advances deliver on their promise of near-constant, global biodiversity monitoring (Allan et al., 2018; Besson et al., 2022; Perry et al., 2022), such monitoring will be insufficient to address the challenges of biodiversity loss. We do not doubt that biodiversity monitoring and assessment are undergoing transformative improvement, particularly in remote sensing (Converse et al., 2024), despite practical challenges around taxonomic coverage (Stephenson, 2020), data processing (Besson et al., 2022; Keitt & Abelson, 2021), and adoption of high-throughput measurement (Lawson et al., 2025). But faith in technology should not be allowed to create a false sense of security by importing assumptions from finance, where short-term predictability is possible, into local ecosystems defined by complexity, uncertainty, and a dependency on historical context. Using existing long-term monitoring, natural history collections, or deep-time evolutionary information (Barak et al., 2016; Rick & Lockwood, 2013; Willis & Birks, 2006) could, however, allow us to capitalise on technological advances to prioritise monitoring and management (Pyke & Ehrlich, 2010; Willis et al., 2007).

Biodiversity finance needs to take into account the locality of ecological systems by appropriately structuring contracts and information transmission. Many financing methods are, of course, local in the sense that they rely on local information and context (see Allen & Gale, 2000). The first formal institutions for finance were banks, which have been around for thousands of years and were initially very local. Banks raised money through deposits and lent money to local businesses and families; depositors did (and still do) have little knowledge about loans that were made. Over time, banks have become larger and more spread out geographically, but most loan decisions remain based on local information. Institutions would later develop into what today would be called over-the-counter (OTC) markets (reviewed by Duffie et al., 2005). These were physical gathering places, such as the Rialto Bridge in Venice or the coffee houses of London, where dealers bought and sold financial securities (*e.g.*, bonds and shares) at fairly significant bid-ask spreads to allow them to hold inventories and make a living.

Many bond markets, particularly for corporate bonds, still essentially trade as OTC markets, but later, institutions such as exchanges developed, an early example of which is the Amsterdam Bourse (c. 1602). Crucial to the development of (global) exchanges was standardisation: prices are posted across markets and so processes such as financial arbitrage can operate effectively. Markets' dependencies on standardisation and potential for instantaneous trading are what drive the disconnect between financial and ecological systems (figure 1). Financial systems such as these that do not share this spatio-temporal scaling are essentially 'non-local' (*sensu* Amico et al., 2008): they are highly networked and capable of propagating valuation effects across space on incredibly rapid timescales (Schwarcz, 2008) much faster and further than ecological processes. A transaction executed in one market can affect prices, funding conditions, collateral values, and balance-sheet constraints elsewhere. In our everyday lives, we all rely on local institutions such as banks, using them to save, hold, and invest money on our behalf; such institutions are the bridges between our local lives and non-local global markets. Ecosystems do not, at present, have such a bridge, and as such it is challenging to integrate finance and ecology.

Local ecosystem structure should determine corporate reporting

The standards and frameworks that regulate how firms should measure, manage, and report their impacts on ecosystems (*e.g.*, TNFD) are at an early stage and are still open to refinement. The central problem is not the proposed metrics themselves, but that many metrics are reported at levels of temporal and spatial aggregation that are poorly aligned with the mechanisms by which ecological harm propagates and recovery occurs (Levin et al., 2013). This makes it difficult to connect financial disclosures to ecological processes, and therefore difficult to interpret reported values or to forecast using ecological theory.

From the perspective of an ecosystem, many economic activities (*e.g.*, felling a forest for timber) are exogenous shocks. Reporting frameworks should therefore place greater emphasis on how ecological systems absorb, propagate, and recover from such perturbations (Scheffer et al., 2009). At a minimum, this requires attention to: (a) ecosystem condition before and after the perturbation, (b) the duration and temporal pattern of the perturbation, and (c) the spatial scale over which the effect propagates. Annualised reporting can still be useful for some purposes, but where perturbations are local, pulsed, or state-dependent, annual averages can materially weaken inference and in some cases become misleading. This is different from climate reporting, where the externality is comparatively more global and cumulative. Even there, however, aggregation into CO_2-equivalent units can generate distortions when gases differ in persistence, warming profiles, or reporting standards are not harmonised (Biagini et al., 2026; Cenci & Biffis, 2025). If aggregation is already imperfect in climate, the case for caution is stronger still in biodiversity.

We therefore argue that regulators in biodiversity finance should focus less on proposing new biodiversity metrics and more on how existing ecologically meaningful metrics are collected, time-stamped, spatially located, and reported. For example, the Essential Biodiversity Variables (EBVs; Pereira et al., 2013) provide a plausible starting point. The deeper difficulty is often not the variable itself, but the reporting convention applied to it. Aggregated disclosure across time, geography, or business segments can wash out precisely the local ecological context needed for interpretation. Consider wastewater discharge. Volume and pollutant concentration are intuitive metrics, but the same measured discharge can generate very different ecological consequences depending on whether it is released as a short pulse or continuously, whether it enters a resilient or already degraded ecosystem, and whether downstream effects propagate locally or across a wider hydrological system. The problem is not the metric in isolation: it is the loss of ecological information induced by aggregation.

The problem of pricing biodiversity across space: the challenge of 'ecological arbitrage'

A significant part of the current paradigm of coupled financial-biodiversity systems based on widely accessible markets depends on the development of a *global* crediting framework. This is challenging because a non-local financial market requires a universal measure of value. The spatio-temporal scaling of biodiversity means that there are, in essence, multiple markets that have been expanding, contracting, and exchanging across millions of years, each with separate value systems. Biologists call the local richness of an ecosystem 'α-diversity' and the differences among ecosystems 'β-diversity' (Magurran, 2021); both of these components induce different challenges for financial markets. α-diversity is measured in different ways in different ecosystems, and there are not even rules of thumb for what an appropriate value is (*e.g.*, more species is often better, but degraded systems are often hyper-diverse; Pearse et al., 2018). There are also no short-cuts to assessing ecosystem state: it is rare for the presence of a particular species (*e.g.*, an ecosystem engineer) to reliably indicate an ecosystem's health but, even where such species do exist, they must laboriously be found for each ecosystem and each region (Lindenmayer & Westgate, 2020). β-diversity means that financial systems cannot treat the loss of one habitat (*e.g.*, a forest in Borneo) as equivalent to the gain of another (*e.g.*, a forest in England): distinct ecosystems are not fungible (exchangeable).

Markets that do not account for the spatio-temporal context of ecological systems will generate persistent mispricing. We use 'ecological arbitrage' as shorthand for this broader class of errors: ecologically non-equivalent assets are forced into exchangeable accounting categories, allowing gains to be realised financially while ecological losses remain local, weakly priced, or entirely external to the market. Unlike standard financial arbitrage, where price discrepancies between equivalent claims are traded away, price correction cannot occur in the usual sense because the claims being compared are not genuinely equivalent; they have been falsely treated as commensurable by accounting conventions that suppress ecological reality. Different ecosystem types have radically different species composition, evolutionary history, resilience, and ecosystem service provision, and those differences often matter precisely because benefits and losses accrue at different spatial scales (figure 2). When markets ignore this context, they do not discover the correct price of nature, and the consequent loss of local livelihoods, clean water, and regulating services remain external to the market. Unless checked, this process will shift benefits elsewhere within the market while leaving ecological losses concentrated locally, reinforcing both biodiversity decline and social inequality. In that sense, it is a telecoupled commons problem, with cross-border spillovers, unpriced externalities, and weak collective governance (Hardin, 1968; Liu et al., 2015; Perrings et al., 1992).

A constructive pricing framework might begin from shadow pricing (estimating the contribution or value of something, such as biodiversity, even without a market to trade it) rather than simple unitisation. In practice, nature should be valued through state-contingent, location-specific measures in line with private market valuation methods. This valuation should at least reflect ecosystem condition, ecological irreplaceability, durability of the claimed outcome, restoration lag relative to preservation, vulnerability to tipping-points or irreversible loss, and the scale at which ecosystem services and spillovers accrue. Preservation and restoration claims should not be treated symmetrically (*e.g.*, Duchelle et al., 2018), and credits from ecologically distinct systems should not be freely fungible. Valuations should be adjusted for uncertainty in future ecological trajectories, including threshold effects and feedbacks to regulating services. Better pricing can reduce misclassification and improve capital allocation, but it cannot fully substitute for institutional judgement where ecological trajectories are weakly observable, slow moving, or only partially contractible. The aim should therefore not be to manufacture a single universal price for 'nature', but to design families of contracts and valuation rules that respect ecological non-fungibility, state contingency, and time-horizon dependence.

The problem of changing biodiversity priorities over time: dynamic inconsistency

A central difficulty in biodiversity conservation and restoration is dynamic inconsistency: the changing of policy over time such that earlier, optimal plans are abandoned in favour of shorter-term rewards. This problem is especially acute for biodiversity because ecological systems are slow-moving, state-dependent, and partly irreversible, whereas political and financial decision cycles are short. As a result, governments may commit to long-horizon conservation or restoration, only to weaken standards later when fiscal pressure intensifies, political leadership changes, or the local distribution of costs and benefits becomes politically inconvenient. Private actors face a related commitment problem: investors and firms may support nature-positive strategies in principle, yet retrench when short-term performance pressures tighten, biodiversity outcomes remain difficult to verify at the pace demanded by markets, or the returns to ecological stewardship accrue too slowly to sustain private incentives (Levin et al., 2013; Levin, 1998).

Incomplete contracting makes this problem more severe. Neither public regulation nor private agreements can specify all future ecological contingencies, all relevant states of ecosystem degradation, or all shifts in political, technological, and macro-financial conditions. Critically, delays that seem modest in political or market time could push ecosystems toward states from which recovery is slow, costly, or impossible. Biodiversity finance faces the challenges that complex adaptive systems theory warns against: policy designed under linear, reductionist, or static assumptions will tend to omit the very features that matter most for long-term management (Levin et al., 2013). In practice, biodiversity finance is therefore exposed to a two-level commitment problem: within jurisdictions, policymakers face electoral turnover and fiscal constraints; across jurisdictions, countries and firms can defer effort, free-ride, or relocate ecological pressure elsewhere (*sensu* Putnam, 1988).

The amount of uncertainty through time, both in terms of ecosystem dynamics and also contracting, suggest that biodiversity-linked contracts should rarely be designed as simple pay-for-outcome claims. More credible structures are likely to combine staged capital release, adaptive covenants, independent monitoring, periodic recalibration, and, where feasible, clawback or penalty mechanisms linked to reversals in ecological condition. In many settings, a more credible allocation of responsibilities may be for private finance to absorb shorter-horizon financing, liquidity, or transition risk, while longer-horizon commitment risk remains with public or quasi-public institutions better able to sustain stewardship over time. Finance instruments based around insurance may be useful in these contexts not because biodiversity losses are fully insurable, but because it forces discipline on trigger design, basis risk, verification, and residual risk allocation. Insurance could complement biodiversity finance by supporting adoption and resilience even when basis risk remains material, though it cannot substitute for institutions capable of stewarding slow-moving, path-dependent ecological recovery.

Biodiversity conservation and restoration are not only inter-temporal commitment problems but also commons problems: they concern public goods and common-pool resources whose governance requires collectively accepted constraints on individual or local incentives (Hardin, 1968; Ostrom, 1990). Thus, the challenge is not simply to elicit more private capital, but to determine how different institutional mechanisms (public regulation, collective governance arrangements, and market-based instruments) interact in sustaining cooperation over time. Markets are therefore best viewed not as an alternative to commons governance, but as one possible component of it. Markets operate within a wider institutional environment that defines property rights, admissible trades, enforcement, and the conditions under which private incentives can be aligned with collective ecological goals.

Overcoming these issues of timescale for coupled biodiversity-finance systems is complex. Financial instruments can sometimes supplement weak or politically constrained public action by mobilising capital toward conservation or restoration where regulation is absent or under-powered. But markets are not automatically complementary to regulation; Allen et al. (2023) show that carbon markets can improve outcomes when political support for regulation is absent, but may reduce support for further, needed, regulation when some exists already. Similarly, biodiversity-linked markets and securities may be valuable where states cannot credibly commit, but they may also become part of the commitment problem if they weaken incentives for durable public provision, long-term enforcement, or investment in ecological public goods. The mere existence of some form of biodiversity crediting market may be seen to solve the problem of the biodiversity crisis, even if the market is too small and regulation is absent. This could be viewed as the ultimate form, and final 'success', of green-washing (reviewed in de Freitas Netto et al., 2020).

Beyond global biodiversity crediting markets: the role of biodiversity-finance institutions

Because ecosystems are inherently local, there will be many different kinds of biodiversity problems to be solved, and the costs of assessing and addressing them will be large. Yet there are cases where financial markets have driven successful, local, low-cost interventions (table 1). One example is the World Bank's outcome-contingent Rhino Bond, where investor returns are linked to verified population outcomes over a multi-year horizon (reviewed by Medina & Scales, 2024). Insurance policies have also been successful; The Nature Conservancy worked with the Mexican state of Quintana Roo to fund rapid reef and beach repair after events such as Hurricane Delta (The Nature Conservancy, 2021). These cases do not show that biodiversity can be standardised into a deep universal market, but rather that bespoke (local) financial instruments can work when the ecological objective is clear and can be monitored, and that an intermediary can connect non-local finance to local implementation. Because such instruments are thinly traded, bespoke, and information-intensive, they are more naturally organised as OTC markets. The growth of the carbon market, despite ongoing issues with its auditing, has often been seen as a model that biodiversity crediting could follow (García & Moros, 2025; Sasaki, 2025; Swinfield & Scott, 2025). It is notable that, while there has been great progress in standardising carbon credits and measureable units, for *voluntary* carbon markets where much more information is required, OTC markets are used rather than global, centralised exchanges (Berg et al., 2025).

To date, the scale at which market-based financial interventions have been applied is limited in comparison to the scale of the global biodiversity crisis (see table 1 and Waterford et al., 2024). It is therefore useful to ask how finance is normally supplied when projects are variable and costly, as is true of biodiversity. In most economies, capital is not raised through markets, but through intermediaries such as banks and other financial institutions. These institutions exist precisely because many investment opportunities are bespoke, information-intensive, and so not easily reducible to standardised securities. Small and medium-sized enterprise lending depends on banks: loans are typically bespoke and rely on decentralised judgements of borrower quality, local conditions, and risk. Biodiversity opportunities are essentially the same: assessing the likelihood of success and the return on investment requires detailed, expert understanding of the local ecosystem. If financial institutions have, historically and successfully, acted as the local intermediaries between non-local financial markets and local systems, it seems reasonable that they should again be used to act as intermediaries among global capital and local expertise.

Biodiversity finance may require an intermediary architecture beyond today's mix of disclosure frameworks, fragmented project finance, and voluntary crediting. A World Biodiversity Organisation (WBO) is one possible model, particularly if understood not as a replacement for existing institutions but as a coordinating and capacity-building layer. This model has been successfully followed in other settings, such as The World Bank (World Bank Group, 2025), which successfully deals with development issues, and the World Health Organisation (WHO; WHO, 2025), that focuses on health in all countries. A WBO could be funded in a variety of ways much like the World Bank, where there is a private sector arm, as well as philanthropic, and government funding. Just as the World Bank and WHO have a wide range of experts among their staff, the WBO would also have broad capabilities, covering biodiversity, socio-economic systems, finance, and the interplay between them. Critically, just as banks act to manage the complexities of complying with financial policy, investment decisions for stored wealth, and the safety of assets, the WBO would manage the complexities of local ecosystem processes. By acting as a trusted intermediary, the WBO would work with partners on-the-ground to ensure broader improvement in biodiversity, similarly to how the WHO works with on-the-ground partners to share knowledge, expertise, and support public-health policy. A WBO would not replace or overlap with the roles of organisations like the IPBES (Díaz et al., 2015, 2019) or conventions such as the CBD (Chandra & Idrisova, 2011): it would act as a trusted intermediary to facilitate financial transactions.

The World Bank is not the only major development organisation in the financial sector, and we do not propose that a WBO would supplant or replace existing conservation groups. Economic development problems are often regional in nature, and so there are many regional development banks. These include the African Development Bank (AfDB), the Asian Development Bank (ADB), the Asian Infrastructure Investment Bank (AIIB), the European Bank for Reconstruction and Development (EBRD), and the Inter-American Development Bank (IDB). These examples highlight that financial institutions are typically local: just like ecosystems, they have a defined spatio-temporal scope, allowing them to act as a bridge between financial and natural systems. A similar structure of multiple biodiversity organisations would be desirable because biodiversity challenges vary in different parts of the world. This hierarchical nesting of inter-connected organisations would match well to the local structure and functioning of ecosystems and, notably, would match approaches recommended for biodiversity measurement (Gonzalez et al., 2026).

These institutions could even organise markets for biodiversity credits to the extent these are possible or desired, and regulate and manage them. By acting as such a broker, the problems of ecological arbitrage and temporal inconsistency might be entirely avoided by adding oversight of the distribution of biodiversity credits across ecosystems. Managed within a hierarchical framework, these institutions might be a way to leverage global capital and apply it within a series of local, ecosystem-centric markets. Refusing to accept the loss or gain of credits in a particular ecosystem-type might help drive market corrections of price for credits on the basis of the rarity and β-diversity of a portfolio of credits, and help buffer against short-term, local policy changes.

Conclusion

The scale of the biodiversity crisis, but also the lack of the financial and political resources available to address it, have never been greater. The majority of current efforts to conserve biodiversity are focused around traditional conservation and restoration of ecosystems, increasing the efficiency of food supply while decreasing human demand, and developing biodiversity-crediting tools (Leclère et al., 2020). Our goal here is not to suggest that efforts on those three fronts should be slowed, abandoned, or have been poorly conceived. Instead, we have highlighted ways to diversify and increase the financial resources we use to address this crisis based upon careful, interdisciplinary assessment of opportunities and challenges at the intersections of biodiversity and finance. The last decades have seen periods of progress and decline in crediting approaches such as REDD+ (Reducing Emissions from Deforestation and forest Degradation; Duchelle et al., 2018) and the EU's Carbon Removals and Carbon Farming framework (CRCF; Günther et al., 2024; Laktuka et al., 2025; Vidal Morant et al., 2025). Yet all of these approaches are fundamentally based around some kind of traded, credited system and none have yet succeeded in solving the biodiversity crisis. There is clearly capacity within the global community of researchers and market participants to consider more than one approach, and we see no risk that considering alternatives will somehow dilute efforts. As a species, we have overcome global challenges such as smallpox and the hole in the ozone-layer, but we have never done so through the actions of market forces alone. Perhaps now is the time to extend our aim beyond markets towards a global, financial institution such as the World Biodiversity Organisation.

Table 1: **Candidate instruments for 'investable biodiversity'**. The table lists illustrative financial structures that can be tailored to biodiversity projects with different process horizons and uncertainty profiles. For each instruments we list (a) market size, (b) typical tenor (essentially the duration of the contract), (b) dominant risk profile (ecological, measurement, and policy risks), suitability for biodiversity outcomes (including whether outcomes can be credibly measured within the contract window and, where feasible, tied to performance-contingent payments rather than inputs or proxies), (e) typical investors, and (f) examples. We *do not* cover voluntary carbon offsets marketed with biodiversity co-benefits as the carbon market is too large and varied, and we address it instead in the main text. We note that Zhou and Almond (2026) reported market size of c. \$2bn for such credits in 2021, projecting c. \$50bn by 2030, but found no systematic evidence of improved ecological quality across the credits.

Instrument	**Size**	**Tenor (yrs)**	**Risk profile**	**Suitability**	**Investors**	**Example**
Biodiversity credits	Nascent. Allen et al. (2026) report <\$2m sold by 2024 but note that some estimate up to \$5.9m; Waterford et al. (2024) estimate \$0.33–1.85m.	1–30	High for measurement, permanence and policy. Potential low liquidity. Reviewed by Croci et al. (2025b) and Holmlund et al. (2026)	High only with credible integrity rules; weak fit for a fungible global market.	Corporates, impact funds, specialised buyers	Various; reviewed by Croci et al. (2025a).
Offsets / mitigation banking	OECD (2024) records 17 programmes in 9 countries, Vaissière and Levrel (2015) estimate c. \$6.3–9.2 bn/year	5–30	Equivalence, location, restoration, and regulatory risk; liquidity low/moderate & program-specific (Levrel et al., 2017)	Medium where equivalence rules are strict	Developers, mitigation banks, regulated entities	Wetland mitigation banking (Robertson & Hayden, 2008)
Payment for Ecosystem Services (PES)	c. \$10.1 bn/year. OECD (2024) records 51 schemes in 28 countries; earlier (Perry & Karousakis, 2020) work identified 153 programmes in 37 countries.	1–20	Contracting, targeting, monitoring, and slippage risk; illiquid by design (Engel et al., 2008; Jack et al., 2008)	High for repeated local incentives; weak fit for capital-markets scaling	Governments, donors, NGOs, DFIs	Various, many in Costa Rica & Mexico (Engel et al., 2008; Sims & Alix-Garcia, 2017)
Outcome-based conservation bonds	Pilot-scale. Rhino Bond issued at \$150m in 2022 (World Bank, 2022)	3–10	Outcome, verification, and model risk; bespoke structures with limited secondary liquidity (Thompson, 2023)	High if ecological outcomes are independently verifiable during contract	Impact investors, foundations, DFIs	Rhino Bond (reviewed by Medina & Scales, 2024)
Parametric insurance	No robust biodiversity-only total; parent-market comparator is global Insurance-Linked Securities (ILS), c. \$48bn outstanding at end-2024 (Reguero et al., 2020; Swiss Re, 2026)	1–5	Tail-event, basis, trigger, and counterparty risk; liquidity varies with ILS conditions but is only moderate (Bill-Weilandt et al., 2026; Reguero et al., 2020)	High for rapid post-shock funding; indirect for long-run biodiversity recovery	ILS funds, institutional investors, re-insurers, donors	The Mesoamerican Reef Insurance Policy (Wharton, 2024)

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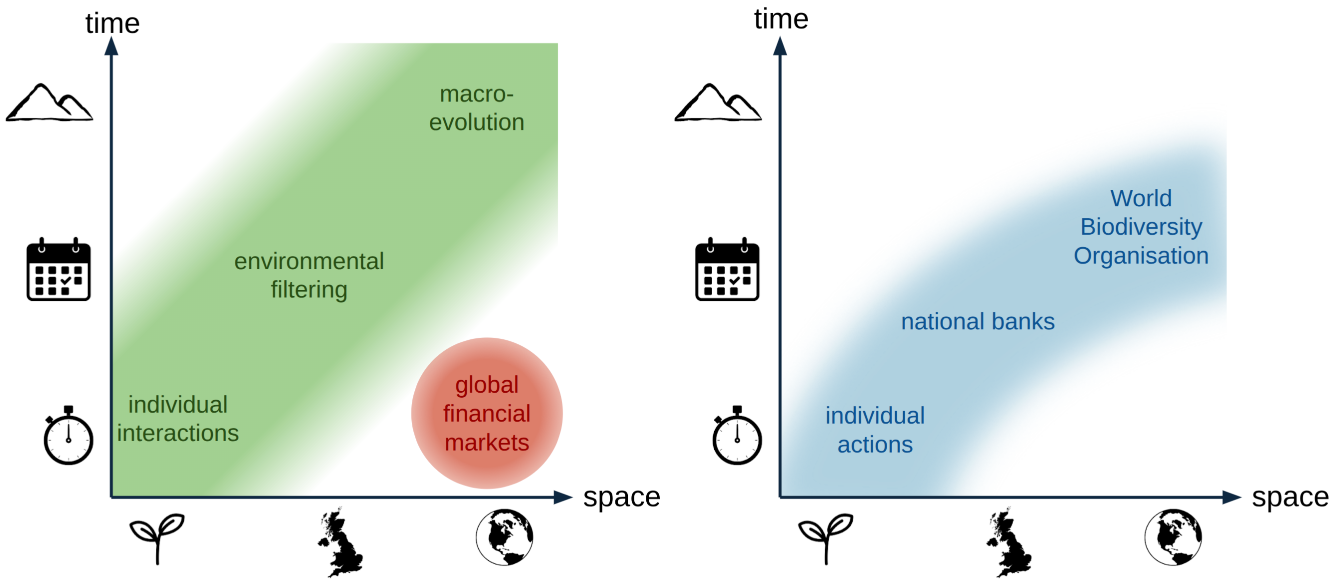
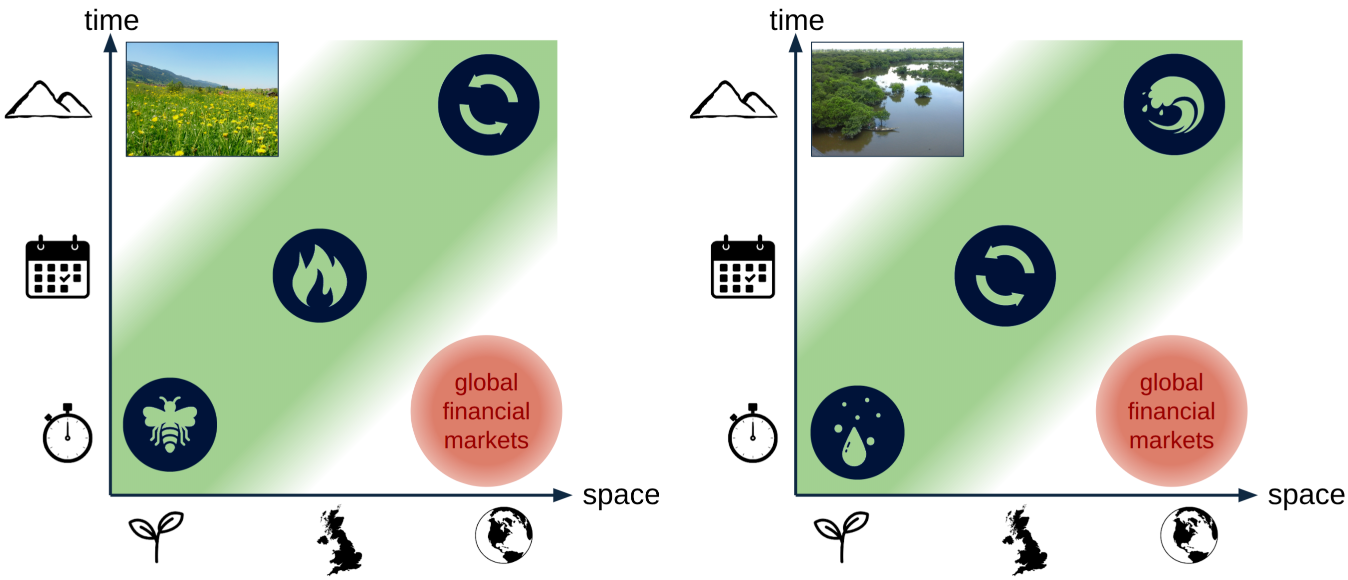
Table 1 – continued from previous page

Instrument	Size	Tenor (years)	Risk profile	Suitability	Investors	Example
Use-of-proceeds green / blue bonds and loans	OECD (2025b) report $639 bn in 2024, but biodiversity is a subset of broader labelled debt	3–15	Credit, execution, and reporting risk; public formats can be liquid, but biodiversity linkage is indirect (Karolyi & Tobin-de la Puente, 2023b)	Medium–high, weaker with strict biodiversity attribution.	Pension funds, insurers, mutual funds, banks, MDBs	Seychelles sovereign blue bond (March et al., 2024)
Sustainability-Linked Bonds & Loans (SLBs/SLLs)	OECD (2025b) reports $35bn global corporate SLBs in 2024, of which biodiversity are a small portion	2–10	KPI calibration and verification risk; issuer credit risk; publicly tradeable but biodiversity link is often weak (Anderson & Kish, 2024; De Mariz et al., 2024; Feldhütter et al., 2024)	Medium–high if robustly linked to biodiversity	Public credit investors, banks	Suzano sustainability-linked securities (Suzano, 2021)
Debt-for-nature swaps	Large but infrequent; average deal c. $700m in 2020–24 (OECD, 2025a)	10–30	Sovereign, FX, political, legal, and governance risk; structured and episodic, with low secondary liquidity (Cassimon et al., 2011; Nedopil & Sun, 2025)	High for long-horizon funding with governance covenants	DFIs, sovereign investors, guarantors, NGOs	Belize ($364m; The Nature Conservancy, 2022) & Ecuador's Galápagos Islands (c. $1.6bn; Inter-American Development Bank, 2023)
Blended-finance vehicles	Convergence (2024) records 1,123 transactions totalling $213bn; biodiversity vehicles are a small subset	7–15	Asset, pipeline, governance, and exit risk; illiquid, dependent on patient and concessional capital (Flammer et al., 2024, 2025a)	High if vehicle internalises monitoring and management	DFIs, endowments, family offices, impact funds	The Fund for Nature (Climate Policy Initiative, 2022)
Biodiversity-themed listed funds	MSCI (2023) identifies 149 funds with c. $60bn of assets as of Sep. 2023, including 15 pure-play funds with c. $1bn of assets. Goldman Sachs Asset Management (2025) described a narrower c. $3.4 bn set in 2025.	Open-ended / perpetual	Thematic concentration, taxonomy drift, and greenwashing risk; listed wrappers may be liquid, but outcome linkage is weak and indirect (Flammer et al., 2025a; Goldman Sachs Asset Management, 2024)	Low–medium for direct additionality; stronger as allocation wrappers than as local biodiversity contracts	Asset managers, wealth platforms, retail and institutional allocators	Goldman Sachs Biodiversity Bond Fund (Goldman Sachs Asset Management, 2025)



(a) Current biodiversity-finance (b) Proposed biodiversity-finance

Figure 1: **Biodiversity processes operate across a local spatio-temporal scale, while current global financial systems are non-local**. In (a), ecologists and evolutionary biologists have long-recognised that biodiversity is structured by processes (green) that operate across different scales of space (horizontal axis, measured in centimetres, kilometres, and hundreds of kilometres) and time (vertical axis, measured in seconds, months, and (millions) of years; Cavender-Bares et al., 2009; Weiher & Keddy, 1995). Current global financial systems (red), on the other hand, are non-local: they can operate near-instantaneously across the entire planet. Our central argument is that no coupled financial-ecological systems can be successful without acknowledging and accounting for this difference. In (b), we show our proposal: a nested hierarchy of interventions that are operating at the appropriate spatial and temporal scales of biodiversity.



(a) Grassland (b) Wetland

Figure 2: **Ecosystem services, and the spatio-temporal scales at which they operate, vary across ecosystems**. The same spatio-temporal scale is shown as in figure 1, but now ecosystem services (functions performed by ecosystems that benefit humans (Millennium ecosystem assessment, 2005) from two different ecosystems (in (a), a grassland, and in (b) a wetland) are shown. In the grassland, local-scale pollination services are provided, while protection from fire (through fire-breaks) and long-term nutrient cycling are provided at larger scales. In the wetland, similar nutrient cycling is provided but now at intermediate spatial and temporal scales, while smaller-scale support of water purification and flood protection at the widest scales are also provided. We emphasise that these are exemplar, hypothetical ecosystems and services, but they illustrate the point that the kind and scale of ecosystem services provided vary across the world (Moffett et al., 2026).

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