Co-crediting system for carbon and biodiversity

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Science for Society

Humankind is facing both climate and biodiversity crises. To ameliorate carbon emissions, carbon offsetting and crediting systems have become well established, whereas equivalent programs are nonexistent for biodiversity. Here we propose a scheme that offers tradable credits for combined aboveground and soil carbon and biodiversity, where species richness of various soil organisms constitutes a biodiversity proxy. We argue that multidiversity - based on high-throughput molecular identification of soil animals, fungi, bacteria, protists and plants - offers a cost-effective method that captures much of the terrestrial biodiversity. We anticipate that such a voluntary crediting system increases the quality of carbon projects and may contribute to much of global biodiversity funding in a 10-year perspective.

Summary

Carbon crediting and land offsets for biodiversity protection are implemented to tackle the challenges of increasing greenhouse gas emissions and loss of global biodiversity, but these two mechanisms are not optimal when considered separately. Focusing solely on carbon capture – the primary goal of most carbon-focused offsetting commitments – often results in the establishment of non-native, fast-growing monocultures that negatively affect biodiversity and soil-related ecosystem services. Soil contributes a vast proportion of global biodiversity and contains traces of aboveground organisms. Here we introduce a carbon and biodiversity co-crediting scheme based on the multi-kingdom molecular analysis and carbon analysis of soil samples and remote sensing for above-ground carbon analysis. Combined, such a co-crediting scheme could help halt biodiversity loss by incentivising industry and governments to fully account for biodiversity in carbon sequestration projects, prioritising protection before restoration and promoting socially and environmentally sustainable land stewardship in society's journey towards a 'Net Positive' future.

Keywords: biodiversity crediting, carbon crediting, soil biodiversity, DNA metabarcoding, molecular identification, ecological sustainability, net positive effect, biodiversity banking, offsetting, conservation

Introduction

The release of greenhouse gases and the continued expansion of agriculture and forestry have collectively resulted in massive losses of native biodiversity worldwide[1-3]. Today, land use changes constitute the primary threat to species worldwide, with climate change driving key additional risks such as increased physiological stress and loss of suitable habitat or mutualistic partners[4,5]. In an effort to mitigate climate change, there has been a tremendous interest by industry, governments and other parts of society to rapidly develop schemes to sequester carbon, either through technological inventions for locking carbon into the substrate or through nature-based solutions, such as the mass planting of trees[6]. The problem is that these carbon capture solutions are often deleterious to biodiversity, for example by promoting rapidly growing tree monocultures instead of natural vegetation[7,8]. Furthermore, short-rotation bioenergy plantations only poorly mitigate climate change relative to fossil resources and fail to support biodiversity[9].

Biodiversity is crucial for ecosystem functioning and for increasing resistance to perturbations, particularly in stressful and increasingly unpredictable environmental conditions[10]. Positive biodiversity-ecosystem functioning effects are inherent to all domains of life – from microorganisms such as bacteria and fungi to macroorganisms[11]. Much of the biodiversity is built up of rare species[12], which can have a disproportionate effect on ecosystems by performing unique ecosystem services, such as generating micro-climates, controlling diseases, and promoting tight nutrient cycling[13]. Recent estimates indicate that only around one quarter of the required funding sources are invested into biodiversity globally[14].

Programs for offsetting carbon and environmental protection have a short history. In 1989, the US-based AES company invested 2 million USD to offset carbon emissions by planting and conserving rainforest in Guatemala. In the early 1990s, the first carbon crediting initiatives were developed to support land owners practising sustainable management of agroecosystems, grasslands, and forests that promoted carbon sequestration in aboveground biomass and topsoil[15]. Similarly, conservation offsetting programs have been pursued to counterbalance agriculture-related or industrial land degradation[16]. For example, a payment-for-ecosystem-services program has been implemented in Costa Rica since 1997[17], and the Chinese Green for Grain program has been developed to prevent erosion since 1999[18]. In the 2000s, offsetting schemes for habitats of endangered species were developed in California[19]. While offsetting is related to compensating harm elsewhere and regarded as the last resort for conservation[16], biodiversity credits are designed solely to promote conservation[20]. Although carbon crediting schemes increasingly account for biodiversity effects, no large-scale, operating biodiversity crediting schemes exist (Table 1). In 2022, principles of tradable biodiversity crediting schemes were developed for terrestrial and aquatic biota[21]. In spite of the current biodiversity crisis, the relatively slow evolution of biodiversity credits is likely due to the multitude of alternative biodiversity metrics[22,23], the lack of consensus around biodiversity baselines[24], and difficulties in accurately surveying and quantifying biodiversity[25] compared to estimating carbon sequestration potential. Here we explore what we call *the biodiversity and carbon co-crediting concept*, and discuss how its implementation could transform the conservation, restoration, and off-setting landscape to help societies achieve a greener road to Net Zero – a state of balance between anthropogenic emissions and anthropogenic removals.

The biodiversity-carbon co-crediting concept

We propose that biodiversity should be explicitly incorporated into carbon marketing schemes to increase environmental and social sustainability in land use. All carbon marketing schemes should adopt the no net biodiversity loss criterion. For this integration to become possible, biodiversity needs to be robustly and efficiently measured. This is required to allow for assessments of how various forms of intervention (such as reforestation, habitat restoration, agroforestry, etc.) may affect biodiversity as compared to previous land use or management practice.

However, biodiversity is currently difficult and costly to comprehensively estimate across multiple ecosystem components such as soil, wood, air, and tree canopy. Recent advances in high-throughput DNA sequencing analysis of environmental samples (eDNA analysis) offer a promising tool for rapid, cost-effective evaluation of biodiversity, a technique now thoroughly validated for water, soil and bulk animal samples[26]. If we accept that eDNA-based biodiversity assessments are today feasible and well validated[26,27], encapsulating a much larger proportion of the planet's biodiversity than previously possible through manual assessments, the next question of implementation is: how can metrics of biodiversity be aligned with carbon markets?

Past research has shown that market-based incentives can be important mechanisms for driving conservation policy[17]. Integrating biodiversity credits into existing or novel carbon crediting mechanisms could encourage landowners to proactively manage land. If biodiversity and carbon are rewarded in the same scheme, land managers are more likely to optimise different types of benefits for the particular land cover in the region[28,29]. For instance, today only net gains in carbon can be considered under Net Zero schemes, which directly incentivises cutting and reforestation, instead of protecting a forest from felling in the first place (Fig. 1). Restoring rather than protecting is always a significantly worse and more expensive solution in both biodiversity and carbon storage terms, given the manifold advantages of an old-growth forest, as compared to any form of tree planting or natural regeneration. Today many carbon crediting schemes are blindly focused on 'cheap carbon' – supporting interventions that in fact lead to the lowest levels of both carbon storage and biodiversity in the medium term (Fig. 1). Therefore, all carbon offsets and credits affecting land use and land cover should have baseline estimates for biodiversity effects.

Directly coupling carbon and biodiversity credits would prevent other perverse incentives, such as excess fertilisation and planting monocultures, that strongly favour carbon over biodiversity[7]. A framework that directly integrates carbon and biodiversity credits needs to be practical and well-tested, setting clear rules that are easy to follow[30]. From a global perspective, these rules would benefit from general biodiversity policies[31].

As most carbon crediting schemes account only for aboveground biomass production, carbon storage in soil remains usually overlooked. In some regions, topsoil carbon stocks alone are comparable in size to aboveground carbon, but vary greatly across biomes and land cover types[32], such as lower biomass accumulation in nutrient-poor rainforests. Soil carbon stores also tend to increase with sustainable land management including organic farming, moderate grazing pressure, selective timber harvesting and establishment of mixed plantations[33-35].

Biodiversity proxies

Because soil contributes to a vast proportion of biodiversity (most terrestrial species have at least part of their life cycle underground), productivity and functioning of terrestrial ecosystems[11,36], soil biodiversity has a potential to constitute a proxy for biodiversity and ecosystem health in most forest, grassland, and agricultural habitats[37]. Soil biodiversity analyses follow the HAND(Y) principle - they are High-tech, Accurate, Novel, Detailed and Yielding. Comprehensive assessment of soil biodiversity, including both macro- and microorganisms, can be carried out using an internationally standardised soil sampling scheme (e.g., SoilBON) coupled with cross-kingdom global analyses of soil biota[38-40]. Such analyses can also help us develop a better global picture of cryptic biodiversity, such as where hotspots of micro-organismal diversity are located[37,38]. Using soil biodiversity as a metric to evaluate the impact of reforestation and habitat restoration increases the ease of measuring, comparing and monitoring biodiversity across diverse landscapes and over time[41].

In biology, genes, individuals and species are the main ecological units. Since genes and individuals are more difficult to measure and species are easy to grasp, the species-level metrics are of greatest public and conservational interest, with species richness, effective number of species and multidiversity as the best biodiversity proxies[22,42]. Functional and phylogenetic diversity offer additional insights into ecosystem functioning[43], although ascertaining impacts on ecosystem functions requires further information about the ecology of individual species, which is lacking for most soil organisms.

Species also differ in abundance, which in turn affects their contributions to ecosystem functioning. The redundancy and additionality of rare species can be difficult to assess due to the low statistical power in observational studies. Rare species are often habitat specialists or sensitive to anthropogenic impact[13]. Therefore, rare, especially threatened species, can be considered more important from the conservation and crediting perspectives[21,44]. However, the conservation status for the vast majority of species has never been assessed[3]. One pragmatic approach is to weigh the importance of all species equally, until we can rank all species based on their conservation value or distinguish them by function and habitat, for example identifying keystone forest species in re/afforestation projects[45]. The rapidly growing traits and occurrence databases (e.g., GBIF, www.gbif.org; TRY Plant Trait Database, www.try-db.org; FungalTraits[46]) may facilitate the identification of target species for ecosystem restoration in the near future.

The crediting process

To maximise biodiversity and carbon benefits, a robust crediting system should deploy evidence-based criteria for the selection of areas for potential conservation and restoration using a combination of field surveys, remote-sensing, soil maps and machine learning algorithms[47]. Rewarding companies and communities for positive change requires a robust monitoring, evaluation and reporting framework.

In the process of land evaluation, representative plots are randomly surveyed by accredited institutions using standardised procedures that are verified independently (Fig. 2)[48]. The representative plots for monitoring should be of sufficient size and number, and located randomly in the survey area, avoiding edge effects. The sampling standards may follow well-elaborated protocols for large-scale sampling schemes, such as SoilBON (https://www.globalsoilbiodiversity.org/soilbon), but these may differ by project, considering representativeness of sampling, type of habitat, target organisms, etc. Sampling should capture a significant proportion of biodiversity, and optimal sampling intensity should be determined based on pilot studies or information from scientific literature. It is important to consider time of sampling (in growing season) and storage of samples to avoid loss of diversity through DNA degradation[26] to enhance comparability across time. Molecular analysis of as many taxonomic groups as possible – plants, animals, fungi, micro-eukaryotes and prokaryotes – offers the most accurate views on overall biodiversity, reducing taxon-specific biases[42]. Additional standardised semi-automated technologies may be used for recording images and/or sounds of mammals and birds, followed by identification using machine learning techniques (e.g., https://www2.helsinki.fi/en/projects/lifeplan).

The carbon-biodiversity co-benefits can be calculated based on temporal changes relative to control plots and near-natural reference plots (endpoints) to account for climatic effects and batch effects (i.e., temporal sampling effects). The control plots should occur in comparable vegetation in nearby lands not affected by the interventions being evaluated, and reflect a situation of average management intensity or the "business as usual" scenario – how carbon and biodiversity would have changed without the intervention applied (Fig. 3). It is important to perform temporal sampling in the same representative and control plots to minimise analytical error and provide feedback about the best and worst performing areas (while keeping plot localities undisclosed). Along with remote sensing-based measurements of aboveground carbon, soil carbon can be additionally estimated using deep cores to include subsoil. Biodiversity assessments are best performed from topsoil that contains high biomass and highest biodiversity of most soil organisms. Biodiversity monitoring can be performed in five to ten year intervals, which is a typical time frame in carbon crediting businesses[48]. Biodiversity and carbon crediting mechanisms should secure longevity, i.e. potential to prolong contracts for decades or centuries – instead of the mere 30 years currently used under most carbon crediting schemes. Upgrading initial contracts to higher-value contracts should also be considered, for example for young forests that become more highly valued when they become old and support more biodiversity and soil carbon. To maintain such a long-term monitoring process, project managers should take care of proper storage of materials and data. Carefully preserved DNA samples can be reused decades later when better DNA sequencing methods emerge, or when additional taxonomic groups or markers are added for more comprehensive analysis of biodiversity. Currently, molecular analysis of soil samples from 100 plots (corresponding to a medium-size project) samples cost 3000 euros upwards, while sequencing costs per unit data continue to decline.

We propose that the metric for biodiversity crediting should include positive change in a unit of time (e.g., 5 years) over a certain area (e.g., 1 ha). So, the tokens are related to both time interval and area, which may differ across projects but not magnitude of change. The Wallacea Trust[21] suggested that 1% uplift of biodiversity relative to reference sites represents a suitable metric. However, we find that reliable detection of 1% difference requires prohibitively large sample sizes, e.g. several hundred composite soil samples in our case[49] and perhaps more for the stochastic macroorganism inventories. Furthermore, combined animal and plant inventories, metabarcoding surveys of specifically captured invertebrates and measures of several ecosystem services, as advocated by The Wallacea Trust[21], render biodiversity estimates more time consuming and expensive compared with simple soil metabarcoding surveys. Crediting for carbon sequestration should follow widely accepted protocols and units; inclusion of soil carbon should offer better revenues compared with standard aboveground carbon projects.

Crediting institutions should release credits after data analysis and verification rather than based on future pledges, although ex-ante payments should be considered to reduce poverty in developing countries[20]. Occasional verification must be performed by independent assessors to secure transparency and validity of approaches and measurements. The weighting of carbon and biodiversity components should remain flexible because of the potentially changing stakeholder expectations over time. Complementarity of the co-crediting components is crucial; for example, a project that maintains or restores a natural savanna may, for instance, not capture as much carbon as a new tree plantation, but help preserve highly threatened biodiversity.

Trading parties

While carbon credits are issued by international and national governmental organisations, biodiversity credits can be issued by parties that own or lease land and are interested in long-term conservation and income, for example governments, private and corporate landowners and indigenous communities. Hence, for co-crediting, private issuers should collaborate with local governments or buy carbon credits to sell co-credits. Buyers of these credits include conservation-aware companies and persons such as the tourism sector, philanthropists, as well as private resellers, i.e. parties acting in the carbon and developing biodiversity markets. To avoid offsetting and greenwash and hence bad reputation, companies with harmful actions on climate and nature could be excluded from this trade by project rules. Trading can be performed via tokens or cryptocurrency in banks as implemented for carbon credits and offsets.

Since much of the conserved and restorable land is available for biodiversity-carbon co-crediting, it will be of great importance to share benefits with local communities, including indigenous people. This should include both a part of monetary revenues and involvement through performing sustainable management practices, guarding of project areas and avoiding certain unsustainable practices, such as slash-and-burn agriculture and landscape burning to ease hunting.

Conclusions

The urgency for our societies to reach Net Zero in the shortest possible amount of time is triggering vast investments and initiatives around the world. However, trying to combat one major challenge - climate change - while making another one worse (biodiversity loss), would represent a huge opportunity loss. The inclusion, valuation and validation of biodiversity and other functional and ecosystem services-related co-benefits within carbon crediting and offsetting schemes will help reduce global biodiversity loss by incentivising carbon crediting beneficiaries to account for biodiversity in their carbon sequestration projects[28]. Given the increasing pressure on biodiversity, it is likely that the relative valuation in biodiversity increases compared with carbon, especially when developed countries reach their emissions reduction goals. Such monetary biodiversity benefits will promote environmentally sustainable stewardship of land globally and contribute much of the global financing for conservation[14].

Resource availability

Lead contact

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Materials availability

This article produced no unique materials.

Data and code availability

This study did not generate data or code

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Author Contributions

LT and JS generated the initial concept; ASM, MK, KE, RR, KH, EB, RP, BG, FV, TK and AA further developed the concept from various perspectives; LT, TK and AA wrote the manuscript, with input from all authors.

Declaration of Interests

The authors declare no conflict of interest.

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Figure legends

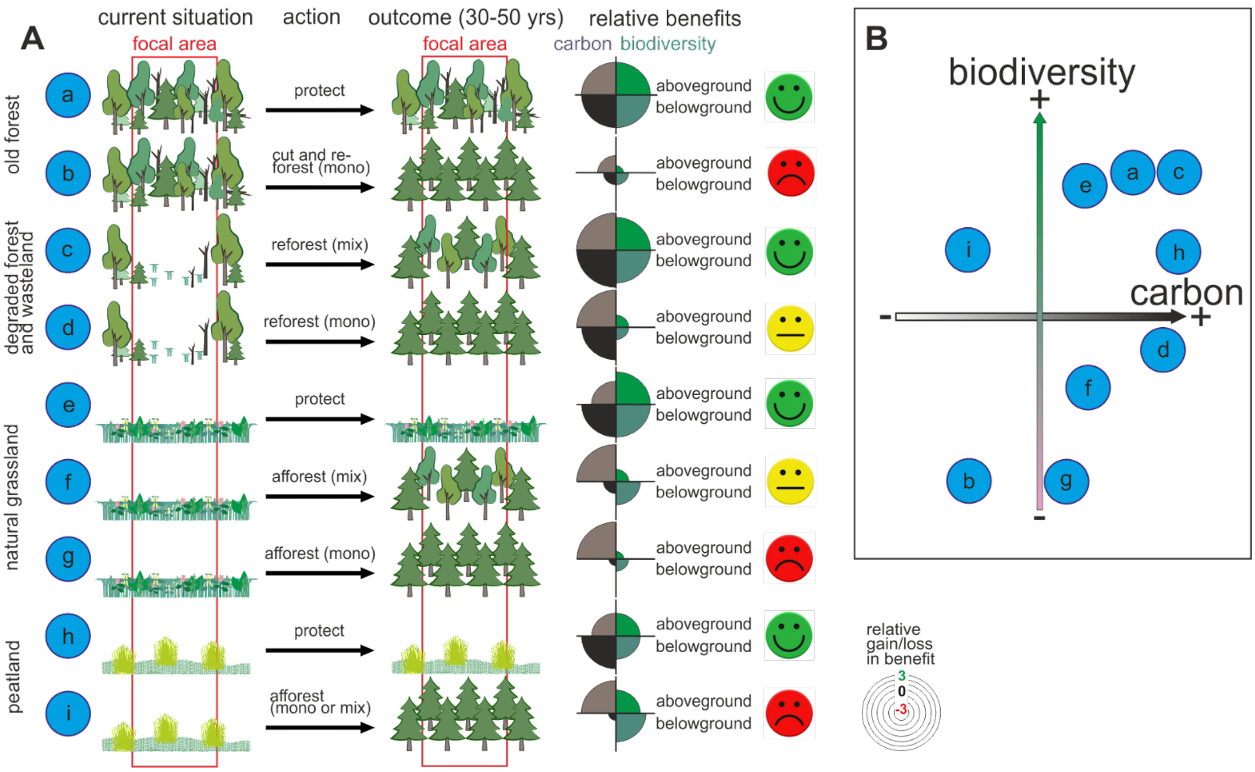

Figure 1. Schematic representation of A) relative above- and belowground carbon and biodiversity net benefits from protection and aff/reforestation of various ecosystem types and B) win-win and lose-lose situations of these from the biodiversity and carbon perspectives. Based on data and interpretations from references 9, 30, 38 and 49-53.

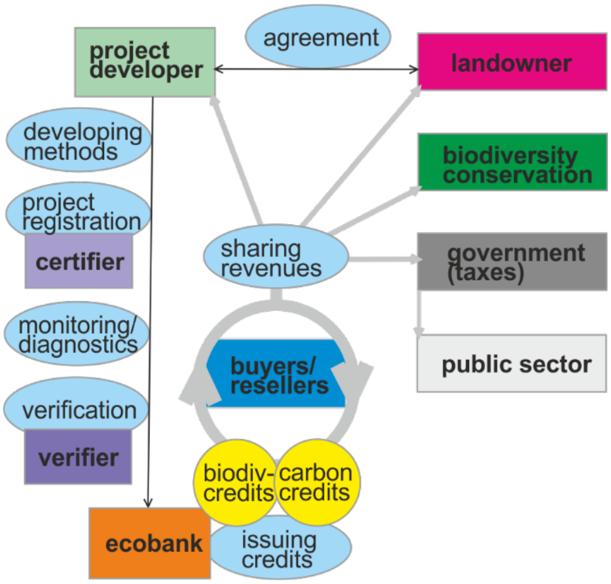

Figure 2. Conceptual scheme of carbon-biodiversity co-crediting.

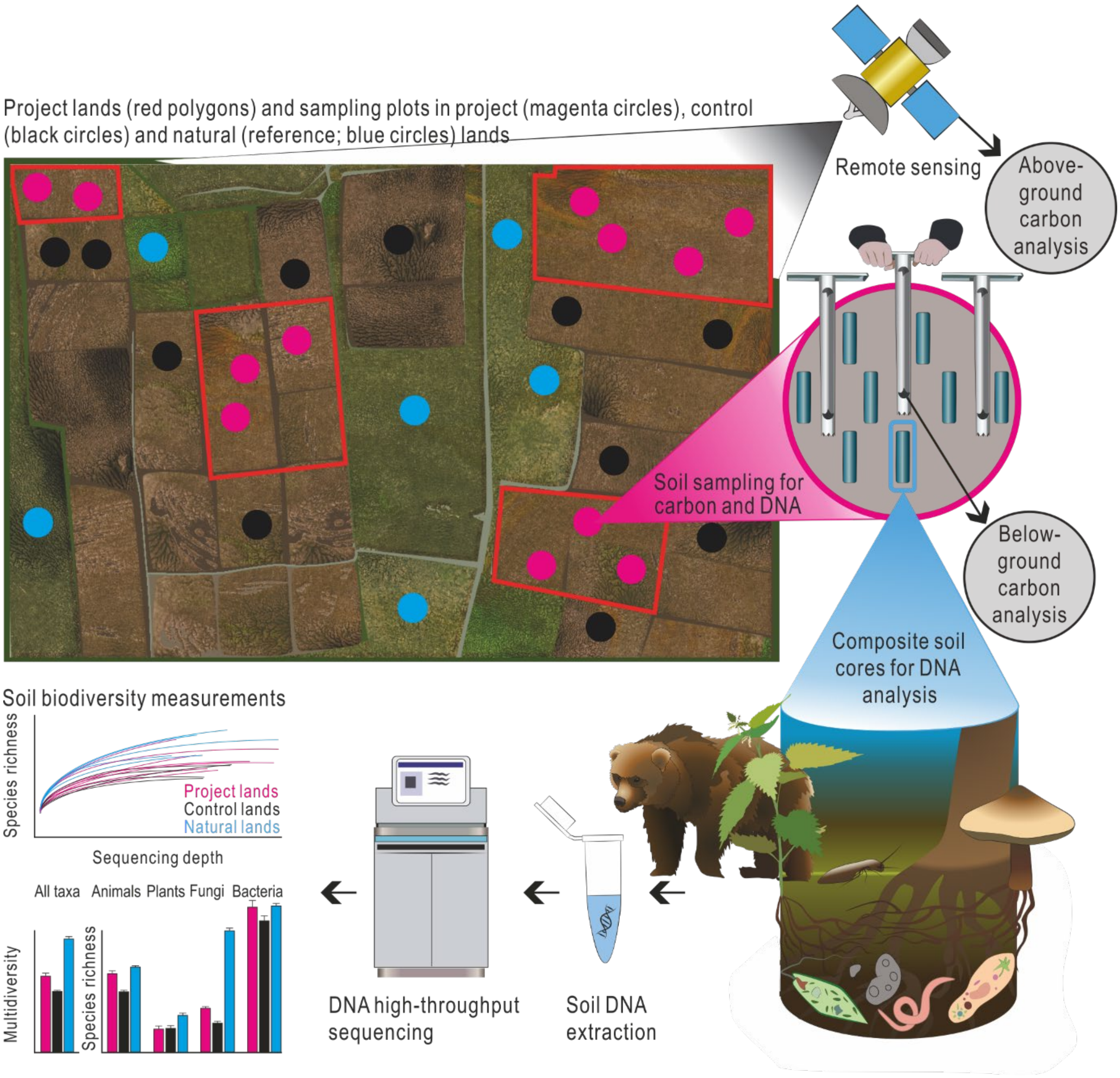

Figure 3. Analytical workflow of above- and belowground carbon and soil eDNA analysis.

Table 1. Comparison of the proposed carbon-biodiversity co-crediting scheme to other biodiversity or carbon projects.

Certification scheme	Carbon and biodiversity assessment	Methodology for biodiversity	Biodiversity measurement units	Comments on biodiversity	Reference
Proposed carbon-biodiversity co-credits	soil biodiversity, aboveground and soil carbon	soil DNA metabarcoding (prokaryotes, microeukaryotes, plants and animals)	multidiversity increase (relative to reference) / ha over 5 years; carbon: 1 t CO_2-eq;	established sampling and analytical protocols	This study
The Wallacea Trust biodiversity credits	biodiversity only (incl. ecosystem services)	plant releves, camera/audio recordings, remote sensing, ecosystem services, invertebrate metabarcoding	1% net biodiversity increase or avoided loss / ha (relative to reference) over 5 years	no available protocols, expensive monitoring, microbiome not considered	https://wallaceatrust.org/wp-content/uploads/2022/08/Biodiversity-credit-methodology-1.5.pdf
WWF Namibia Wildlife “credits”	mammals only	sightings of indicator species	change in wildlife presence in habitat corridors	local communities gain monetary benefits, no tradeable credit or reference	https://wildlifecredits.com/
Terrasos biodiversity “credits”	protected habitat only	NA	10 m^2 for 30 years	offsetting for habitat, no monitoring	https://climatetrade.com/climatetrade-and-terrasos-jointly-promote-voluntary-biodiversity-credits-to-support-biodiversity-conservation/
South Pole EcoAustralia carbon+	aboveground carbon (Gold Standard)	NA; carbon: Gold Standard	1.5 m^2 protected Australian	offsetting for habitat,	https://www.southpole.com/sustainability-solutions/ecoaustralia

biodiversity “credits”	and Australian native habitat		vegetation; carbon: 1 t CO_2-eq;	no monitoring	
REDD+ carbon projects	aboveground carbon only; biodiversity not developed[1]	carbon projects must follow SBIA[b] standards for biodiversity	NA	carbon project revenues used for rainforest protection	https://www.redd.plus/
Verra carbon projects	aboveground carbon only; biodiversity under development[a]	new carbon projects must follow CCB[c] standards for biodiversity	NA	ca. 75% carbon projects follow CCB standards for biodiversity	https://verra.org/programs/ccbs/
Gold Standard carbon projects	aboveground carbon only; biodiversity not developed[a]	NA	NA	safeguarding principles for ecosystem services	https://www.goldstandard.org/our-story/sector-land-use-activities-nature-based-solutions
CORSIA carbon projects	aboveground carbon only; biodiversity not developed	NA	NA	biodiversity-rich areas not included in carbon projects	https://www.icao.int/environmental-protection/CORSIA/Pages/default.aspx
Plan Vivo carbon projects	aboveground carbon only; biodiversity not developed[a]	carbon projects must assess biodiversity risks and do no harm	NA	biodiversity-friendly carbon projects	https://www.planvivo.org/
Climate Action Reserve carbon projects	aboveground carbon only; biodiversity not developed	carbon projects must follow sustainable forestry practices	NA	ecologically sustainable carbon projects	https://www.climateactionreserve.org/

[a] Confirmed by personal communication; [b] SBIA, Social and Biodiversity Impact Assessment, https://s3.amazonaws.com/CCBA/SBIA_Manual/SBIA_Part_3.pdf; [c] CCB, Climate, Community and Biodiversity Alliance standards, https://verra.org/wp-content/uploads/2017/12/CCB-Standards-v3.1_ENG.pdf