Mapping the landscape of Voluntary Biodiversity Credits: A systematic analysis and typology of schemes

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DEDICATION

I dedicate this work to my deceased sister, Thaynara Ramos. To my great-grandmother/grandmother Maria Maggi Casagrande and grandmother/mother Nilza Casagrande, who made countless sacrifices to raise me and provide everything they could to make this moment possible.

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ABSTRACT

Growing recognition of the economic risks associated with biodiversity loss is driving demand for new conservation financing mechanisms including Voluntary Biodiversity Credits (VBCs). However, the methodologies developed or used by VBC schemes are diverse and lack comprehensive characterization. This dissertation aims to systematically identify, characterize, and classify the schemes proposed by VBC organizations and initiatives in order to establish a typology of existing approaches. The 39 identified schemes were qualitatively analyzed based on 21 aspects, and a subset of 15 variables was used in a multivariate statistical analysis involving a Chi-Square test and k-Medoids clustering. The results indicate a market at different stages of maturity, with a notable geographic discrepancy between the headquarters of the organizations (Global North) and their predominant areas of operation (Global South). The typological analysis revealed five groupings of identified VBC schemes and methodologies with distinct developmental stages and approaches, concluding that schematic robustness is associated with assessments across multiple ecological domains, considering off-site impacts (leakage), avoiding double counting, and ensuring long-term monitoring with a retroactive baseline period. As the VBC market is emerging in the wake of skepticism from other nature markets, it would be expected that the organizations design their schemes and frameworks with high levels of transparency and methodological rigor, however, as our research indicates, the observed lack of transparency and the heterogeneity in the available data are particularly concerning. This suggests that these challenges may be systemic and inherent to voluntary nature markets, pointing to a disconnect between the proclaimed objectives of high integrity and the pressures of a market that demand simplicity and scalability with ecological rigor in the assessment. Fundamentally, the current scenario of the Voluntary Biodiversity Credits market faces uncertainties and the risks of greenwashing, requiring all actors to make a genuine effort to ensure high integrity, transparency and effectiveness in their biodiversity measurement.

Keywords: Biodiversity Certification; Biodiversity Conservation Initiatives; Market-based instruments; Natural Credit Markets; Voluntary Schemes.

RESUMO

O crescente reconhecimento dos riscos económicos associados à perda de biodiversidade impulsiona a procura por mecanismos de financiamento, incluindo os créditos voluntários de biodiversidade (VBCs – sigla em inglês). Contudo, as metodologias desenvolvidas pelas organizações e esquemas de VBCs são diversas e carecem de caracterização abrangente. Esta dissertação visa sistematicamente identificar, caracterizar e classificar os esquemas propostos pelas organizações e iniciativas de VBCs, a fim de estabelecer uma tipologia das abordagens existentes. Os 39 esquemas identificados foram analisados qualitativamente com base em 21 aspectos, e um subconjunto de 15 variáveis foi usado em uma análise estatística multivariada envolvendo o teste Qui-quadrado e o agrupamento k-Medoids. Os resultados indicam um mercado em diferentes estágios de maturidade, com uma notável discrepância geográfica entre as sedes das organizações (Norte Global) e as suas predominantes áreas de operação (Sul Global). A análise tipológica revelou cinco agrupamentos de esquemas e metodologias de VBC identificados com distintos estágios de desenvolvimento e abordagens, concluindo que a robustez esquemática está associada a avaliações em múltiplos domínios ecológicos, considerando impactos externos a área do projeto, evitando dupla contagem de outros créditos naturais e garantindo monitoramento de longo prazo com um período retroativo para a avaliação da linha de base. Como o mercado de VBC está emergindo na esteira do ceticismo de outros mercados de natureza, seria esperado que as organizações projetassem seus esquemas e estruturas com altos níveis de transparência e rigor metodológico, no entanto, como nossa pesquisa indica, a falta de transparência observada e a heterogeneidade nos dados disponíveis são particularmente preocupantes. Isso sugere que esses desafios podem ser sistêmicos e inerentes aos mercados de natureza voluntários, apontando para uma desconexão entre os objetivos proclamados de alta integridade e as pressões de um mercado que exige simplicidade e escalabilidade com rigor ecológico na avaliação. Fundamentalmente, o cenário atual do mercado de Créditos Voluntários de Biodiversidade enfrenta incertezas e os riscos de *greenwashing*, exigindo que todos os atores façam um esforço genuíno para garantir alta integridade, transparência e eficácia em suas medições de biodiversidade.

Palavras:-chaves: Certificação de biodiversidade; Iniciativas de conservação da biodiversidade; Instrumentos baseados no mercado; Mercado de crédito natural; Esquemas voluntários

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LIST OF ABBREVIATIONS

AfN	Accounting for Nature
AI	Artificial Intelligence
ALIGN	Aligning accounting approaches for Nature
ASV	Amplicon Sequence Variant
BBOP	Business and Biodiversity Offset Programme
BPC	Brics Policy Center
BBUs	Biological Biodiversity Units
BDP	Biodiversity Disclosure Project
BGCI	Botanic Garden Conservation International
BIC	Biodiversity Impact Credit
BO	Biodiversity Offset
BOL	Biological Organization Level
BRFR	Biodiversity-Related Financial Risks
BSI Flex	British Standards Institution Flex
CBD	Convention on Biological Diversity
CBZs	Cost-benefits zones
CDC	Caisse des dépôts et consignations
CDP	Carbon Disclosure Project
CDSB	Climate Disclosure Standards Board
CICES	Common International Classification of Ecosystem Services
CISL	Cambridge Institute for Sustainability Leadership
COP	Conference of the Parties
CORINE	Coordination of Information on the Environment
CPI	Climate Policy Initiative
CPZs	Conservation Priority Zones
CSA	Corporate Sustainability Assessment
CSRD	Corporate Social Responsibility Directive
DAC	Development Assistance Committee
DJSI	Dow Jones Sustainability Indices
EEA	European Environment Agency
EFRAG	European Financial Reporting Advisory Group
EI	Ecosystem Integrity
EIA	Environmental Impact Assessment
EII	Ecosystem Integrity Index
ESRS	European Sustainability Reporting Standards
EU	European Union
EU B@B	European Union Business @ Biodiversity Platform
FAO	Food and Agriculture Organization of the United Nations
FSC	Forest Stewardship Council
F4B	Finance for Biodiversity Initiative
GBF	Global Biodiversity Framework
GBS	Global Biodiversity Score

GBFF	Global Biodiversity Framework Fund
GCA	Global Commons Alliance
GEF	Global Environment Facility
GGDP	Global Gross Domestic Product
GHGs	Green House Gases
GIBOP	Global Inventory of Biodiversity Offset Policies
GIS	Geographic Information System
GPS	Global Positioning System
GRI	Global Report Initiative
GSR	Goods, Services and/or Resources
HCVs	High Conservation Values
HCVAs	High Conservation Value Areas
IAS	Invasive Alien Species
IIED	International Institute for Environment and Development
IPBES	Intergovernmental Platform on Biodiversity and Services
IPCC	Intergovernmental Panel on Climate Change
IPLCs	Indigenous Peoples and Local Communities
ISSB	International Sustainability Standards Board
IUCN	International Union for Conservation of Nature
KBAs	Key Biodiversity Areas
KMGBF	Kunming-Montreal Global Biodiversity Framework
LIAB	Low Impact Areas for Biodiversity
LiDAR	Light Detection and Ranging
LULC	Land Use and Land Cover
MBIs	Market-based instruments
MDS	Multidimensional Scaling
MEA	Millennium Ecosystem Assessment
ML	Machine Learning
MRV	Monitoring, Reporting, and Verification
MSA	Mean Species Abundance
NBG	Net Biodiversity Gain
NBS	Nature-Based Solutions
NBSAP	National Biodiversity Strategy and Action Plan
NCC	Natural Capital Coalition
NCP	Natural Capital Protocol
NDVI	Normalized Difference Vegetation Index
NIC	Nature Investment Certificate
NNL	No Net Loss
NPI	Net Positive Impact
NPP	Net Primary Productivity
NOG	Non-Governamental Organization
OBC	Organization for Biodiversity Conservation
OCC	Ocean Conservation Commitment
ODA	Official Development Assistance
OECD	Organisation for Economic Cooperation and Development

OECMs	Other Effective Area-Based Conservation Measures
ONU	Organizations of the United Nations
PAs	Protected Areas
PACRP	Protected Area Connectivity and Representativeness Index
PADDD	Protected Areas downgrading, downsizing and degazettement
PCoA	Principal Coordinate Analysis
PES	Payment for Environmental Service
RTCI	Residual Trap Catch Index
SASB Standards	Sustainability Accounting Standards Board
SBNs	Sustainable Business Networks
SBTN	Science-Based Targets for Nature Network
SCI	Sites of Community Importance
SCU	Sustainability Credit Unit
SDUs	Sustainable Development Units
SDGs	Sustainable Development Goals
SLU	Swedish University of Agricultural Sciences
SPAs	Special Protection Areas
SRP	Systematic Review Protocol
STAR	Species Threat Abatement and Restoration Metric
TBC	The Biodiversity Consultancy
TNFD	Taskforce for Nature-related Financial Disclosures
TSR	Threatened Species Richness
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USSC	Umbrella Species Stewardship Credits
VBC	Voluntary Biodiversity Credits
VNU	Verifiable Nature Unit
WBCSD	World Business Council for Sustainable Development
WCMC	World Conservation Monitoring Centre
WEF	World Economic Forum
WBG	World Bank Group
WWF	World Wildlife Fund

1. INTRODUCTION

Nature is on the brink of a global crisis that endangers the stability and sustainability of life systems on Earth. Human socio-productive development has historically induced constant changes in Land use and Land cover (LULC), modifying the structure, functioning and composition of ecosystems including biodiversity (IPCC, 2018) at multiple levels (Noss, 1990). These lead to increasing forest loss and fragmentation (Pingali *et al*., 2017; FAO, 2020b) initiating complex and cascading relationships within terrestrial, freshwater and marine ecological systems (Keith *et al*., 2013; Keck *et al*., 2025).

The cumulative effects of human pressures can cause species extinction and the irreversible loss of genetic resources (Pelicice *et al*., 2021), impact directly and indirectly essential ecosystem functions and services that these systems provide (FAO, 2020a). These also affect the climate, increasing global temperature through changes in the carbon dioxide cycle and changing precipitation patterns globally and locally (Han & Zhu, 2020; IPCC, 2022). The simultaneous collapse of marine ecosystems affects the oceans ability to mitigate the effects of climate change by reducing their capacities of capturing excess atmospheric CO2 (IPCC, 2018), accelerating global biodiversity loss (Jacobson *et al*., 2019).

Given this scenario, global biodiversity conservation goals and targets have been established in international policies and frameworks focus in the implementation of efforts and mobilization of financial resources to combat biodiversity loss and climate change (Hahn *et al*., 2022). The main objective of these efforts is to increase voluntary financial resources while promoting different types of financial mechanisms, such as payments for ecosystem services, green bonds, voluntary and offset biodiversity credits, and co-benefit mechanisms involving social and environmental actors (CBD, 2022). Unfortunately, the historical evolution of global milestones and agendas reveals a persistent lack of effectiveness and consistent commitment from both public and private actors in the implementation of the objectives and targets by signatory countries (BCP, 2020).

Increasingly, policymakers, central banks, and market participants recognize that biodiversity loss poses a systemic risk to economic activities and financial stability. This drives the development of policies and initiatives that integrate Market-Based Instruments (MBIs) through the monetary valuation and commodification of nature (Gómez-Baggethun & Ruiz-Pérez, 2011). Consequently, environmental certification schemes for biodiversity emerge as viable alternatives to capture private financial resources for conservation, often within a neoliberal economic perspective (Fletcher, 2020; Wunder *et al*., 2024)

These schemes qualify and quantify nature by abstracting the physical and biological parameters of environmental goods, services, and resources into units of ecological functions s (Peterson *et al*., 2010; Dauguet, 2015). However, with the growing number of institutions and organizations offering qualitative and quantitative certification schemes for generated Voluntary Biodiversity Credits (VBC), there is a limited knowledge and scientific work of the conditions, criteria, aspects, and proposals under which these certification schemes have emerged (Ford *et al*., 2024; Wauchope, 2024).

In light of the issue, the main objective of this study is to systematically identify, characterize, and classify VBC schemes in order to establish a typology of approaches currently applied in the emerging Voluntary Biodiversity Credit Market. Specifically, this study aims to i) characterize the VBCs landscape based on a predefined set of technical, ecological and socio-economic aspects; ii) identify patterns of approaches to understand the similarities and differences among schemes; iii) understand the geographical distribution of VBC schemes; and iv) understand and how biodiversity is quantified and measured in assessments.

To this end, the dissertation is structured into five chapters. The Introduction aims to contextualize the problem of biodiversity loss and the emergence of VBCs, justify the importance of the study, establish the general and specific objectives, and describe the structure of the dissertation. Chapter 2 (State of the art) is dedicated to the literature review, addressing the current state of biodiversity, relevant political and financing frameworks, concepts of VBCs and environmental certification, as well as the mapping of the models and metrics commonly used in biodiversity assessments. Chapter 3 (Methodology) details the methods of data collection and analysis, including research classification, systematic review protocol, documentary research and quantitative and qualitative data analysis techniques. The main results are presented and analyzed in Chapter 4 (Results and Discussion), which includes the quantitative and qualitative analyses discussion, the identification and characterization of the typologies, and as limtações da pesquisa. Chapter 5 (Conclusion) synthesizes the main conclusions of the study and suggests futures works.

2. STATE OF THE ART

2.1. Biodiversity

Biological diversity, as defined by the Convention on Biological Diversity (CBD), encompasses the "variability among living organisms of all origins, including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and ecosystems" (UNEP, 1992, p. 1). This definition describes diversity across three levels: genetic diversity, species diversity, and ecosystem diversity.

However, as Noss (1990, p. 356) noted, this classification fails to mention processes, such as interspecific interactions, natural disturbances, and nutrient cycles. He argued that understanding the levels of biodiversity organization can also be approached through its properties, such as composition, structure/configuration, and dynamics/function (Fig. 1), and across scales, considering the genetic, species, ecosystem, and landscape levels (Wu *et al*., 2000; Estes *et al*., 2018).

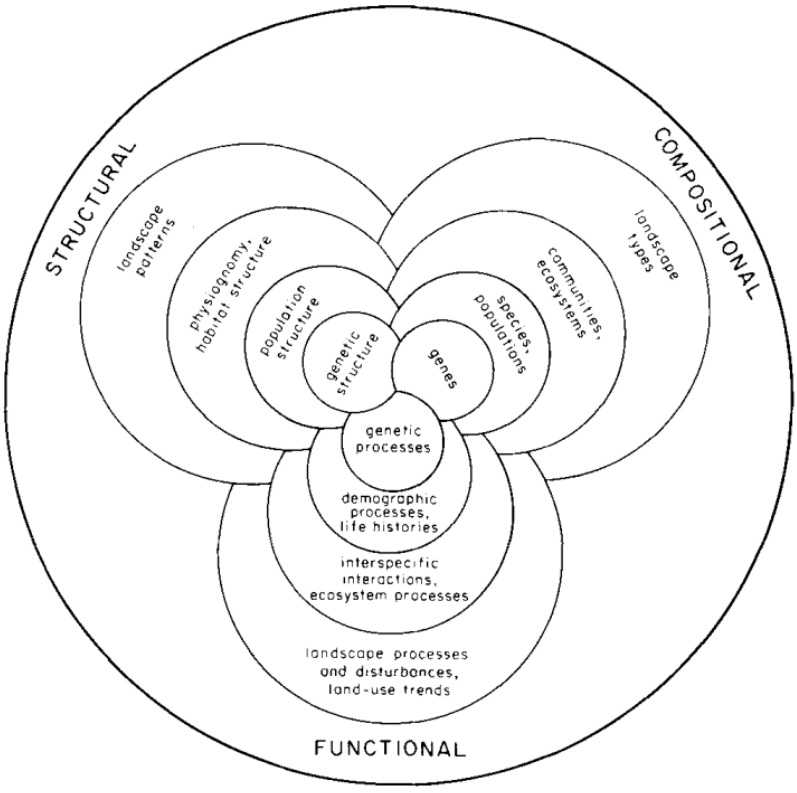

Figure 1: *Hierarchical diagram created by Noss (1990) integrating the levels of biological organization related to their compositional, structural and functional properties and attributes at multiple scales.* Reprinted from Noss (1990).

Genetic diversity refers to the difference in genes among individuals and populations within a species (Hoban *et al*., 2021). Mitigation of the loss of genetic diversity presents one of the greatest global biodiversity challenges (Shaw *et al*., 2025), specially because genetic variability plays a crucial role in species adaptation to environmental changes, supports community structure, maintains ecosystem functions, integrity, and resilience, and enhances biodiversity stability in the face of climate change and anthropogenic pressures (Cardinale *et al*., 2012; Jaureguiberry *et al*., 2022). Genetic diversity also promotes socioeconomic benefits, such as sustainable resource use, and food production and security (Hoban *et al*., 2025).

Species diversity, the second level of biodiversity, refers to the variety of groups of organisms composed of individuals that can interbreed within the same species, while remaining reproductively distinct from other groups (National Academies of Sciences, Engineering, and Medicine, 2019). Species defined the basic unit used to differentiate among individuals and populations, classified by their morphological, ecological, functional, and phylogenetic diversity (Arponen, 2012; Wong *et al*., 2018). This allows genetic and species-level approaches to complement each other, representing more interrelated properties (Gregorius *et al*., 2003). Species are sensitive to geographically varied climate and land-use change (Newbold *et al*., 2020). Moreover, interactions among species are crucial for sustaining biodiversity and ensuring ecological communities function properly (Raffard *et al*., 2018; Dehling *et al*., 2022). These interactions determine how communities and ecosystems respond to disturbances, including their recovery processes (Loreau & De Mazancourt, 2013).

Ecosystem diversity is the third level included in the concept of biodiversity. An ecosystem can be defined as "a dynamic complex of plant, animal, and micro-organism communities and their non-living environment, interacting as a functional unit" (UNEP, 1992). Functional unity arises from the coexistence of living organisms with interconnected and diverse abiotic components through fluxes of energy and matter (Gonzalez *et al*., 2020). The dynamic interactions within and between ecosystem components are fundamental for the provision of essential ecosystem services for human well-being, climate regulation, and the maintenance of diverse habitats (IPBES, 2019).

Ecosystem services encompass the direct and indirect benefits of ecosystems to humanity. These services are categorized into three classes by the Common International Classification of Ecosystem Services (CICES) of the European Environment Agency (Haines-Young & Potschin, 2018):

- Provisioning services: Covers all nutritional, non-nutritional material and energetic outputs from living systems as well as abiotic outputs (including water). Examples are food (from crops, animals, fisheries, gathering), freshwater (for various uses), materials (timber, fibers, biochemicals), biomass for energy, and genetic resources.
- Regulating and Maintenance Services: All the ways in which living organisms can mediate or moderate the ambient environment that affects human health, safety or comfort, together with abiotic equivalents. Examples include climate regulation, hydrological cycle regulation, erosion control, pollination, biological control (pests and diseases), waste remediation, and maintenance of nurseries and habitats.
- Cultural Services: All the non-material, and normally non-rival and non-consumptive, outputs of ecosystems (biotic and abiotic) that affect physical and mental states of people. Examples are recreation and tourism opportunities, aesthetic and landscape values, artistic and cultural inspiration, educational and scientific opportunities, spiritual well-being and religious experiences, and cultural identity.

Landscape, as a level of biological organization, can be defined as a geographically explicit area containing a mosaic of interacting ecosystems and land uses (Turner & Gardner, 2015), characterized by three essential properties: (i) composition, referring to the variety and abundance of landscape elements (e.g., forest types, agricultural fields); (ii) structure or configuration, which describes the spatial arrangement of these elements, including the size, shape, and isolation of habitat patches; and (iii) function (dynamics), which involves the flows of energy, matter, and species among the mosaic elements (Noss, 1990; Turner & Gardner, 2015). Notably, research has indicated that spatial heterogeneity, defined as non-uniformities in the physical and ecological characteristics of the landscape, significantly influences the distribution and organization of biodiversity in all other levels (Wu, 2007)

Beyond the ecological structure, landscapes also hold significant socio-cultural value (Pascual *et al*., 2017). From a phenomenological perspective, landscapes provide physical and psychological experiences, opportunities for learning and inspiration (Oliveira, 2016) while supporting the construction and valuation of environmental perceptions through the attribution of a sense of place via collective or individual experiences (Seamon, 2019). This perspective directly relates to the Cultural Ecosystem Services and highlights the importance of considering human values and traditional ecological knowledge in biodiversity conservation initiatives (Tisdell, 2014) which is relevant in the context of biodiversity credit schemes by the necessity

to engage Indigenous Peoples and Local Communities (IPLCs) for their important role in biodiversity conservation (Silva *et al*., 2025).

Given the complexity of biodiversity across these multiple levels, properties, and scales, it would be overly simplistic to approach schemes of environmental certification systems for biodiversity solely from the perspective of the normalization that defines them. Thus, before discussing the specific norms, characteristics, scopes, and limitations, it is necessary to understand the underlying ecological and socio-cultural processes and dynamics from which they emerge.

2.2. The current state of biodiversity

Human socio-productive development, characterized by continuous changes in Land Use and Land Cover (LULC), has profoundly altered the organization and functioning of biodiversity at various levels (IPCC, 2018) leading to forest loss and fragmentation (Pingali *et al*., 2017; FAO, 2020b), triggering complex cascading relationships within ecological systems (Keith *et al*., 2013).

Forest loss significantly impacts terrestrial and aquatic ecosystems landscapes, as well as seascapes (Han *et al*., 2023). This leads to several critical consequences, including decreased connectivity and increased fragmentation (Gonzalez-Ávila et al., 2024), habitat degradation, alterations in community structure, and shifts in species distribution (Capellesso et al., 2022). Furthermore, it causes reductions in both local and overall species richness and genetic diversity (Forest Europe, 2020; Pelicice *et al*., 2021; Yin *et al*., 2021). Collectively, these impacts directly and indirectly affect essential ecosystem functions and the supply of ecosystem services (FAO, 2020a).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) provides a broader framework for understanding the drivers of biodiversity decline. In the 2019 Global Assessment Report, IPBES identified five key direct drivers of change in nature, ranked by their relative global impact to date: (1) changes in land and sea use; (2) direct exploitation of organisms; (3) climate change; (4) pollution; and (5) invasive alien species (IPBES, 2019). It is crucial to recognize that these drivers do not operate in isolation, they interact synergistically, thereby amplifying their impacts. For example, rising temperatures related to climate change correlate with increased richness, abundance, and establishment of invasive alien species in new territories, exacerbating pressure on native species already weakened by habitat degradation (Pilotto *et al*., 2020).

Changes in land and sea use, along with the direct exploitation of flora and fauna, substantially alter community composition and reduce local diversity across all terrestrial, freshwater, and marine ecosystems (Keck *et al*., 2025), accelerating global biodiversity loss (Jacobson *et al*., 2019). These processes also affect the climate, increasing temperatures through changes in the carbon dioxide cycle and in precipitation patterns (Han & Zhu, 2020; IPCC, 2022). The simultaneous collapse of marine ecosystems affects the oceans ability to mitigate the effects of climate change by reducing their capacities of capturing excess atmospheric CO_2 (IPCC, 2018).

Direct drivers (or pressures) stem from a range of underlying indirect factors and processes, including demographic shifts, economic activities, technological developments, and societal values related to production and consumption patterns (IPBES, 2019). Importantly, these drivers frequently interact synergistically, thereby intensifying the adverse effects on biodiversity (Maxwell *et al*., 2016). The cumulative effects of these pressures are evident in the status of species populations globally, many threatened or experiencing critical declines (IUCN, 2022).

The World Wildlife Fund's (WWF) 2022 “Living Planet” report, tracked the abundance of monitored vertebrate populations (mammals, birds, amphibians, reptiles, and fish), revealing an average decline of 69% in the relative abundance of endangered species worldwide between 1970 and 2018 (WWF, 2022). This decline is even more alarming in tropical regions, where habitat loss and overexploitation are most intense. In Latin America and the Caribbean, for example, the average decline reached 94% over the same period. Freshwater ecosystems are among the most impacted, with an average global reduction of 83% in the abundance of their monitored populations, highlighting the vulnerability of these systems to pollution, river fragmentation, and water extraction.

Recent studies indicate a drastic collapse in insect populations across the world. This directly threatens vital ecosystem services such as pollination and decomposition of organic matter (Sluijs, 2020). The situation in marine environments is equally critical. Rising ocean temperatures are causing mass bleaching in coral reefs, ecosystems that, despite covering less than 1% of the seafloor, harbor approximately 25% of all marine life (Hughes *et al*., 2017; IPBES, 2019).

Losing biodiversity is more than just a decreasing number of species. It represents losses in ecosystem functional integrity, degradation and increasing the risk of potentially irreversible regime shifts (Scheffer *et al*., 2001). On a large scale, for instance, the ongoing deforestation

and degradation of the Amazon rainforest are pushing this biome towards a tipping point. Beyond this threshold, the humid tropical forest could transition into a seasonally dry savanna. Such a change would not only cause a massive loss of biodiversity but also drastically alter regional precipitation patterns and the global capacity for carbon sequestration (Lovejoy & Nobre, 2018; Boulton *et al*., 2022).

2.3. Key policies and milestones for biodiversity conservation

Since the late 20th century, international agendas have aimed to promote global environmental policies and build national capacities for biodiversity conservation (Vargas & Rodrigues, 2009). The 1992 United Nations Conference on Environment and Development (UNCED), Earth Summit, in Rio de Janeiro, Brazil, marked a crucial step yielding five key agreements that establish a foundation for global biodiversity governance: the Rio Declaration, Agenda 21, the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), and the Non-legally binding authoritative statement of principles for a global consensus on the management, conservation and sustainable development of all types of forests (UNEP, 1992).

The Convention on Biological Diversity (CBD) has held 15 Conference of Parties (COPs) since 1994, leading to the Cartagena Protocol on biosafety (CBD, 2000) and the Nagoya Protocol (CBD, 2011), advancing instruments for biodiversity action. The 10th COP that took place in 2010 presented the guidelines for establishing a new international program, the "Strategic Plan for Biodiversity 2011-2020," structured with goals and sub-goals for implementation during the period established by the UN as the "Decade of Biodiversity". This included the "Aichi Biodiversity Targets" aiming to tackle biodiversity loss, reduce pressures, improve status, enhance benefits, and facilitate implementation (IUCN *et al*., 2011; CBD, 2013). While ambitious, the subsequent assessment revealed that these targets were not fully met, highlighting the persistent challenges in global biodiversity conservation (BCP, 2018).

In 2015, the "2030 Agenda for Sustainable Development" introduced 17 SDGs, including biodiversity-focused goals (14 e 15), and the "Paris Agreement", under the UNFCCC, recognized market-based instruments such as natural credit markets (UN, 2015). Succeeding the 1999 "Kyoto Protocol," the Paris Agreement sought to enhance the worldwide effort against climate change. Its goal was to limit the rise in global average temperature to well below 2°C, with a preference for 1.5°C (Vargas & Rodrigues, 2009; Rogelj *et al*., 2016). Notably, Article 6 of the agreement recognized the potential for collaborative strategies, including market-based

instruments, promoting the expansion and strengthening of natural regular capital markets as a mechanism for achieving sustainability targets (UNFCC, 2025).

These market-based approaches to climate change developed under Kyoto Protocol included the Clean Development Mechanism (CDM), International Emissions Trading (IET) and Joint Implementation (JI) (Spilker & Nugent, 2022). The Kyoto Protocol's Clean Development Mechanism (CDM) allows developed countries to meet part of their mandatory international carbon neutrality policy targets by financing mitigation projects in developing countries (Chen, 2021; UNDP, 2023).

Carbon neutrality means a commitment to balance annual greenhouse gas emissions by preventing or removing an equivalent amount from the atmosphere over a specific period (IPCC, 2022). Essentially, carbon neutrality involves achieving a net-zero carbon footprint through the implementation of the Kyoto and Paris strategies to reduce emissions (IEA, 2021). However, achieving carbon neutrality does not automatically imply achieving “net zero” (Fankhauser *et al*., 2022), and the interpretation of net zero has varied among countries, resulting in historical failure to meet international carbon emissions targets (Kuramochi *et al*., 2023).

In addition, the lack of full achievement of Aichi targets led to the 14th COP in 2018, focusing on biodiversity and the economy, resulting in a new National Biodiversity Strategy and Action Plans (NBSAP) for 2021-2030 emphasizing the continued need for action (BCP, 2018). The UN General Assembly proclaimed 2021-2030 the "United Nations Decade on Ecosystem Restoration" (UN, 2019), reaffirmed historic agreements and recognized the critical importance of nature-based solutions in ecosystem conservation and restoration efforts for food security, climate change mitigation and adaptation, and biodiversity maintenance.

This movement also initiated the development of a new draft of the global framework for biodiversity for the year 2050, a document titled the “Post-2020 Global Biodiversity Framework”, developed to guide biodiversity conservation, ecosystem restoration, sustainable use, and benefit sharing, including a focus on business sector engagement (CBD, 2021a).

Effective implementation of the new framework's agreements was significantly impacted by the COVID-19 pandemic. This was particularly evident during COP 15, held in Montreal, Canada, in 2022. The outcomes of this conference were encapsulated in the Kunming-Montreal Global Biodiversity Framework (KMGBF) (CBD, 2022). This document, aligning with UN General Assembly Resolution No. 73/284, aimed to reaffirm the commitment to expanding the effectiveness of ecosystem protection, highlighting the need to reach at least

30% of terrestrial, coastal, and marine ecosystems for protection and restoration by 2030 (the '30x30' target). Furthermore, it underscored the crucial role of IPLCs in the management, restoration, conservation, and protection of natural areas (Silva *et al*., 2025).

The KMGBF includes essential goals (Fig. 2), such as Goal 14 which aims for the full integration of biodiversity policies across all government and private sectors or Goal 19 that specifies the need for public-private financial mobilization for the implementation of new NBSAPs seeking to progressively and substantially increase voluntary financial resources and stimulate the support of innovative schemes, such as Payments for Ecosystem Services (PES), green bonds, voluntary and offset biodiversity credits, and co-benefit mechanisms involving social and environmental actors (CBD, 2022). The explicit mention of VBC within a major global policy framework underscores the growing relevance of this contribution approach. In the context of NBSAP, integration, refers to the "capacity of NBSAP processes to produce institutional changes in various policy sectors to include biodiversity in the agenda and central objectives of their decision-making" (Sarkki *et al*., 2016).

Despite efforts, the historical implementation of global biodiversity goals has faced challenges, with public and private actors often lacking full commitment (WEF, 2023), highlighting the need for effective solutions. Therefore, shared responsibility and the utilization of technological and financial mechanisms, including public-private partnerships (UNEP, 2021; Sun *et al*., 2022) are crucial for achieving global biodiversity goals, making the study of mechanisms such as VBC highly relevant in the current political and financial context.

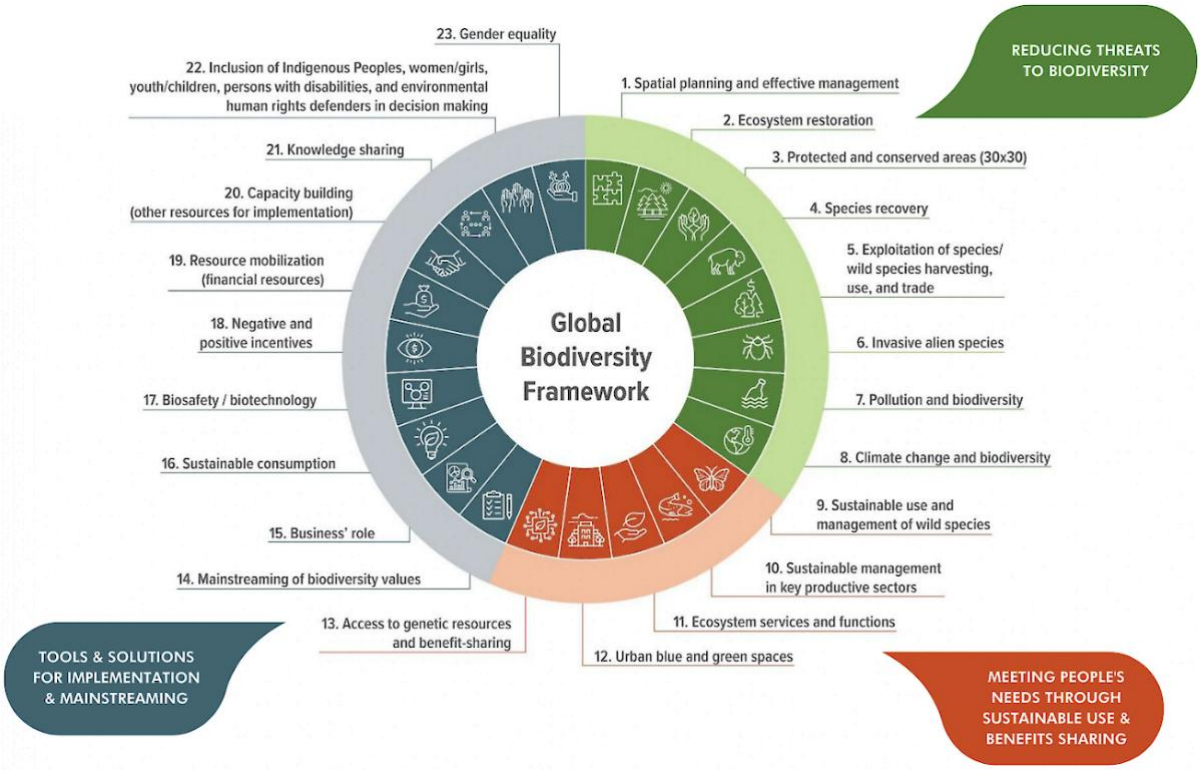

Figure 2: *Targets of the Kunming-Montreal Global Biodiversity Framework (KMGBF) by thematic objectives*. Reducing threats to biodiversity (in green), sustainable use and benefit sharing (in orange) and tools and solutions (in blue). Reprinted from (WCS, 2024).

2.4. Biodiversity conservation financing

Given the current state of global biodiversity and the ambitious goals established in international policy frameworks, the pressing need to mobilize financial resources on a global scale for conservation and restoration actions become evident. However, a significant deficiency in the current economic structure lies in the limited recognition and valuation of natural capital (Addison *et al.,* 2018; WEF, 2020).

The substantial value provided by biodiversity and ecosystem services frequently remains underestimated or omitted from market assessments (OECD, 2021; Marco-Fondevila & Álvarez-Etxberría, 2023). This systemic failure results in the devaluation of the importance of natural capital and ecosystem services, indirectly incentivizing resource depletion and generating chronic underinvestment in its maintenance (Dallimer *et al*., 2020; WBG, 2020). This creates, however, an opportunity for the exploration of new financing mechanisms for environmental conservation through nature markets (Chen *et al*., 2024). These markets are driven by regulatory compliance, government-mediated payments, and voluntary private-sector schemes (Doswald *et al*., 2012).

Environmental economics emerges as a field of study that seeks to integrate environmental dimensions, including the value of biodiversity into economic structures (Marco-Fondevila *et al*., 2018). Its scope involves forms of economic organization and prioritization of goals to integrate the socioecological and economics dimensions of the long-term sustainable growth (Nunes *et al*., 2016). The implementation of environmental economics approaches and methods frequently relies on a variety of monetary valuation instruments and investments from diverse sources, including the public, private, national, and international spheres (Félix, 2022).

Monetary Valuation seeks to attribute economic value to environmental goods or services that traditionally do not have a market price (Guijaro & Tsinaslanidis, 2020), while commodification refers to the expansion of trade and markets into previously non-marketed areas or spheres, where environmental goods, services or resources are standardized and treated as commodities (Hahn *et al*., 2015). The monetary valuation provides a discursive and technical foundation for commodification to occur (Gómez-Baggethun & Ruiz-Pérez, 2011).

Although complex and subject to debate, these processes are inherent to the development of instruments that aim to integrate biodiversity into nature markets (Robertson, 2006; Pisani *et al*., 2021). As Bakker (2005) suggests, commodification, as a dimension of the neoliberalization of nature, involves a transformation throughout the valuation chain. This transformation entails shifting from the measurement of physical and biological characteristics (Robertson, 2004) to the reduction and abstraction of their functionalities into economic ecological units (Peterson *et al*., 2010; Dauguet, 2015).

From the neoliberal conservation perspective, the establishment of natural credit markets is often framed as a solution to environmental challenges rather than as their cause (Fletcher, 2020). In this context, the Market-Based Instruments (MBIs) stand out aiming to correct market failures related to environmental goods, resources and services and to create continuous economic incentives for actors to internalize environmental externalities and achieve conservation goals in a cost-effective manner (OECD, 2021).

A key operational principle for many MBIs is the ability to measure impacts (positive or negative) on nature and represent them as quantifiable units, such as credits or debits, facilitating their integration into established economic and financial mechanisms and decision-making processes (Robertson, 2006; Guijaro & Tsinaslanidis, 2020). Implementation of MBIs is usually done through taxes, fees, and tariffs; tradable permits and rights; green bonds and subsidies; liability and compensation schemes; and ecological labelling (Efetec, 2010).

Tradable permits and rights category refers to the allocation of quantified permits or rights (e.g., goods, resources, services), that were traditionally not considered market goods, that can be bought and sold in an open market system (McCarthy & Prudham, 2004; Neuteleers & Engelen, 2015). Payment for Environmental Services (PES) exemplifies a system of tradable permits and rights, characterized by both conditionality and voluntariness (Wunder, 2015). The assessments conducted via PES evaluation and implementation, as noted by Marino and Pellegrino (2018), have the potential to improve the effectiveness of conservation actions at various spatial and administrative levels.

Nevertheless, the transactions of nature-based credits in different nature markets implies abstracting the value of the investment in concrete interventions so that it can become fungible (i.e., the extent to which units are interchangeable between sites) (Fletcher, 2020; Wauchope *et al*., 2024), confronting the fundamental challenge of markets for a universally, standardized, and interchangeable metric (Brunetti *et al*., 2023; Chen *et al*., 2024), which frequently raises concerns about the lack of additionality, or double counting, of the same conservation action (Fox *et al*., 2011; Swinfield *et al*., 2024).

In carbon markets, for example, the European Union's Emissions Trading System (EU ETS), the world's largest, accounting for over three-quarters of international carbon trading (Europe Union, 2020), operates on a cap-and-trade model, establishing a selling on emissions and allowing the trading of permits within this limit. These projects generate Certified Emission Reductions (CERs), or a carbon credit equivalent to 1 ton of CO_2 avoided, reduced, or removed from the atmosphere.

In the context of PES, voluntariness implies that participation in PES schemes is not mandatory but is based on the willing agreement of both the service buyer and the service provider (Wunder, 2015). Providers choose to engage in these schemes because the payments offer an incentive to manage their land in a way that generates environmental benefits, often foregoing other potentially more profitable land uses (Andeltová *et al*., 2015). Conditionality, on the other hand, means that payments are made only if the agreed upon environmental service is actually provided or if specific land management practices, designed to secure that service, are implemented (Wunder, 2015).

Once these parameters are incorporated into an exchange relationship, they are reduced to an exchange value. Direct methods evaluate changes "ex-ante" and "ex-post" in environmental goods (Pisani *et al*., 2021), enabling the integration of these values into the economic market system. This system typically features two distinct types of payment

approaches: action/effort-based and outcome/performance-based, or a combination of both (Gibbons *et al*., 2011; Andeltová *et al*., 2015).

Action-based payments, related to the efforts, involve incentivizing land managers or project developers to implement specific conservation activities or management practices regardless of the direct, measurable biodiversity outcome achieved (Andeltová *et al*., 2015). These payments are typically tied to the undertaking and maintenance of these actions, with the expectation that these actions will eventually lead to the biodiversity outcomes, under which they are expected to have a positive impact on biodiversity (Maher *et al*., 2018). These actions might include planting native trees, controlling invasive species, or establishing buffer zones, implementing specific land management practices (Andeltová *et al*., 2015; Armsworth & Banerjee, 2012).

In parallel, in outcome-based payments approach, directly rewards the attainment of biodiversity outcomes rather than the execution of predetermined activities (Andeltová *et al*., 2015). Although these practices are designed for biodiversity enhancement focus adapted to local conditions and circumstances (Maher *et al*., 2018), such as a population increase for a particular species, enhanced habitat quality, or the restoration of a certain percentage of forest cover, as well as avoided deforestation and afforestation (Svadlenak-Gomez *et al*., 2007; Wuepper & Huber, 2022; D'Alberto *et al*., 2024).

Therefore, the development and application of technologies for assessing and management the measurement, reporting, and verification (MRV), that adequately represents metrics, attributes and/or outcomes, constitute an indispensable prerequisite and a critical point for the credibility and functionality of any payment interventions (Leclère, 2020; Ford *et al*., 2024; BCA, 2024a).

2.4.1. Public financing

Recognizing the intrinsic economic value of nature is crucial. Market-wide pricing of nature throughout the global economy could significantly increase nature preservation and restoration (Nature Finance & UNEP-WCMC, 2022). Governments are essential in the growth of privately funded and regulated nature markets, as their fiscal and regulatory actions can cultivate more credible efforts and Sustainable Business Networks (SBNs) (Nature Finance, 2023a), increasing efficiency in the political mechanisms for the implementation of green financing, thereby influencing the adoption of new financial solutions in both public and private sectors (Hahn *et al*., 2022).

Policy and management responses to international agreements have increased lately, with more countries signing and changing national legislation for biodiversity protection, contributing to the expansion of Protected Areas (PAs) and Key Biodiversity Areas (KBAs) networks. However, the progress in addressing the global goals and targets for biodiversity conservation varies across countries (Butchart *et al*., 2010). Conservation spending is higher in wealthier countries, yet these countries often have lower biodiversity (McClanahan & Rankin, 2016). Furthermore, the protection of endangered species is primarily associated with financial capital (Rodrigues *et al*., 2014).

Conservation efforts at national, regional, and local levels vary depending on the specific region and the extent of PA coverage (Yang *et al*., 2020), largely influenced by the interplay between “democratic forces” and “levels of inequality” within a society (Kashwan, 2017). A comprehensive understanding of these country-level variations in biodiversity conservation responses is crucial, as it can help identify potential approaches for increasing positive conservation outcomes (Baynham-Herd *et al*., 2018).

Protected areas are defined as managed geographic spaces for long-term nature conservation (Dudley, 2014) preventing agricultural expansion, maintaining ecosystem services, and promoting resilience (Dudley *et al*., 2010). However, not all sites of significance for nature conservation are managed as nationally or internationally designated protected areas. "Other effective area-based conservation measures" (OECMs), recognized in Aichi Target 11, also contribute to conservation outside designated PAs (UNEP-WCMC & IUCN, 2016a).

Moreover, the current global coverage of PAs is often insufficient to achieve comprehensive conservation objectives (Rodrigues *et al*., 2014). For example, between 2016 e 2025, the geographic coverage of terrestrial and inland waters protected areas and OECM increased by 14.48% (15% in 2016 up to 17.54% in 2025), marine and coastal protected areas and OECM under national jurisdiction by 48.93% (10% in 2016 to 19.58% in 2025) and by 53.43% for ocean PA and OECM (4% in 2016 to 8.59% in 2025) (UNEP-WCMC & IUCN, 2016a; UNEP-WCMC & IUCN, 2025). These figures highlight the need to implement new political financing mechanisms for managing and encourage continuous growth of the geographic coverage of PAs and support conservation beyond them (Neugarten *et al*., 2018).

One potential solution to achieve the goals of global milestones and increase the extent of PA and other conservation areas is the inclusion of areas identified as critical or of extreme importance based on approaches such as conservation priority zones (CPZs) (Li *et al*., 2021) or biodiversity hotspots (Myers *et al*., 2000) within NBSAPs. This would allow for the mapping

of cost-benefit zones (CBZs), characterized by low human impact, for the designation of protected areas, potentially reducing the associated costs (Yang *et al*., 2020). On the other hand, the implementation of taxes, fees, and charges can increase government revenue for biodiversity measures (OECD, 2021).

One example is the European network of protected sites - Natura 2000, established by the Birds Directive (79/409/EEC) and the Habitats Directive (92/43/EEC). The Birds Directive assists in the designation of Special Protection Areas (SPAs), while the Habitats Directive helps to identify Sites of Community Importance (SCI) (Maiorano *et al*., 2007) by listing the EU funding needs needed for the implementation of conservation measures (Kettunen et al., 2014). These directives constitute the main legislation for nature conservation in the European Union (Gantioler *et al*., 2010) aiming to the identification and assessment of threatened species and habitats to ensure the long-term protection at local, regional, national and European level (Marino & Pellegrino, 2018).

However, traditional conservation approaches alone have not been sufficient to achieve desired conservation outcomes (CBD, 2020). The public sector provided over two-thirds of the US$91 billion in annual global biodiversity finance between 2015 and 2018 (OECD, 2020). However, the estimated annual monetary requirement at the beginning of the "Decade of Biodiversity" to promote a positive impact on nature was approximately US$ 364 billion (CPI, 2012). Projections indicate that at least US$ 600 billion to US$ 823 billion will be needed by 2030 to support conservation and maintenance actions for terrestrial and marine ecosystems (CBD, 2021b).

2.4.2. Private financing

Given the high costs of conservation and the unfeasibility of relying solely on public funds, private economic incentives are increasingly vital for addressing environmental challenges (Calvet *et al*., 2015). Private companies, whose dependence on natural capital assets and ecosystem services (whether direct or indirect via supply chains) differ across industries, can therefore play a key role in achieving systemic market transformation (Félix, 2022).

Achieving measurable net improvements in nature requires fundamental shifts in organizations production and consumption systems, substantially reducing impacts and increasing investments in conservation (Bull *et al*., 2022). Growing consumer interest and regulatory pressures promoting standardized natural capital accounting (EU, 2022), alongside the KMGBF Target 15 on corporate disclosure (Businesses Assess, Disclose and Reduce

Biodiversity-Related Risks and Negative Impacts) (CBD, 2022), are driving increased corporate accountability. Credit rating agencies and institutional investors are also increasingly considering biodiversity-related financial risks (F4B, 2020).

Consequently, a growing number of policymakers, financial institutions, and market participants recognize the economic and systemic risks posed by biodiversity loss (OECD, 2023). Financial institutions and private companies are actively seeking for methods to evaluate the biodiversity performance of their investments (Lammerant *et al*., 2021), which is driving an increase in projects centered on protected areas and ecosystem services (Simkins *et al*., 2023). However, achieving nature-positive outcomes necessitates a comprehensive biodiversity strategy integrated across all business units and supply chains (Marco-Fondevila *et al*., 2018; Zu Ermgassen *et al*., 2022).

Despite this, corporate biodiversity disclosure remains relatively low, appearing in under half of corporate reports in 2019 (Addison *et al*., 2018). Analysis of 2021 reports indicates that most companies still do not strategically prioritize biodiversity, with only a third having operational initiatives in this regard, and reported information often lacks detail (Marco-Fondevila & Álvarez-Etxberría, 2023). Mitigating risks and adapting to new challenges requires integrating biodiversity into decision-making and policy (Dallimer *et al*., 2020), necessitating collaboration among investors, companies, and policymakers (CISL, 2020).

That way, new policy agendas encouraging nature-oriented financing are increasingly promoting voluntary corporate actions for biodiversity conservation. The emergence of voluntary natural credit markets has the potential to transform the economy, especially with the KMGBF Target 19 aiming to mobilize $200 billion annually for biodiversity (including $30 billion from international finance). However, this transformation hinges on these markets being governed with a focus on positive impact and equity (Nature Finance, 2023b). Similar to the impact of CBD recognition on offset biodiversity credits, accepting and implementing voluntary biodiversity credits within a regulated market can also be transformative.

2.5. Biodiversity offset

The concept of offsets is widely applied to CO_2 removal measures, but less so to biodiversity protection. Offsets relating biodiversity, climate change mitigation, and other contributions of nature are rarely evaluated in conjunction (IPBES & IPCC, 2021). The use of biodiversity credits, initially termed offsets, dates back over 20 years (Porras & Steele, 2020),

but it has recently gained renewed prominence in biodiversity national and international policies (Hrabanski, 2015).

According to the Business and Biodiversity Offsets Programme (BBOP, 2009, p. 15), biodiversity offsets are "Measurable conservation outcomes resulting from actions designed to compensate for significant residual adverse biodiversity impacts arising from project development and persisting after appropriate prevention and mitigation measures have been implemented. The goal of biodiversity offsets is to achieve no net loss, [NNL] or preferably a net gain, of biodiversity on the ground concerning species composition, habitat structure and ecosystem services, including livelihood aspects".

Biodiversity offset programs represent a diverse set of regulatory mechanisms within the broader category of MBIs. These programs operate under various national policies, even within the same country (Kujala *et al*., 2022). They have been increasingly adopted in the regulatory systems of public policies as a strategic mechanism for environmental compensation, often with a mandatory component in more than 100 countries (GIBOP, 2019), including Brazil, the United States of America, Australia, and most countries within the European Union (Bull *et al*., 2016; Brunetti *et al*., 2023).

Application of biodiversity offsets typically follows the mitigation hierarchy presents in Figure 3, without the consideration of the voluntaries contributions: avoid, minimize, remedy, restore, and compensate (Gardner *et al*., 2013). Mitigation and compensation policies are often based on the principle of equivalence between the negative impact of a project implementation or performance and the unit of compensation, aligning with the polluter-pays principle (Kujala *et al*., 2022). The underlying concept is to promote economic incentives for internalizing negative externalities resulting from biodiversity losses, thereby compensating for the environmental harm caused by development (Damiens *et al*., 2021).

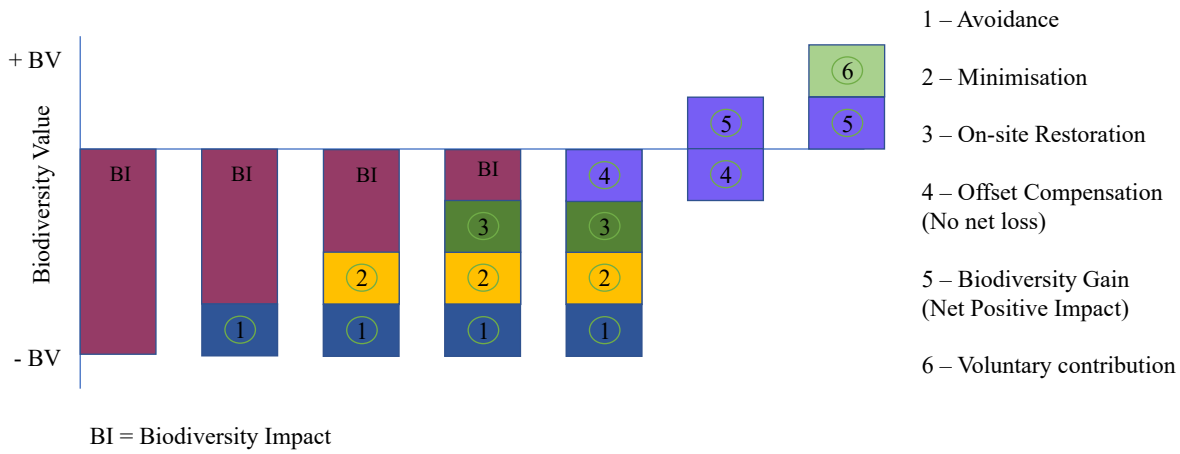

Figure 3: *Hierarchy of Mitigation of Impacts on Biodiversity (BI)*. Represents the sequential phases of action for net biodiversity gain and the incorporation of voluntary contributions for positive results. Vertical axis represents variation of the biodiversity value (BV) (positive and negative). Reprinted from RPS Groupe (s/n) and IUCN (2014).

By combining a regulatory approach (legal compliance), compensation mechanisms have gained increasing credibility and interest within political spheres (Calvet *et al*., 2015). These obligations require companies to meet stringent environmental regulations through recognized mechanisms ensuring their reduction efforts are legally recognized and reported (Spilker & Nugent, 2022). However, alongside the rapid adoption of biodiversity offset policies, skepticism regarding the efficiency of their corresponding mechanisms is also growing (Kujala *et al*., 2022). Brunetti *et al*. (2023) argues that there are three primary limitations to effectively implementing biodiversity compensation strategies. The first is the difficulty in accurately quantifying biodiversity, highlighting challenges in the metrics and criteria chosen for the offset strategies application. The second is the inherent difficulty of compensating for the loss of endemic or critically endangered species and ecosystems. The third limitation is the temporal aspect of compensation, since restoration often has medium- to short-term impacts.

In response to the movement to discredit compensation strategies, Simpson *et al*. (2022) noted a shift in public policy focus towards the Net Positive Impact (NPI) and Net Biodiversity Gain (NBG) approaches at the affected site. These approaches aim to improve the state of the environment relative to its pre-impact condition, pursuing the goal of No Net Loss (NNL). Gains can be considered through the cumulative effects of several actions carried out at a single compensation site and must be proportional to the losses, meaning minor impacts should correspond to small gains, and significant impacts to substantial gains (WBG, 2016). When a total loss of biodiversity is compensated in a site that supports considerable biodiversity levels,

NNL may not be achievable, either because the biodiversity losses are irreplaceability (Moreno-Mateos *et al*., 2015) or because no net gain is generated (Bezombes *et al*., 2019).

2.6. Voluntary Biodiversity Credit

Voluntary Biodiversity Credits (VBCs) are a certificates that represent a measured and evidence-based unit of a commodified quantified improvement, maintenance or avoided loss and nature positive impact in biodiversity that can be used to finance biodiversity-enhancing interventions to ensure a long-term and additional positive ecological outcome (Porras & Steele, 2020; BCA, 2024b; Manez & Clifton, 2024; Wunder *et al*., 2024).

The growth of VBC markets is driven by multiple correlated factors in response to the pressing need to scale up financing for conservation and in line with the directives of global policies. On the demand side, there is increasing in interest from the corporate sector in the need to manage nature-related risks and dependencies due to pressures from investors and consumers to meet their voluntary sustainability commitments in line with new regulatory and financial disclosure frameworks (WEF, 2022; Ducros & Steele, 2022; Chen *et al*., 2024). For Bull et al. (2022, p. 422) "for most organisations, achieving measurable net improvements in nature relative to an equilibrium baseline will require fundamental transformations in their consumption systems that seek to substantially reduce their impacts and increase the amount of their investments in nature conservation".

However, it is necessary to understand that while voluntary markets enable companies to demonstrate a commitment to sustainability and environmental stewardship, these actions do not replace or fulfil the legal requirements imposed by compliance frameworks (Skrindo, 2024). Instead, they serve as an additional layer of responsibility embraced by companies aiming to contribute positively to global goals, such as KMGBF Target 19, validate and stimulate the exploration of these innovative schemes as complementary instruments for achieving global environmental objectives (Katic *et al*., 2023; Zu Ermgassen *et al*., 2025).

In this scenario, the methodological framework of each environmental certification scheme assumes an indispensable role. A certification scheme is a conceptual or operational structure that organizes and describes the aspects, processes and criteria necessary for the development, implementation and validation of methods and models, being procedures that can be applied systematically (Karpínski, 1980). These frameworks, run by private programs, provide sets of rules and procedures, including eligibility criteria, indicators, assessment models, and MRV processes, that enable the conversion of an ecological intervention or a state

of nature into defined outcomes (BCA, 2024b). Meanwhile, the substantial heterogeneity and the lack of systematic characterization of the methodological approaches within existing schemes (Newman *et al*., 2023; Wauchope *et al*., 2024; Wunder *et al*., 2024) constitute a critical knowledge gap that the present dissertation aims to address.

The specific goals, context, and available resources of a certification scheme and its supported project often determine which outcome type to prioritize. Biodiversity uplift generally refers to a positive change (gain) in biodiversity conditions of a specific area compared to a defined baseline, approximated by proxy-based biodiversity indicators or managerial efforts (Ducros & Steele, 2022; Thomsen *et al*., 2022; The Nature Conservancy, 2024). This improvement can be achieved through different interventions, such as ecological restoration indicated by the changed-on conditions of the target ecosystem, species populations or habitat, enhancing existing ones, or even preserving areas under threat measures (Chase *et al*., 2020; Keith *et al*., 2022; Dias, *et al*. 2023; BCA, 2024b; Brancalion *et al*., 2025).

Averted loss refers to the biodiversity gains or maintenance achieved by safeguarding existing biodiversity rather than actively enhancing or restoring areas that have already been degraded (Maseyk *et al*., 2020). This outcome is realized by implementing conservation or maintenance activities that prevent the anticipated decline in biodiversity that would likely occur without the intervention, which might include creation of new protected areas to conserve a threatened species or habitat (Li *et al*., 2021; Cazalis *et al*., 2020), implementing measures to prevent deforestation (Buchadas *et al*., 2023), controlling invasive species that are degrading an ecosystem (IUCN, 2018; Pilotto *et al*., 2020), or mitigating other pressures land use change and exploration (Han & Zhu, 2020; Dennis *et al*., 2024).

Positive impact on biodiversity represents a target for project outcomes where the interventions taken not only balance any negative impacts, dependences, and risks but demonstrably outweigh them, resulting in a NPI on biodiversity as reward for the existing management efforts (IUCN, 2015; Smith *et al*., 2024). This goes beyond achieving NNL and focuses on actively supporting the restoration, enhancement, or preservation of biodiversity in a way that leads to measurable gains (Ducros & Steele, 2022).

Beyond the outcome quantification, the ecological integrity and market credibility, determining factors for the quality of the credit (TBC, 2022), depend on the incorporation of fundamental principles into the scheme design. Additionally, they require that any "assessment of project additionality considers baseline conditions" (BCA, 2024b, p. 12) in relation to anticipated outcomes which demands the demonstration that the credited outcome exceeds a

baseline scenario assessment. Project permanence requires the establishment of minimum temporal boundaries and robust criteria to ensure the durability of biodiversity benefits over 20 time (project permanence) (BCA, 2024a). It is also crucial to consider impacts outside the area of projects (leakage) and the risk of double-counting with other natural credits (BCA, 2024a). The incorporation of social safeguards and the promotion of equitable involvement of Indigenous Peoples and Local Communities (IPLCs) are also important dimensions (Garibaldi *et al*., 2021; BCA, 2023a).

2.7. Biodiversity significance

A central element for the integrity and effectiveness of biodiversity credits is the concept of biodiversity significance. Significance can be understood as global indicators for evaluating biodiversity elements and biogeographical properties of a given location, aiming to establish the relative importance of an intervention area in the form of complementary spatial information (Pereira *et al*., 2016; Hill *et al*., 2019).

The concept of significance encompasses multiple domains and geographical overlaps of different spatial indicators can occur, whether these indicators are defined at national/local or international scales, or by governmental (Legal/Administrative Designations) and non-governmental initiatives (Brancalion *et al*., 2019). According to Keith *et al*. (2013), geographical assessments are more effective when based on classifications established at national, regional, or local scales, integrated with international assessment units (Borrini-Feyerabend *et al*., 2017). These assessments should also be justified as appropriate indicators for different levels of biological organization and across multiple scales of detail (IPBES & IPCC, 2021).

These categories include the establishment of indicators for geographic designations and structures with ecological characteristics, characterization and status at the species level, as well as quantitative metrics and indices. Geographical designations can be represented by more general classifications, such as biogeographic category (Olenin *et al*., 2017; Mucina, 2019), from conservation status as deforestation frontier (Buchadas et al., 2023), Forest Conservation Status (FAO, 2020b) and from Structures such as IUCN Global Ecosystem Typology (Borrini-Feyerabend *et al*., 2017) or Red List of Ecosystems and/or Habitats (Keith *et al*., 2020). Also designations for Protected Area Categories (UNEP-WCMC and IUCN, 2016a; Yang *et al*., 2020) or Ramsar Wetland Classification (Ramsar, 2025).

Another example of geographical designations are priorities areas for conservation such as Key Biodiversity Area (Neugarten et al., 2018), irreplaceable biodiversity and irrecoverable carbon sites (IUCN, 2016b) or biodiversity hotspots (Myers *et al*., 2000). The identification of priority conservation actions, due to their potential to contribute to the global maintenance of biodiversity, provides critical information for national decision-makers and private companies. This information is also valuable for global agreements and private actors to guide ecological safeguarding measures and justify investments for intervention implementation. (Li *et al*., 2021; Liu *et al*., 2023).

The Species-Level Traits and Status category focuses on the attributes of species that determine their Conservation Value found within a project area, such as their distribution, conservation status, ecological role, or legal standing (IUCN, 2018; HCV Network, 2025), exemplified by migratory, endemic, and umbrella species (Park, 2007; UNEP-WCMC, 2024) and species listed on Red Lists of Threatened/Endangered species at different hierarchical spatial scales, including both governmental and non-governmental initiatives (Keith *et al*., 2013; CITES, 2023).

Quantitative Metrics and Indices category represent calculated values derived from spatial data and ecological models to quantify specific aspects of biodiversity status, threat, or conservation potential, such as MSA (Alkemade *et al*., 2009) and the STAR metric (Mair *et al*., 2021).

3. METHODOLOGY

This study investigates the establishment of Voluntary Biodiversity Credits, a novel financial mechanism for voluntary international biodiversity conservation. For this reason, this study employs an exploratory-descriptive design utilizing a mixed-method (quantitative-qualitative) approach.

Descriptive research aims to "analyze the characteristics of facts or phenomena" to uncover associative relationships between variables (Marconi & Lakatos, 2022, p. 204). Exploratory research, conversely, focuses on formulating questions or defining problems through systematic procedures for "empirical observation or data analysis" (Marconi & Lakatos, 2022, p. 204-5). Combined or mixed-methods approaches can involve "both quantitative and/or qualitative descriptions and accumulation of detailed information" to achieve a comprehensive description of a phenomenon (Marconi & Lakatos, 2022, p. 205). Furthermore, the mixed-methods approach, integrating quantitative and qualitative aspects, seeks to "broaden and deepen the understanding and corroboration of the results" (Gil, 2017, p. 41).

Therefore, this study employs three research techniques (Figure 5). Systematic review, the first research technique, is divided into a conceptualization of the systematic protocol, protocol application and initiatives and organizations screening. The goal is to identify, select, critically appraise, and synthesize relevant literature to initiatives and organizations proposing Voluntary Biodiversity Credit schemes.

The second technique is Documentary research, focusing on identifying documents from the organizations and analyzing the available information obtained from them. The objective is to perform critical reading, typological classification, aspect characterization, and comparison of public documents (e.g., methodological proposals, scheme designs) from relevant initiatives and organizations.

The third technique, Data analysis, was applied to first conduct quantitative analysis to explore correlations among structural and methodological aspects from the VBCs and develop hierarchical and non-hierarchical classifications using data collected. Subsequently, qualitative interpretation, discussion and characterization informed by the quantitative findings was performed to provide deeper contextual understanding.

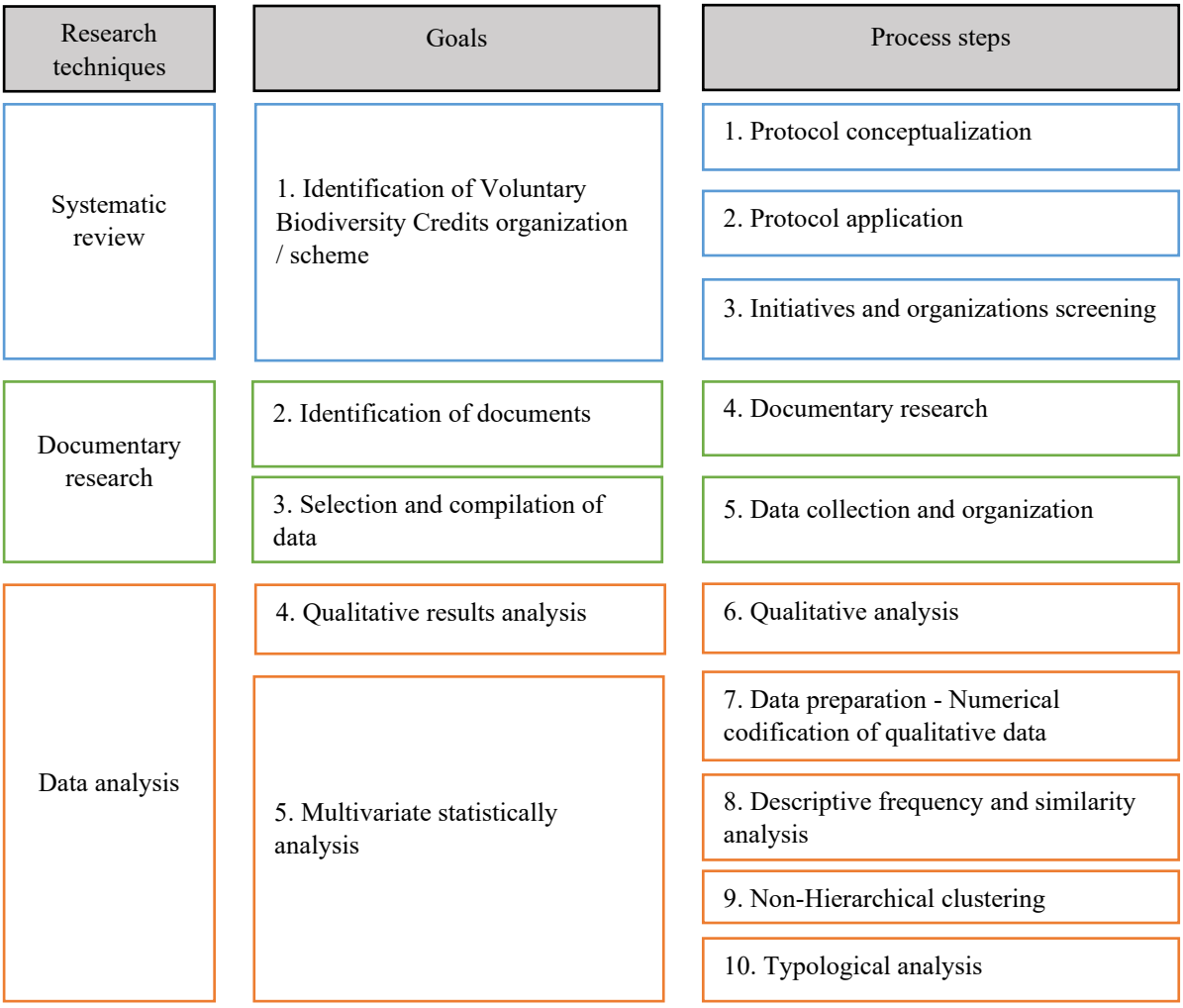

Figure 4*: General framework of the research process followed in this study*.
Note: The colors represent the sequence defined in the methodological application.

3.1. Systematic review

As a research method, a systematic review utilizes existing literature on a specific topic as its primary data source. A systematic review can be defined according to The SURE Collaboration (2011, Glossary) as a "Synthesis of research evidence addressing a formulated question using systematic and explicit methods to identify, select and critically evaluate relevant research and collect and analyze data from the studies included in the review".

Systematic reviews enable the incorporation of a wider range of relevant findings through the application of protocols to enhance the replicability and reproducibility of the research, thereby guiding future investigations. In this study, a systematic review protocol was employed to minimize subjectivity in the collection and analysis of data pertaining to certification methodologies. A predefined protocol for information retrieval was established prior to its implementation (Appendix A).

The stages and phases of this research were defined through the conceptualization and application of a Systematic Review Protocol (SRP) (Moher *et al*., 2015). The SRP is subdivided into two parts. The first application encompasses the process of the initial broad search for initiatives and organizations involved in the development of Voluntary Biodiversity Credits. The second part involves the screening of schemes to analyze and classify the initiatives and organizations identified in the preceding phase, based on the predefined criteria established during the SRP development stage.

The objective of this stage is to select the initiatives and organizations that develop specific Voluntary Biodiversity Credits schemes. To be included in this study, a scheme should: i) be a voluntary biodiversity credit scheme or methodology; ii) not be related only to biodiversity offset; iii) be available in Portuguese, Spanish, French, or English; and iv) have a publicly available information source directly related to the biodiversity credit initiatives. Schemes that addressed other ecosystem components, such as carbon emissions, but did not address biodiversity, were not included. Additionally, schemes that were unavailable for evaluation were excluded according to the selection criteria detailed in the following section.

3.1.1. SRP – Search strategy, selection criteria, and study selection

The systematic literature review was based on the search terms "Biodiversity credit," "Biodiversity credits initiatives," "Biodiversity credit methodologies," and "Biodiversity credit metrics," combined in four distinct languages (Portuguese, Spanish, French, and English), to identify schemes and organizations involved in the Voluntary Biodiversity Credit market. The searches were conducted between March 4 and 6, 2024, utilizing the *Google Search* platform as the primary source database, thus resulting in links that refer to grey literature for the subsequent screening of Organizations/schemes.

The search parameters were set to “anonymous mode”, "all filters", "Safe Search = Blur explicit images," and "any language" within the tools selection. A custom date range was specified, with a cut-off date of March 4, 2024. *Google search* was chosen because it is possibly the most comprehensive source of grey literature and governmental, and institutional reports (Piasecki *et al*., 2018; Briscoe *et al*., 2022) in addition to other types of sources. The application of the parameters aimed to ensure replicability and reduce research subjectivity, while the anonymous mode was employed to prevent bias from selective exposure and mitigate user and *Google Search* personalization issues (Curkovic, 2019; Yoshida *et al*., 2024).

Thus, the initial 40 pages found on the platform page were considered for each search terms in each language, totalizing 160 pages per language, with the exception of searches conducted in English, for which the first 80 pages were analyzed, totalizing 320 pages. This adjustment in pages was made to account for the greater volume of scientific publications in the English language, as well as the tendency of the private market to establish and disseminate its activities in English (Di-Bitetti & Ferreras, 2016).

This identification phase initially generated 800 links, which were screened in multiple stages: i) excluded repeat, blocked, and offline links; ii) excluded videos and social media platforms, non-freely accessible content, duplicate entries in the same language, and content not thematically related to biodiversity; iii) excluded links without initiatives, metrics, or methodologies related to the biodiversity credit landscape, those solely focused on offsets, and duplicates across different languages.

To be included, each link was analyzed to identify whether the following criteria were met: the organization has explicit references to organizational involvement or the development of voluntary biodiversity credit schemes and methodologies.

3.1.2. SRP – Screening of initiatives

The second phase of the SRP involved classifying the initiatives and organizations selected by category of type or nature (Table 1). This classification was based on information gathered from the organizations' official websites. To complement the search of official portals, when necessary (i.e., in cases where it was not possible to find the organization by name alone), the search terms "[name of organization] biodiversity initiative" or "[name of organization] nature initiative" were also used in *Google Search* platform and *LinkedIn* social media.

Table 1: *Categories of initiatives/organizations in the Screening the initiatives in SRP Research phase 2*

Category	Description
Funding platform	Organizations or initiatives that provide financial support to other organizations or initiatives or that fund specific projects.
Market Place	Organizations or initiatives that facilitate the trade of natural assets.
Project Developer / Executor	Organizations or initiatives that develop or implement various types of projects (e.g., restoration, conservation, sustainability) that quantify or generate benefits for nature and biodiversity.
Voluntary Biodiversity Credits organization/scheme	Organizations or initiatives that hold or apply a defined method for quantifying biodiversity in a specific area or project and based on this quantification, enable the generation of voluntary biodiversity credits.
Biodiversity assessment organization (not Voluntary Biodiversity Credits)	Organizations or initiatives that apply schemes to quantify biodiversity in a specific area or project but do not facilitate the generation of voluntary biodiversity credits.
Project Certifier	Organizations or initiatives whose primary scope is to certify and verify the conformity of methodology application in a given project.
Organization or scheme for Biodiversity Offset Credits	Organizations or initiatives that direct their operations, activities, and methodological proposals towards the biodiversity offset market.
Organization or scheme for others natural credits	Organizations or initiatives that act as "methodology developers (credited or non-credited)" and/or "project developers/executors" focused on other types of natural assets, such as carbon credits, water credits, sustainability credits, plastic credits, or any credits directed towards the use and/or generation of renewable energy.
Other organization or initiatives	Organizations or initiatives that offer services such as project consulting, analysis, and reporting; tradable products (e.g., technology for measurement, reporting, and verification - MRV); environmental education and/or training; and voluntary social funding.
Inconclusive results	Instances where the search did not yield concise results for the organizations classification (e.g., a search presenting multiple selection options or where the organizations name is ambiguous).

3.2. Documentary research and data collection

Documentary research, as a method, considers any object capable of substantiating a fact or event as a document, regardless of whether the documentary source is internal or external to the organization (Gil, 2017). In this study, documentary research was conducted using the official websites of each identified organization to locate sources of information pertaining to their biodiversity credit schemes, which included peer-reviewed and gray literature sources. Each document considered as relevant in this regard was then downloaded. Concurrently, for organizations that did not offer downloadable documents, the data available on their official website was utilized. Table 2 below presents the extracted aspects to be analyzed from the schematic documents included in this review. The aspects that have possible listing information were grouped into categories to facilitate the analysis of the results and are marked with a *.

Table 2: *Aspects selected for analysis of VBC schemes*

Id	Aspect	General Category	Aspect description	Outcome
1	Credit name and definition*	Area under specific management	To verify the general objectivity and disclosure form of the credit as developed by schemes	-
		Based on outcomes or ecological impacts		
		Long-term durations, periodic annual or monthly units		
		Monitoring cycles and the process of verification		
2	Development status	-	Use to identify the methodological development maturity of schemes	Fully operational Under development Pilot without negotiation of credits Pilot with negotiation of credits Block or retired
3	Alignment with global initiatives and frameworks *	Policy Frameworks and Global/Regional Goals	To understand the external relationships of organizations with global conservation efforts	Informed Nor informed Not applied
		Disclosure and Reporting Standards		
		Frameworks, Tools, Metrics, and Methodological Approaches		
		Scientific Foundations and Social Principles		
4	Headquarters and operation countries of organization	-	To understand the territorial dynamics of VBC developments	Informed * Nor informed Not applied
5	Territorial scale of implementation of schemes	-	To understand the geographical range of scheme	Local/regional National International Intercontinental
6	Geographic coverage /boundary	-	To determine if there are geographic limitations of implementation on site-level	Geographical restriction No Geographical restriction
7	Reference site	-	To verify if schemes use test sites to compare with the ecological conditions of project areas	Consider Not consider
8	Payment approach	-	Model of valuation of biodiversity attributes by schemes	Action/efforts-based Outcome/performance-based Combined
9	Outcome	-	To verify the expected results of biodiversity evaluation	Averted loss Biodiversity upflit Positive impact Combinations

Continues on the following page.

Table 2 (Continued)

Id	Aspect	General Category	Aspect description	Outcome
10	Credit issuance/release mechanisms	-	To verify the different periods and forms of verification and credit release	Ex-ante Ex-post regularly Ex-post ecological/management milestones Ex-post not informed Combinations
11	Project permanence period	-	To evaluate the durability of biodiversity benefits from intervention over time	Without permanence 1-10 years 11-20 years 21 - 30 years >30 years Permanent Not applied Not informed
12	Baseline assessment period	-	To evaluate the duration of the initial ecological condition assessment	0 years 1-2 years 3-5 years 6-10 years >10 years Not informed Not applied
13	Activity/project *	Restoration and Regeneration	To understand the proposes interventions implemented to quantify the outcomes	Informed Nor informed Not applied
		Conservation and Preservation		
		Sustainable Management		
		Species-Specific interventions		
		Threat Management and Mitigation intervention		
		Education, Legislation and Infrastructure Management		
14	Ecological realm or domain	-	To identify the environments that have been most frequently assessed	Terrestrial Freshwater Marine Wetland Combinations
15	Biological Organization Level (BOL)	-	To verify which levels of biological organization are most utilized in VBC generation	Genetic Species Ecosystem Landscape
16	Spatial scale of BOL	-	To determine at which scales biodiversity was most frequently evaluated	Biome Bioregions Landscape Ecosystem Species Habitat Ecological niche Combinations

Continues on the following page.

Table 2 (Continued)

Id	Aspect	General Category	Aspect description	Outcome
17	Significance indicators *	Geographic Designations and Frameworks Species-Level Characteristics and Status Quantitative Metrics and Indices	To verify the approaches implemented in the use of complementary spatial information of the project area	Calculation use Management use
18	Biological metrics and indicators	-	Assessed to identify how ecological aspects are evaluated by schemes	Informed Nor informed Not applied
19	Leakage	-	To identify if the schemes consider impacts outside project area	Consider Not consider
20	Measurement, Reporting, and Verification (MRV) technologies*	In-situ Monitoring Technologies Remote Sensing Technologies Data Management and Analysis Tools Genetic and Molecular Methods	To determine which technologies are most applied or accepted to determine the ecological aspects of the project area	Informed Nor informed Not applied
21	Double-accounting with other natural credits		To identify if the schemes evaluate other ecosystem services units beyond biodiversity in the same project or by the same interventions	Consider Not consider

Note: Marking * represents aspects that require a listing for analysis with the exception of Significance indicators, which in addition to analyzing outcomes also allow analysis of the listing.

3.3. Data Analysis

3.3.1. Qualitative Procedures

A structured qualitative analysis was conducted to interpret and contextualize the findings, focusing on the integrations of the aspects excluded from the quantitative analysis and the categorized attributes for each scheme. Initially, an overview was conducted to understand how biodiversity credits are defined, their units of measurement, and organizational alignments with global standards. Afterwards, a spatial analysis was performed by juxtaposing the headquarters' countries of organizations with the operational countries to identify patterns in global distribution.

The investigation then explored how 'Biodiversity Significance' is operationalized, distinguishing for example between its use in credit calculation versus its role in project management. Then, the Biodiversity change by Interventions section analysis involved synthesizing the relationships between proposed interventions, payment models, and expected ecological outcomes, informed by the literature, typological results, and geographic context.

Finally, Measuring biodiversity was examined, focusing on MRV technologies, specific indicators, and approaches to baseline assessment.

3.3.2. Quantitative Procedures and Variable Selection

To explore patterns among the VBC schemes and establish typologies, a multi-step quantitative analysis was performed. First, the data collected from the documentary research was prepared which involved converting the qualitative characteristics of each scheme into a categorical data matrix.

The analytical procedure began with a preliminary exploration of the data, which included the calculation of the frequency distribution. Following this, to assess the existence of statistical associations between the variables, the chi-square test of independence ($\chi 2$) was used. Finally, for the typologies, the non-hierarchical clustering K-Medoids/PAM (*Partitioning Around Medoids*) algorithm was used to partition the organizations and schemas and obtain a more stable and optimized final grouping of the schemas. This was followed by a detailed characterization and interpretation of the profiles that define each cluster.

3.3.2.1. Data preparation

From the 21 aspects initially characterized (Table 2), a subset of 15 variables was selected for the multivariate clustering model. The criterion for this selection was the suitability of each aspect for categorical codification and statistical analysis. Aspects that were purely descriptive were excluded from the quantitative model but were retained for the subsequent qualitative discussion.

The qualitative characteristics of each organization/scheme, categorized according to the aspects above, were converted into a categorical data matrix (organizations/schemes × variables). In this matrix, each variable corresponds to an aspect, and the numerical values are codes for outcomes of the categorical variables assigned to each aspect (Table 3). A frequency test was calculated for each of the 15 categorical variables (i.e. aspects) in the analysis to characterize their distributions and general properties. The test was conducted in RStudio (R Development Core Team, 2025) with the package "tidyr" for data manipulation and preparation and the package "dplyr" along with function "pivot_longer()" were used for restructuring the database (Appendix G).

Table 3: *Outcomes of the aspects considered in the quantitative analysis with indication of codes assigned*

Id	Aspect	Outcome	Code
1	Development status	Block or retired	1
		Under development	2
		Pilot without negotiation of credits	3
		Pilot with negotiation of credits	4
		Fully operational	5
2	Territorial scale of the scheme implementation	Not applied	1
		Not informed	2
		Local / Regional	3
		National	4
		International	5
		Intercontinental	6
3	Geographical coverage / boundary	Not applied	1
		Not informed	2
		Geographical restriction	3
		No geographical restriction	4
4	Reference site	Not informed	1
		Yes	2
		No	3
5	Payment approach	Not applied	1
		Action/efforts-based	2
		Outcome/performance-based	3
		Combined	4
6	Outcome	Averted loss	1
		Biodiversity Upflit	2
		Positive Imapct	3
		Averted loss + Positive Impact	4
		Biodiversity Upflit + Positive Impact	5
		Combined	6
		Combined + Positive impact	7
7	Issuance or credit release	Not Applied	1
		Not informed	2
		Ex-ante / Ex-post (Not informed)	3
		Ex-ante + Ex-post (regularly)	4
		Ex-post (Not informed)	5
		Ex-post (ecological/management milestones)	6
		Ex-post (regularly)	7
8	Project permanence	Not applied	1
		Not informed	2
		1 year	3
		5 years	4
		10 years	5
		20 years	6
		25 years	7

Continues on the following page.

Table 3 (Continued)

Id	Aspect	Outcome	Code
8	Project permanence	10 - 50 years	8
		20-50 years	9
		30 years	10
		50 years	11
9	Baseline assessment	Not informed	1
		0 year	2
		1 year	3
		2 years	4
		3 years	5
		5 years	6
		2 - 10 years	7
10	Realm	Not informed	1
		Marine	2
		Terrestrial	3
		Terrestrial + wetland	4
		Terrestrial + marine	5
		Terrestrial + wetland + freshwater	6
		All	7
11	Biological Organization Level - BOL	Not applied	1
		Not informed	2
		Genetic	3
		Species	4
		Ecosystem	5
		Landscape	6
		Genetic + species	7
		Landscape + Ecosystem	8
		Species + Ecosystem	9
		Species + landscape	10
		Genetic + Species + Ecosystem	11
		Landscape + Ecosystem + species	12
		All	13
12	Scale of BOL application	Not informed	1
		Biome	2
		Ecosystem	3
		Habitat	4
		Biome + Habitat	5
		Bioregions + habitat	6
		Ecoregion + Habitat	7
		Landscape + Habitat	8
		Ecosystem + habitat	9
		Habitat + Species	10
		Habitat + Ecologic Niche	11
		Bioregions + landscape + habitat	12
		Ecoregion + ecosystem + habitat	13
		Ecoregion + ecosystem + species + habitat	14

Continues on the following page.

Table 3 (Continued)

Id	Aspect	Outcome	Code
13	Significance indicators	Not applied	1
		Not informed	2
		Management	3
		Calculation	4
14	Leakage	Not applied	1
		Not informed	2
		Yes	3
15	Double-accounting with other natural credits	Not applied	1
		Not informed	2
		Yes	3
		No	4

3.3.2.2. Analysis of correlation between variables (Chi-Square test)

To investigate the relationships among the 15 categorical variables representing the methodological aspects of the schemes, a non-parametric chi-square test (Satorra & Bentler, 2025) was conducted in RStudio (R Development Core Team, 2025). The "tidyr" package was used for data manipulation and preparation. Additionally, the "dplyr" package, along with its "pivot_longer()" function, was employed for restructuring the database, and the "tibble" package ensured data structure consistency. For network analysis in R, the "igraph" package was utilized. Specifically, the "graph_from_data_frame()" and "degree()" functions were used to calculate network metrics, such as the degree of each node (i.e., the centrality of each methodological variable).

The choice of this test is justified by the categorical nature of the variables, which aims to verify for each pair of variables whether the co-occurrence observed between their categories is statistically significant (positive association) or whether it is likely to have occurred by chance (negative association) (Franke *et al*., 2012; McHugh, 2013), providing a preliminary understanding of the data structure previous to the clustering analyses.

To facilitate the visual identification of these patterns, the results of the chi-square tests were used to construct a node-link association network diagram. Association Network Analysis is a two-dimensional visualization technique that seeks to map the association structure of the system, representing methodological variations in community structure, organized in the form of nodes (points), and their statistically significant interrelations as edges (connecting lines) (Zoss *et al*., 2018; Fortunato & Newman, 2022). Node-link diagrams or adjacent matrices employ force-directed layouts, allowing a quick identification of the most influential or central

variables (hubs) and the observation of how subgroups of variables connect to each other (Abdelaal *et al*., 2020; Gino *et al*., 2023).

3.3.2.3. Non-hierarchical clustering analysis (K-Medoids/PAM)

To obtain a partition of the organizations into distinct groups, the non-hierarchical k-medoids algorithm also known as PAM, was applied to the same scaled data matrix used previously (Reynolds *et al*., 2004; Jin & Han, 2017). The k-medoid method aims to minimize the distance between the medoid and other sequences within the same cluster (Johnson *et al*., 2019). The objective was to segment the 38 organizations/schemes into the number of clusters identified by the Gower distance to identify clear typologies of schemes of voluntary biodiversity credits. K-Medoids/PAM analysis was applied in RStudio (R Development Core Team, 2025).

The "tidyr", “dplyr” and “tibble” packages were used for data manipulation and preparation and for the cluster analysis, the package “cluster” was utilized, including the “daisy()” function for calculating the Gower dissimilarity matrix and the “pam()” function for applying the Partitioning Around Medoids (PAM) algorithm. The “pheatmap” package was then used to visualize the Gower dissimilarity matrix among the methodological variables (Appendix I).

To enable quantitative cluster analysis, it was necessary to measure the dissimilarity between organizations based on the 15 methodological variables. Given the heterogeneous nature of the data, which includes scores on nominal and interval scales, standard distance considerations, such as the Euclidean, were considered inconvenient (Gower, 1985; Bulé & Sørensen, 2024).

For this reason, the Gower dissimilarity coefficient, a metric designed for mixed-method data, was chosen. This coefficient operates by normalizing the differences for each variable, considering the amplitude for quantitative data and a binary function for qualitative data, and subsequently calculating the weighted average of these contributions (Gower, 1985).

The result of this procedure was an N x N dissimilarity matrix, which quantifies the overall methodological difference between each pair on a normalized scale from 0 (total identity) to 1 (maximum dissimilarity). The generated dissimilarity matrix is a high-dimensional object that prevents direct visual interpretation of the structure of relationships between entities. To overcome this limitation, the MDS technique, specifically Principal Coordinate Analysis (PCoA), was applied.

MDS is a dimensionality reduction method that projects the dissimilarity matrix into a low-dimensional Euclidean space, typically two-dimensional (r=2), iteratively searches for a spatial configuration of points that minimizes a "stress" function, quantifying the discrepancy between the original dissimilarities of the Gower matrix (Gower, 1985) and the Euclidean distances in the new low-dimensional space (Park & Jun, 2009; Jin & Han, 2017).

4. RESULTS AND DISCUSSION

4.1. SYSTEMATIC REWIEW

Figure 5 describes the sequence followed in the systematic review protocol (SRP).

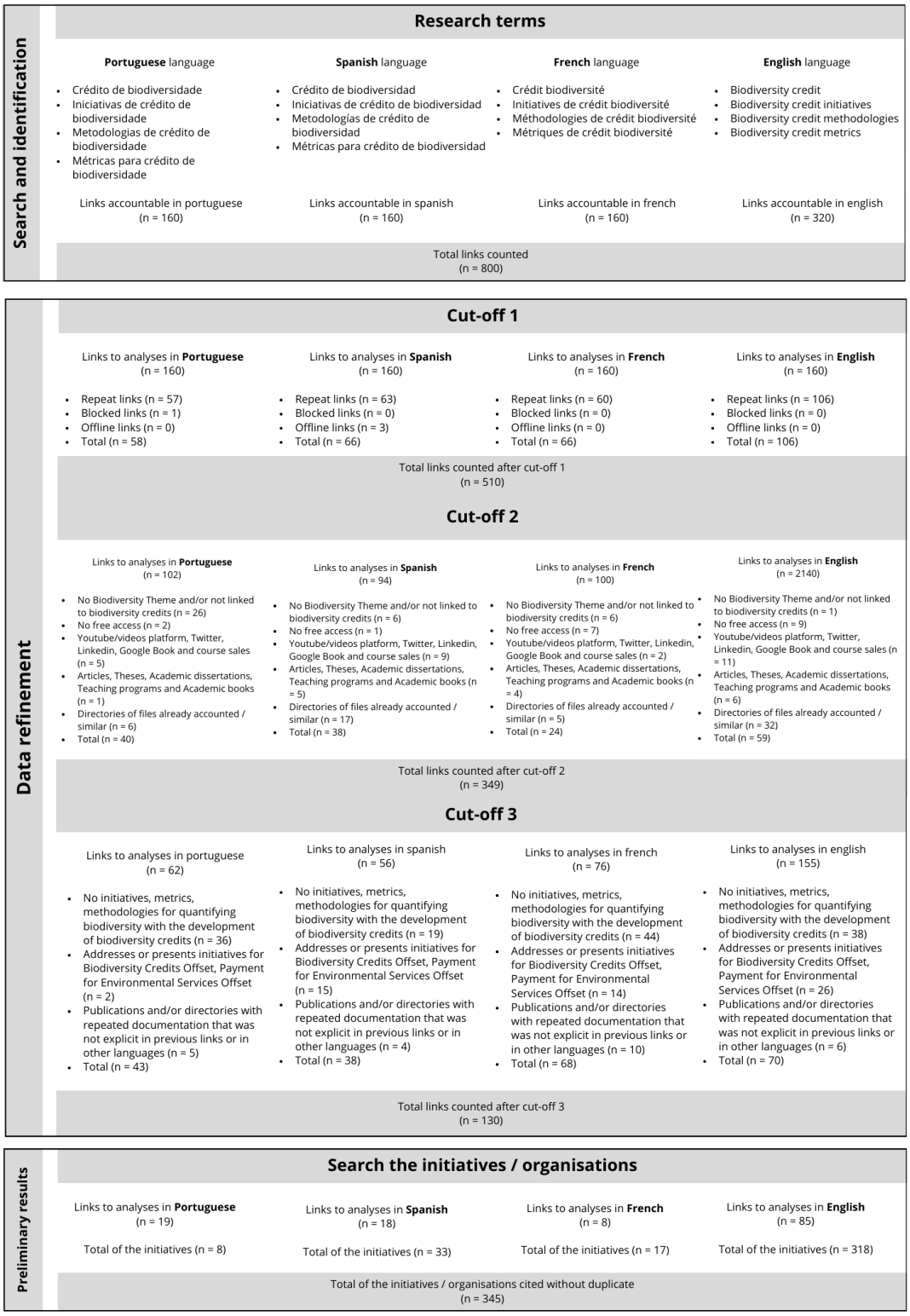

Figure 5: *Results of general stages of Phase 1 of the Systematic Review.* Organized by i) search and identification, ii) data refinement and iii) preliminary results.

As a result, a set of 130 links was obtained for analysis in the final step, comprising 19 in Portuguese, 18 in Spanish, 8 in French, and 85 in English (Figure 5). The identification was found in a final set of 345 organizations. The entire SRP and the list of organizations were organized using a spreadsheet.

Following the completion of Screening of Initiatives the systematic review identified 39 organizations or schemes that were classified as "Organization or scheme for Voluntary Biodiversity Credits" (Figure 6). The specific documents and references for each organization/scheme are detailed in Table 8 in Appendix B.

Figure 6: *Distribution of the 345 initiatives/organizations selected by category.*

4.2. Analysis of Voluntary Biodiversity Credit schemes by aspect

The 39 schemes selected in this dissertation will be analyzed in detail throughout the following sections where the most relevant aspects of these schemes will be compared and highlighted.

4.2.1. Types of credits and alignments

In the emerging context of Voluntary Biodiversity Credit (VBC) schemes, the definition of credit units constitutes a central aspect for market functionality and associated ecological integrity (Peng *et al*., 2024). In a manner similar to carbon, VBCs employ different approaches. These approaches vary based on the scope of biodiversity assessment in the certification process

and the intended disclosure of the ecological units by the organization. Table 9 of Appendix C presents the classification of definitions by scheme.

The analysis of the definitions and their frequency presented in Table 5 indicated two distinct and non-mutually approaches adopted by the schemes. Present in 62% of schemes (Figure 7), the first approach relates to the conceptual basis used for credit quantification and was defined in terms of: i) area under specific management interventions, such as restoration, conservation, protection, preservation and regeneration or recovery (31.8% attendance), and ii) based on outcomes or positive ecological impacts measured, such as the biodiversity net gains, the percentage of change variation in baskets of metrics, or the change in the extinction risk of species (30.3% attendance).

For example, Terrain NRM quantifies its credits based on the improvement of the Rainforest condition (Terrain, 2024). Plan Vivo utilizes two types of certificates, both based on the change in metric values due to interventions relative to an established initial condition (i.e., baseline assessment). One certificate is for restoration interventions, representing a percentage uplift in biodiversity (an increase in a specific metric per hectare), and the other is for conservation interventions, representing a percentage of biodiversity conserved (maintenance in a specific metric value) (Plan Vivo, 2023e).

The second approach, which is equally non-standardized and occurs in combination with the first, relates to the measurement units through the incorporation of the temporal dimension. Here, the credit unit is explicitly defined in terms of: i) long-term durations (periodic annual or monthly units), and ii) a basis in monitoring cycles and the verification process. Only 23.27% of the schemes include any aspect of the temporal dimension in their credit definitions, with an equal proportion attributed to these two types of temporal consideration.

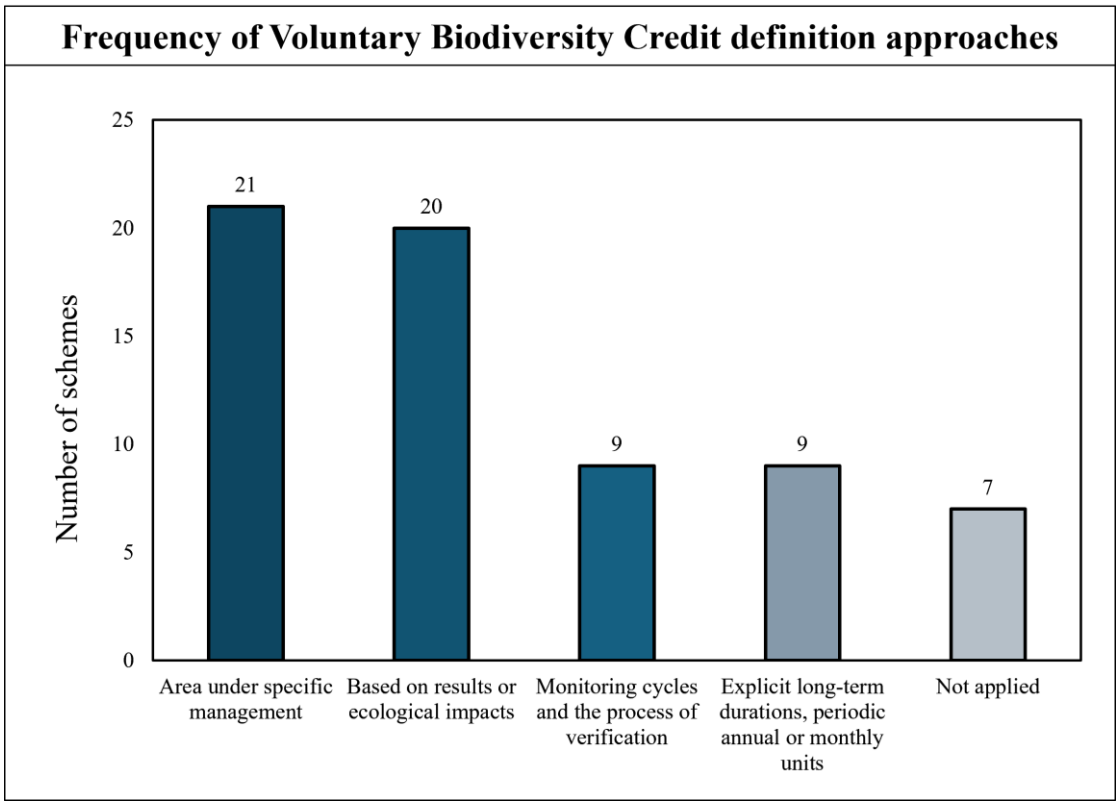

Figure 7: *Frequency of types of Voluntary Biodiversity Credits definitions based on all 39 organizations / schemes.*

Additionally, specific variations in combined definitions include approaches focused on the biodiversity components, specific geographic region or domain, BOL or spatial scale, such species or habitats. For example, InvestConservation uses a token to represent 1 ha for 50 years (InvestConservation, 2023), GreenCollar NaturePlus™ Credit "represents a one-hectare area of measured, audited and certified restoration or conservation of environmental condition over one year" (GreenCollar, 2023a) and LIFE Institute defines the unit as "Nature Positive material and traceable balance of an organization, which can be translated as the net result of positive actions for biodiversity in an area, discounting its pressure, evaluated through an independent audit and certification process" (LIFE, 2024).

The following table shows all credit names and definitions presented by the organization, the development status of the schemes, and whether the organization publicly provides the documents that cover the theoretical framework of the schemes

Table 4: *Description of the 39 Selected Voluntary Biodiversity Credit organizations/schemes with indication of organizations/scheme name, the development status of the schemes and the credit name and definition*

#	Organization / schemes	Development Status	Public documentation	Credit name	Credit definition
1	3bee	Under development	No	Not informed	A BC corresponds to the equivalent of 0.1 hectares of complete ecological regeneration.
2	AfN	Fully operational	Yes	Not applied	Not applied.
3	BeZero Carbon	Under development	No	Not informed	Not informed.
4	BioCarbon Cert	Pilot with negotiation of credits	Yes	BioCarbon Biocredits	A biodiversity credit is a unit of measurement that quantifies the net gains in biodiversity within the geographic boundaries of the conservation initiative (BioCarbon, 2024c).
5	Biota	Under development	Yes	Biodiverse Unit	A biodiverse unit is a defined geographic area that possesses a wide variety of species, genes, and ecosystems interacting in complex ways to sustain vital ecological services (Biota, 2024).
6	BMV Global	Fully operational	Yes	Sustainability Credit Unit (SCU)	SCU are monetization units obtained from the Inventory, Verification, and Valuation of biomass stocks, and their correlation with stored equivalent carbon, biodiversity richness, water potential, and economic vocation (BMV Global, 2023).
7	BGCI	Fully operational	Yes	Biodiversity Impact Credits	Biodiversity Impact Credits package up tree species recovery projects into biodiversity credits calculated based on the change in tree species population due to the projects, in proportion to the current global population of tree species (BGCI, 2024).
8	Climate Action Company	Fully operational	No	Climate Action Biodiversity Certificate	Whio A Establishment = 100m of newly protected Whio habitat per year; Whio B Maintenance = continued protection of 100m of Whio habitat per year; Whio C Protect = Each credit protects 15 hectares of habitat from mustelid species (stoats, ferrets and weasels) from Mohua (Climate Action Company, 2024a, b, c).
9	Cercabono	Under development	Yes	Voluntary Biodiversity Certification	Cercarbono's Biodiversity Certification represents a substantial biodiversity-focused activity conducted in a designated area during a specified verification period (Cercarbono, 2024a).
10	CreditNature	Fully operational	Yes	Nature Credit	Nature Credits represent verified improvements in ecosystem conditions that can be claimed, reported or traded (AfN, 2024).
11	EarthAcre	Pilot with negotiation of credits	Yes	Earth Acre biodiversity credits	Earth Acre biodiversity credits are a result of measured and verified per-unit restoration and/or conservation benefits in biodiversity (EarthAcre, 2024).
12	Earthly	Fully operational	No	Earthly's Voluntary Biodiversity Credits	Earthly's VBC represents an area of land within a project that signifies where actions are implemented to improve the ecological importance of the habitat (Earthly, 2024).
13	Ekos	Under development	No	Sustainable Development Units (SDUs)	SDUs are measurable and verified units created to fund and support projects aligned with the UNSDGs, allowing initiatives like biodiversity conservation or land protection to quantify their impact and secure financial backing through tradeable units (Ekos, 2024).
14	EraBrazil	Fully operational	Yes	Umbrella Species Stewardship credits (USSC)	Each USSC represents one hectare of habitat protection by rewarding land stewards who maintain and enhance biodiversity (ERA, 2024a).
15	Fundatia ADEPT	Under development	No	Not informed	Not informed
16	Gold Standard	Under development	No	Biodiversity Impact Units	Not informed
17	GreenCollar	Pilot without negotiation of credits	Yes	NaturePlus™ Credits	Each NaturePlus™ Credit represents a one-hectare area of measured, audited and certified restoration or conservation of environmental condition over one year (GreenCollar, 2023a).
18	Institute LIFE	Fully operational	Yes	LIFE Biodiversity Credits (LBC)	LIFE Biodiversity Credits (LBC) is the Nature Positive material and traceable balance of an organization, which can be translated as the net result of positive actions for biodiversity in an area, discounting its pressure, evaluated through an independent audit and certification process (LIFE, 2024).

19	InvestConservation	Fully operational	Yes	InvestConservation ® Token	InvestConservation ® Token represents 1 ha of tropical forest per 50 years of carbon and biodiversity rights (InvestConservation, 2023).
20	LandBanking Group	Pilot with negotiation of credits	Yes	African Parks Verifiable Nature Unit (VNU)	Each unit corresponds to 1 km² of earth that has maintained or improved its ecological integrity for one year (LandBanking Group, 2024).
21	Natural State	Under development	No	Rewilding credit	Not informed
22	New Atlantis Labs	Under development	No	Not informed	Not informed
23	Now Trust	Under development	No	Ocean Conservation Commitment (OCC)	Each Ocean Conservation Commitment (OCC) represents a protection of 1 km² of Niue ocean waters (Niue Ocean Wide, 2023).
24	OpenEarth	Pilot without negotiation of credits	Yes	Marine Biodiversity credits	Each Marine Biodiversity credit represents a 1 square kilometer per year of protected ocean area (OpenEarth, 2023).
25	OBC	Under development	Yes	Not informed	Not informed
26	Plan Vivo	Pilot without negotiation of credits	Yes	Plan Vivo Biodiversity Certificate	Each Plan Vivo Biodiversity Certificate represented a 1% increase in the Multimeric in one year in one hectare (Plan Vivo, 2023e).
27	Queen Mary University	Fully operational	Yes	Biodiversity Impact Credit (BIC)	Biodiversity Impact Credits (BICs) quantify the positive and negative effects that interventions in the natural environment have on mean long-term global species extinction risk (Rossberg *et al*., 2024).
28	Recelio	Block or retired	Yes	Dynamic Biodiversity Tokens	Each Dynamic Biodiverstiy Token represents a regenerated biodiversity on a specific plat of land (Recelio, 2023).
29	Savimbo	Fully operational	Yes	Indicator-species-based voluntary biodiversity credits	Each credit represents one hectare of 100% conserved biodiversity in a biodiversity hotspot for one month (Savimbo, 2024).
30	Single.Earth	Fully operational	Yes	MERIT Token	Each MERIT Token represented 100 kg of CO_2 captured in biodiverse nature (Single.Earth, 2022).
31	SLU	Pilot with negotiation of credits	Yes	Biodiversity credits	Biodiversity credits are a measurable and verifiable unit of biodiversity based on a defined basket of metrics and expressed in biodiversity credits per hectare and year (BC/ha/yr) (SLU, 2022).
32	South Pole	Pilot without negotiation of credits	No	Australian Biodiversity Unit / Biodiversity Credit	An Australian Biodiversity Unit, equal to 1.5 m2 of government-accredited, permanently protected Australian vegetation (South Pole, 2024a). Biodiversity credits - 50 square meters of the ecosystem Plant tree (South Pole, 2024b).
33	Terrain NRM	Pilot without negotiation of credits	Yes	Cassowary credit	One cassowary credit represents one unit of rainforest condition improvement (Terrain, 2024).
34	Terrasos	Full operational	Yes	TEBU	TEBU is a transactional unit representing 10m² of an ecosystem that has been preserved and/or restored (LIFE, 2024).
35	University of Notthingham	Under development	No	Not informed	Not informed
36	ValueNature	Under development	No	Nature Investment Certificate (NIC)	NIC represents 1 hectare of land conserved or restored (Terrasos, 2024).
37	Verra	Under development	Yes	Nature credits	A Nature Credit represents one percent of net biodiversity outcomes, measured in quality hectares (Qha), generated during a monitoring period as a result of the project intervention (Verra, 2024a).
38	Wallacea Trust	Pilot without negotiation of credits	Yes	Biodiversity Gain Unit	A 1% gain (uplift or avoided loss) per hectare in the median value of a basket of metrics that reflects the conservation objectives of the habitats within the project site (Wallacea, 2023).
39	Wilderlands	Pilot with negotiation of credits	Yes	Biological Biodiversity Units	Each Biological Biodiversity Units represents 1 km² of high strategic conservation value land (Winderlands, 2024).

Note: Research was conducted between October and November 2024.

The initiatives and frameworks listed in Table 5 do not exist in isolation but rather in a complex and interconnected governance landscape. An influence hierarchy is observed, where global agreements such as the Kunming-Montreal Global Biodiversity Framework (KMGBF) and the Paris Agreement establish high-level global goals, which are subsequently translated into regional regulations (such as the CSRD in the EU) and inform the development of voluntary reporting standards (e.g. GRI, ISSB, ESRS) and assessment tools (e.g. TNFD, SBTN, CDP). There is a clear temporal evolution, with more recent frameworks superseding earlier ones (KMGBF succeeding the Aichi Biodiversity Targets, CSRD expanding the NFRD) and a growing trend of integration between climate and nature agendas.

Table 5: *Global Initiatives and Frameworks cited for alignment by Voluntary Biodiversity Credit Organizations*

Category			
Policy Frameworks and Global/Regional Targets	**Disclosure and Reporting Standards and Frameworks**	**Tools, Metrics, and Methodological Approaches**	**Scientific Foundations and Social Principles**
Aichi Biodiversity Targets	CDP – Climate Change 2023 Questionnaire (C15 Biodiversity)	Aligning accounting approaches for Nature	IPCC (AR6)
CBD post-2020 Biodiversity Framework	European Financial Reporting Advisory Group - EFRAG	British Standards Institution Flex (BSI Flex)	UN Declaration on the Rights of Indigenous Peoples
Corporate Social Responsibility – Directive (CSR-D)	European Sustainability Reporting Standards - ESRS	CDC Biodiversité Global Diversity Score (GBS)	
Global Biodiversity Framework (GBF)	European Union Corporate Sustainability Reporting Directive (CSRD)	DJSI: Annual Corporate Sustainability Assessment (CSA) Questionnaire Biodiversity Exposure & Assessment (2.6.2)	
Kunming-Montreal Global Biodiversity Framework - KMGBF	Global Reporting Initiative (GRI)	Science-based Target Network (SBTN)	
Nature Restoration Law	International Sustainability Standards Board (ISSB)	UN SEEA guidelines	
Non-financial Reporting Directive - NFRD	SASB Standards		
Paris Climate Agreement	Taskforce on Nature-related Financial Disclosures (TNFD)		
UN SDGs - 2030 Agenda			

4.2.2. Geographic distribution of schemes

The territorial analysis of Voluntary Biodiversity Credit (VBC) schemes reveals a disconnect between the location of organizational/scheme headquarters and the countries where their projects effectively operate (Figure 8). Europe stands out with eighteen organizations, including seven in the United Kingdom, two in France and Germany, one in Switzerland, Italy, and Estonia. Six organizations are headquartered in the United States, North America.

However, regions of megadiversity in the Global South show minimal or null representation of organizations headquarters. No selected scheme has its headquarters in Continental Africa or Central America. In South America, despite its crucial importance for global conservation, with Brazil, Colombia, and Peru listed among the top 5 most biodiverse countries in the world (World Rainforests, 2023), only six locally headquartered organizations were mapped: BioCarbon, Cercarbono, and Terrasos in Colombia, and BMV Global, ERA Brazil, and LIFE Institute in Brazil. In Oceania, eight headquartered, mainly in Australia (GreenCollar, New Atlantis Labs, Terrain, Wilderlands) and New Zealand (Climate Action Company, Ekos), with only Now Trust headquartered in Niue (Figure 8).

The analysis of operational locations demonstrates a significant concentration of activities to the Global South, aligning project implementation with the geographical distribution of threatened species richness (IUCN, 2022), hotspots (Myers *et al*., 2000) and forest intactness areas with higher biodiversity significance (Hill *et al*., 2019). As noted, many organizations with intercontinental or international operations have their headquarters in the Global North. On the other hand, several schemes operating at a national or local/regional scale are headquartered in their countries of operation, suggesting a more restrictive geographical focus and, possibly, a distinct scheme and operation model.

Organizations headquartered in the Global North frequently develop projects in biodiverse countries of the Global South. In Africa, for example, Natural State (USA) operates in Kenya, Namibia, and Tanzania, LandBanking Group (Germany) focuses on the African continent, and ValueNature (UK) implements projects in Uganda, South Africa, and Zambia, as well as Verra (USA) and Plan Vivo (Scotland) operating in multiple African countries. A similar pattern occurs in Latin America with Savimbo (USA) operating in Colombia, Single.Earth (Estonia) in Brazil, and organizations such as Verra, Wallacea Trust (UK), and OBC (France) operating in Colombia, Brazil, Mexico, Peru, and Costa Rica. In Asia, examples include InvestConservation (Italy) operating in Borneo and Plan Vivo and Verra in Indonesia.

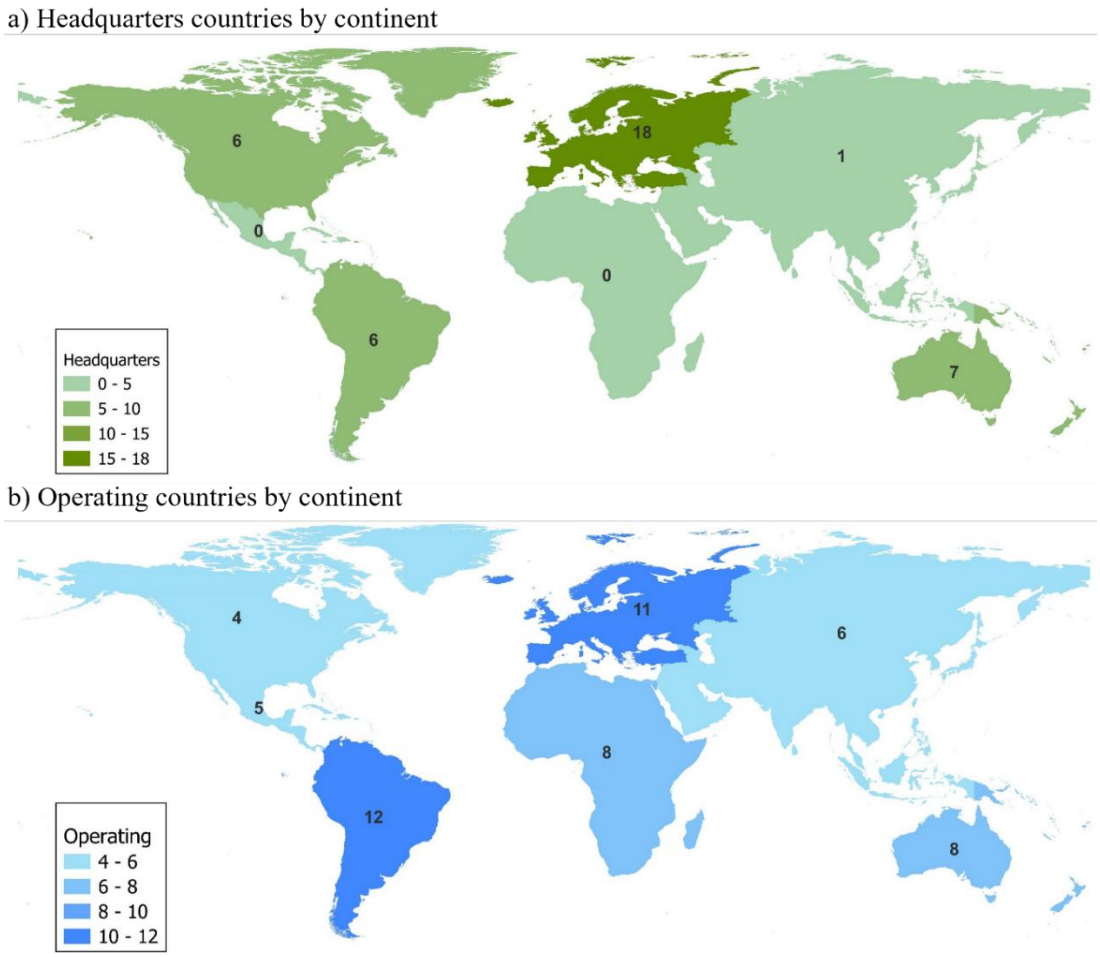

Figure 8: *Geographical distribution of Headquarters (a) and Operation Countries (b)of Voluntary Biodiversity Credit Schemes by continent.*
Note: Research was conducted between October and November 2024.

This geographical pattern reflects the Global North access to international financing centers, concentrated technical expertise and a substantial portion of international funding for biodiversity conservation (Beyerlin, 2006), and proximity to the main buyer markets for natural credits, predominantly located in Europe and North America (Pollination, 2024). Official Development Assistance (ODA) from developed countries, members of the Development Assistance Committee (DAC) of the OECD, are considered the main financial channel, with flows directed towards developing countries (OFB, 2024).

The GBF targets of mobilizing at least US$20 billion per year by 2025 and US$30 billion per year by 2030 in international flows to developing countries are heavily dependent on contributions from the Global North (CBD, 2024). Multilateral funds such as the Global Environment Facility (GEF) and the newly established Global Biodiversity Framework Fund (GBFF) play an important role in channeling these resources that are currently predominantly capitalized by donors from the Global North (CBD, 2024; OFB, 2024).

4.2.3. Biodiversity significance

The incorporation of Biodiversity significance (for definition, see Section 2.6) is critical for the integrity, credibility, and effectiveness of VBCs to demonstrate additionality and become established in the natural credit market. Ensuring that voluntary financing is directed to projects that yield the best conservation benefits requires schemes to consider the context and relative importance of intervention areas (Moreno-Mateos *et al*., 2015).

A frequent is observed (Fig. 9) to Geographical designations (Cat. 1), such as Protected Area categories and Priority Areas for conservation, and to Species Status (Cat. 2), particularly Red Lists of Threatened/Endangered Species. This trend may reflect the broader availability of globally standardized data for these categories or a strategic alignment with conservation frameworks already recognized by public policies and private market (Addison *et al*., 2018; Castro-Pardo *et al*., 2022). In contrast, Quantitative Metrics (Cat. 3) that can be used to estimate the value of biodiversity (Hill *et al*., 2019) appear less prevalent among schemes, perhaps due to technical complexity or the need for more granular data (Nicholson *et al*., 2019).

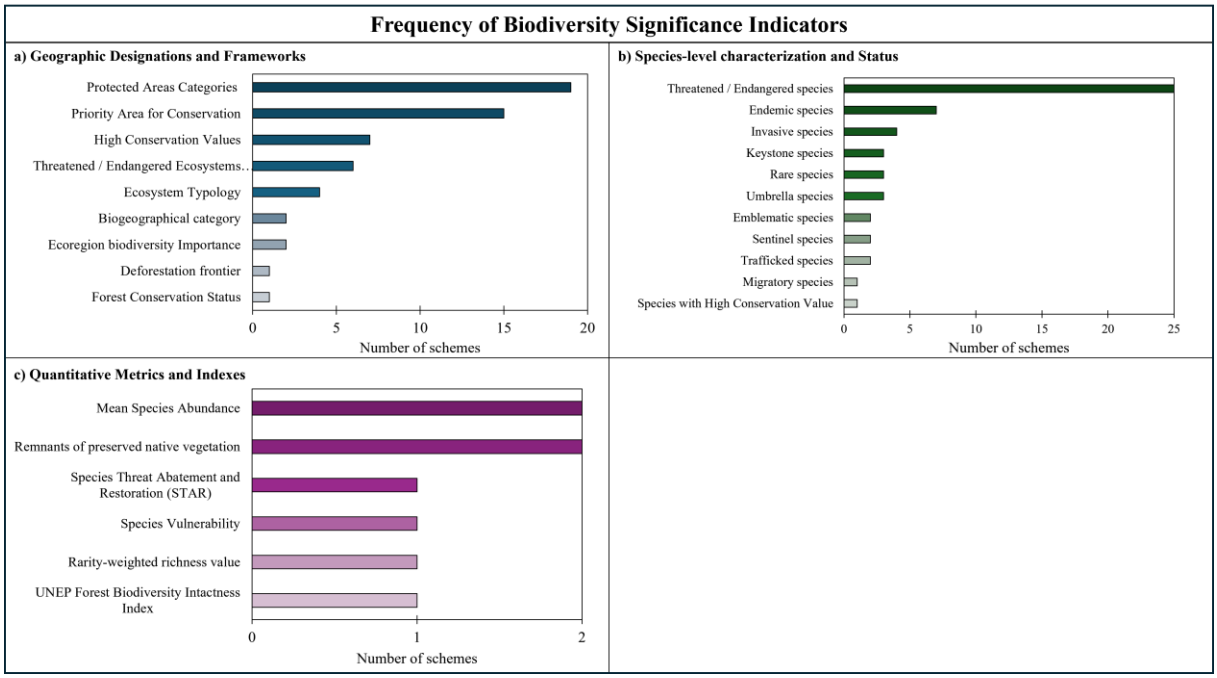

Figure 9: *Significance indicators classification frequency per number of Voluntary Biodiversity Credits based on all 39 organization/schemes.*
Note: Ordered by a) Geographic Designations and Frameworks, b) Species-Level Characteristics and Status, and C) Quantitative Metrics and Indices.

It is rare for schemes to rely on a single category, rather, the overlapping of information from different functional groups is more common. However, the multifaceted and context-dependent nature of biodiversity makes the definition, standardized measurement, and recognition of the concept of significance problematic, resulting in a use scenario with heterogeneous approaches.

From the analysis of the compilation and listing of significance indicators (Table 11, Appendix D) and the characterization of each scheme usage, it was possible to understand the use os significance indicators. It is observed that ten schemes explicitly integrate significance through its implementation in their credit generation Figure 10. For example, these significance-adjusted area-based units (i.e., tiered credits) include the Biodiversity credits by Biota, which considers in the equation the importance of conservation, wild protected areas, national registries of wetlands, and essential areas for biodiversity support (Biota, 2024). Tebu by Terrasos, which includes ecosystem threat as a factor in credit generation, thus generating a larger quantity of credits in more threatened or better-connected areas (Terrasos, 2024).

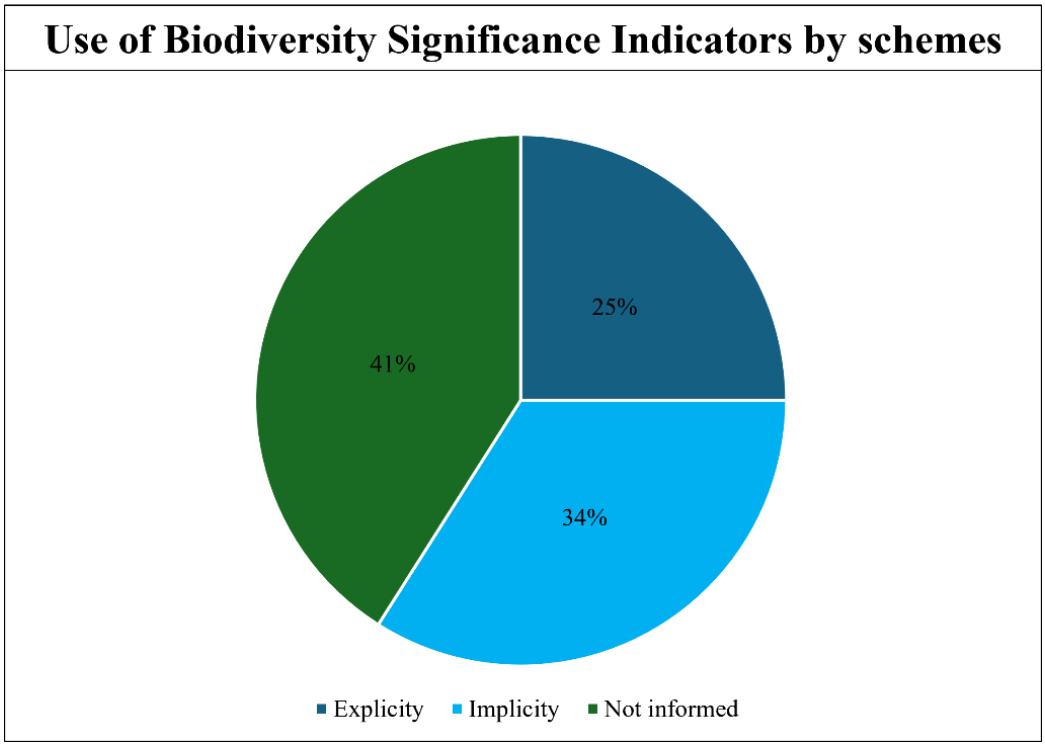

Figure 10: The role of the Significance indicators *based on all 39 Voluntary Biodiversity Credits organization/schemes.*

In contrast, thirteen schemes implicitly consider significance only as complementary spatial information accompanying credit generation. Area significance can influence project eligibility criteria, as in the case of Plan Vivo and Winderlands, which target sites of "globally significant biodiversity," limiting projects to areas considered of high value or threat. It also influences metric selection and additionality, as Wallacea demonstrates by requiring a threat assessment for avoided loss projects to prove that detrimental development would occur without credit financing.

The utilization of significance can also serve to leverage and enhance the attractiveness of the scheme/project to globally or locally prioritized areas (Brancalion *et al*., 2019; Wauchope *et al*., 2024) as approached by Verra, which uses significance to reflect the project's potential to contribute to GBF objectives. Similarly, some schemes also feature a system of stepped weights assigned to the significance of the area, which is an important method to differentiate the importance of the project size (Castro-Pardo *et al*., 2022). Savimbo assigns ecosystem value by classifying areas into levels (platinum, gold, silver, and bronze) based on incorporating the threat/importance of the project area and GreenCollar issues three levels of NaturePlus credit based on the significance of the project area, as defined by biodiversity values recognized at state, territorial, national, and international levels.

The LIFE Institute serves as an example of a scheme that applies both uses of significance. The LIFE methodology aims to qualify and quantify the environmental impacts of any organization's productive activities, regardless of scale (Reale, 2022), assigning scores based on 16 qualifiers to generate positive impact units through the implementation of conservation and management actions and efforts in formally or informally protected areas (LIFE, 2024). Within the 16 qualifiers, Ecoregions biodiversity Importance, Category of threatened species, Species according to CITES, Category of invasive potential of exotic species, Management category, and Protected area categories are the significance indicators that qualify biodiversity impacts.

If the significance of a project area or credit is inadequately defined or considered by schemes, funding may flow to projects with lower conservation impact or low ecological value areas (Hill *et al*., 2019) simply because they are easier and/or cheaper to implement or measure (Manez & Clifton, 2024). This scenario would result in an inefficient allocation of scarce financial resources for conservation and a reduction in the overall markets effectiveness in curbing biodiversity loss (Swinfield *et al*., 2024).

The direct and non-standardized integration of significance into credit quantification (or its absence) may reflect the continuous tension between capturing site-specific ecological complexity and aligning with global biodiversity frameworks and policies (Fletcher *et al*., 2016), thereby complicating the standardized valuation of significance. Thus, there is a clearer understanding of the importance of aligning with scientific benchmarks and global initiatives (Brancalion *et al*., 2019), as well as the need for greater clarity on how significance influences credit quantification and value across different schemes.

4.2.4. Biodiversity change by interventions

The analysis of the activities and projects of the 38 schemes revealed a wide range of eligible interventions (Table 12, Appendix E). Heterogeneity is also observed in how the interventions ensure the period to guarantee the ecological results are described by the schemes, which reflect the differences in philosophy, design/objective of approach, and the stages of maturity.

Some schemes provide more detail than others, specifying actions like "Restoration of degraded native vegetation areas", "Re-establishment of a degraded area in terms of its function, structure or composition", or "Planting of stems to reforest cleared or heavily degraded areas of land". Others adopt a more generic approach, listing broader categories such as "ecosystem restoration/conservation projects", "Sustainable Land Management" or "avoided loss projects". This influences the understanding of the types of ecological outcomes generated and poses operational challenges, such as demonstrating additionality (Swinfield *et al*., 2024).

The listing and categorization of activities and projects cited by the schemes show a higher occurrence of Restoration and Regeneration interventions (Figure 11a) among schemes, particularly those focused on the Enhancement of Degraded Natural Landscape, Ecosystem, and Habitat Condition (n=23). The Maintenance and Protection of Natural Landscapes, Ecosystems, and Habitats within the Conservation and Preservation category (Figure 11b) is the second-largest grouping of interventions found among the schemes (n=12). This is followed by Sustainable and Regenerative Agriculture, Aquaculture and Pasture (under Sustainable Management – Fig. 11c) and Reforestation and Revegetation, also in Restoration and Regeneration category (both with n=8).

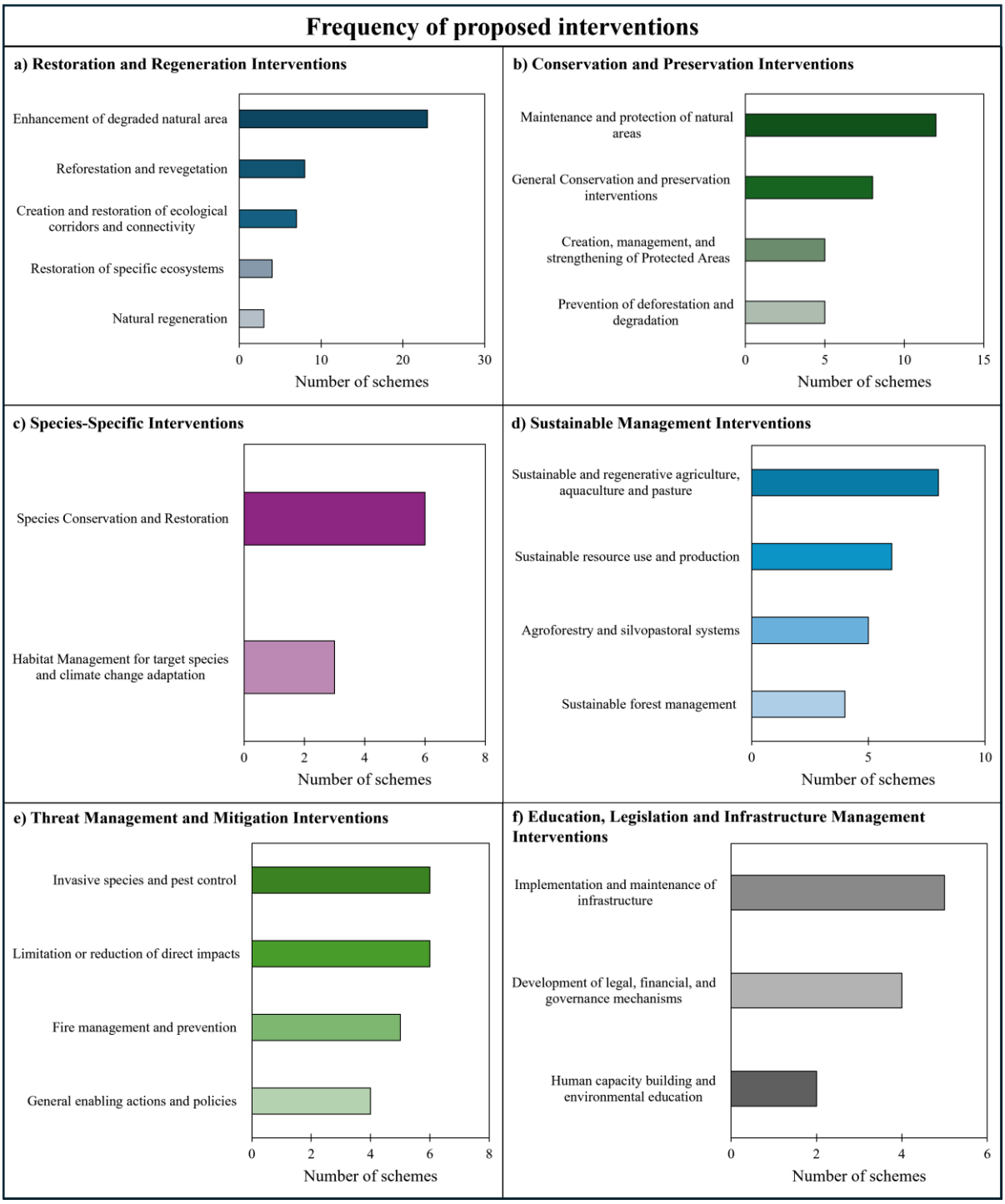

Figure 11: *Interventions classification frequence per number of Voluntary Biodiversity Credits based on all 39 organizations/schemes*.
Note: Ordered by a) Restoration and Regeneration, b) Conservation and Preservation, c) Sustainable Management, d) Species-Specific Interventions, e) Threat Management and Mitigation, and f) Education, Legislation and Infrastructure Management. Values expressed by the number of schemes included in each intervention

This diversity of activities reflects the multiplicity of outcomes that VBCs can certify, ranging from avoided losses to net gains and condition improvements. It is also intrinsically linked to the complexity of the indicators and metrics and the MRV technologies and systems

required for each type of intervention or for evaluating the ecological condition of the area of interest (Ruaro *et al*., 2020; Mamo, 2023; Manez & Clifton, 2024).

Schemes such as BioCarbon, LIFE, OBC, Plan Vivo, and Verra, present a more diverse and detailed range of eligible activities in their documentation, indicating greater flexibility and a broader scope of action, thus validating the attribution of greater robustness to these clusters. This flexibility is viewed positively by companies interested in natural credits (Chen *et al*., 2024), suggesting that the biodiversity market may prefer schemes with a holistic perspective that offer a wider range of interventions focused on different aspects and dimensions of biodiversity (Brancalion & Holl, 2024).

In parallel, cross-analysis with the payment approach suggests that, in many cases, a conceptual alignment exists between the proposed activities, the ecological scope, the payment approach, and the expected outcomes. Restoration interventions, which have a better-performing market compared to the avoided loss market (Zu Ermgassen *et al*., 2019), are prioritized by schemes that focus on biodiversity uplift outcomes, while schemes focusing on 'avoided loss' outcomes prioritize conservation and threat management interventions. For example, Botanic Gardens Conservation International, utilizing the methodology of Queen Mary University to generate Biodiversity Impact Credits, quantifies the positive change in the population of tree species promoted by the implementation of recovery projects (Tree Conservation Fund, n.d).

Schemes that adopted an outcome/performance-based payment approach, relate their measurement of progress to the results of implementation efforts (Andeltová *et al*., 2015) aiming for more combined ecological outcomes covering multiple levels of biological organization and higher spatial scales combined with habitat quality analysis. These schemes tend to list a diverse set of categories of interventions within the "Restoration and Regeneration" and "Sustainable Management" categories, with some interventions, such as Enhancement of Degraded Natural Landscapes, Creation and Restoration of Ecological Corridors and Connectivity, and Sustainable Agroforestry Systems, are designed at a local scale but produce measurable ecological changes at the landscape-level, especially due to the integration of agricultural practices with revegetation, restoration and socio-economic factors (Di-Sacco *et al*., 2020; Brancalion & Hol, 2024).

Brancalion & Holl (2024) demonstrated that the improvement in outcome performance by these interventions follows an increasing spatial scale of application. Several studies also link the positive effects of Threat Management and Mitigation interventions at the landscape

level. For example, fire management could help maintain and improve landscape diversity (Sil *et al*., 2024). Similarly, the creation and restoration of ecological corridors and improvement of connectivity are positive interventions. They reduce the negative effects of fragmentation on biodiversity, support the structure, composition, and functional characteristics of habitats, ensure the long-term stability of ecological functions, and prevent the loss of species and habitats (Azevedo *et al*., 2014; Dennis *et al*., 2024; González-Ávila *et al*., 2024).

Schemes with payment approaches based on actions, presented interventions whose progress is more directly verifiable, and, in these cases, the outcome is more focused on reducing a specific pressure, and the biological organization level and spatial scale tend to be more restricted, such as species or ecosystem within a specific habitat. For example, the Pantanal Jaguar Stewardship Project by EraBrazil, which requires understanding local challenges and disturbances at the habitat scale to establish specific management interventions for species-level conservation, implicitly links baseline/additionality to the threat context for assessing habitat quality, utilizing indicators such as community composition, taxonomic diversity (measured by species richness and diversity), ecosystem structure (according to vegetation type , land use and land cover, and hydrography), native vegetation in an old-growth stage, and ecosystem disturbance mitigation.

The relation of the geographical distribution of the interventions reflects the North-South dynamic observed in the location of headquarters and operations. While the demand and, frequently, the conception of the schemes with broader international reach originate in the Global North, the execution of activities that generate direct biodiversity impact, especially large-scale conservation and restoration, is concentrated in the Global South, where species richness and level of threat justify large-scale interventions.

Interventions related to sustainable management in agricultural or forest landscapes already intensely utilized, such as regenerative agriculture or certified forest management, are found primarily in projects developed in the countries of the Global North. Here, schemes with national or regional territorial scales direct efforts mainly towards reversing historical losses and protecting remnant natural capital, thus integrating biodiversity (and its conservation) into already modified productive landscapes, although these are also present in projects in the Global South.

4.2.5. Measuring biodiversity

According to Ford *et al*. (2024), schemes need to ensure that monitoring is scalable, accessible, granular, and evidence-based. In the analyzed schemes, in situ biodiversity monitoring (Figure 12a) primarily relies on field observations, measures and surveys (n=15), followed by Photopoint monitoring (n=14) and acoustic monitoring (n=13). High-altitude Orbital Sensors (n=12) and Low-altitude Aerial Sensors, such as Drones and UAVs (n=7) frequently appear in the Remote Sensing Technologies category (Figure 12b). In Data Management and Analysis Tools (Figure 12c), "Local, National, International and Global databases," Machine Learning (ML) methods, and Geospatial engineering tools are utilized with equal frequency by schemes, with n=5. For Genetic and Molecular Methods (Figure 12d), eDNA technologies are by far the most utilized, having appeared in ten schemes.

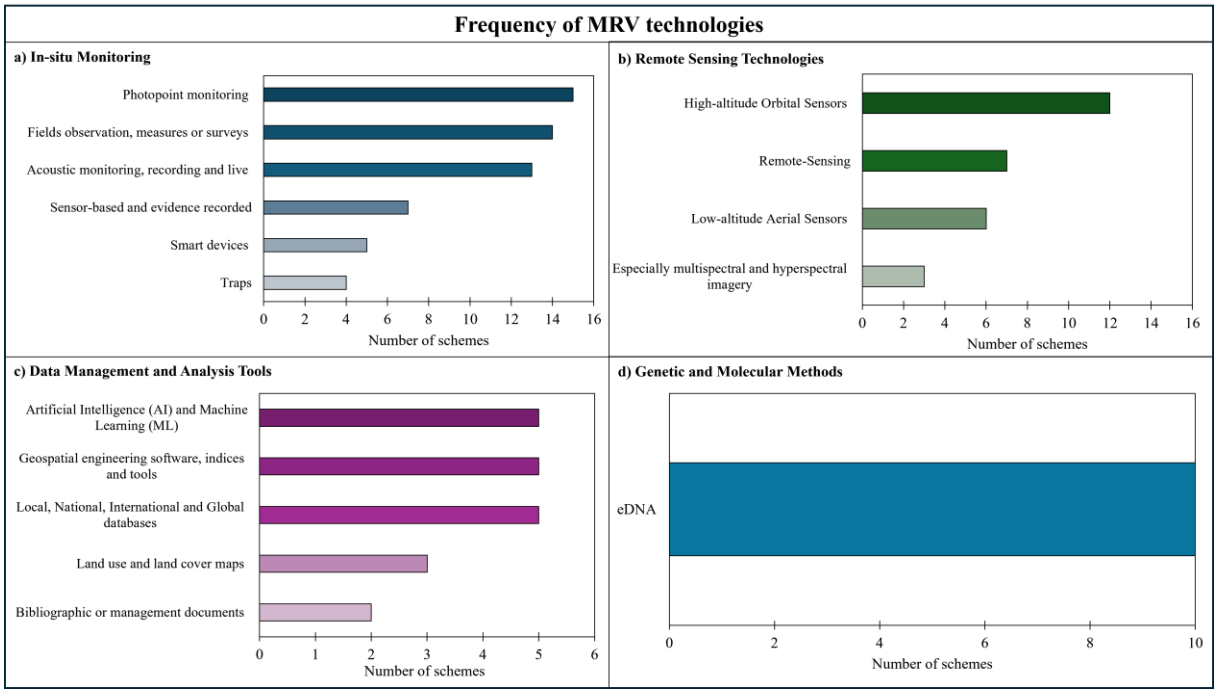

Figure 12: *MRV technologies classification per number of Voluntary Biodiversity Credits based on all 39 organizations/schemes*.
Note: Ordered by a) In-situ Monitoring Technologies, b) Remote Sensing Technologies, c) Data Management and Analysis Tools, and d) Genetic and Molecular Methods. Values expressed by the number of schemes included in each technology.

Mapping individuals and species by field monitoring can contribute to understanding ecosystem functions and species-specific ecological processes (Dehling *et al*., 2022; Mothapo *et al*., 2015). Keck *et al*. (2025) shows that changes in community diversity across spatial scales can be tightly coupled to changes in local diversity. For example, species identity and richness determine community responses to disturbances by human pressures and how communities could recover from disturbances (Loreau & De Mazancourt, 2013; Keck *et al*., 2025).

However, species-specific process predominantly obtains data derived from in-situ technologies, being dependent on sample size (Noss, 1990), with its global coverage exposed to field measurement gaps, thus presenting a geographic bias (Tasser *et al*., 2019; Burgess *et al*., 2024).

The implementation of Remote Sensing technologies and access to global data networks promoted an increase in the capacity to measure and assess ecological conditions in project areas (Hill *et al*., 2019). Regarding their applications by VBC schemes, data are predominantly generated from high-altitude orbital sensors (e.g., satellites imagery) and low-altitude aerial sensors by UAVs (usually RGB and multispectral imagery) thus presenting different spatial, temporal, and spectral resolutions, varying primarily by the ecological and territorial spatial scale (Hansen *et al*., 2021).

Timmermans and Kissing (2023) show that imaging from high-altitude orbital sensors is rare and is used for mapping species distribution, formed mainly by multispectral data. Studies have highlighted a strong correlation between remotely sensed measures of vegetation complexity and various forms of biological diversity (Zellweger *et al*., 2023; Burgess *et al*., 2024). Specifically, research has shown that the complexity of vegetation used as a proxy for species diversity and distribution, assessed through the combination of satellite imagery and aerial surveys, are strongly correlates with the diversity of animal species in an ecosystem or a landscape (Fournier *et al*., 2017; Shi *et al*., 2018).

Different schemes rely on proxies (i.e., surrogate indicators) to assess overall biodiversity, rather than attempting to measure all their components (Ford *et al*., 2024; Burgess *et al*., 2024). Common approaches include the use of indicator or umbrella species (Savimbo, EraBrazil) or metrics focused on habitat condition or structure (Wallacea Trust, Verra, GreenCollar, LandBanking Group, Wilderlands), utilizing different field measurements, evidence records, data from trapping and remote-sensing imagery (Table 7).

Dennis *et al*. (2024) shows the positive effects of using patch/landscape metrics as a proxy for species richness as a function of patch-landscape interactions. The Indicator Species

Biodiversity Methodology (ISBM) by Savimbo uses species as a proxy for the project area's conditions, combining in-situ technologies, remote sensing-imagery and eDNA for the monitoring the proxy in terms of ecosystem and habitat spatial scale, considering the richness and distribution of emblematic, rare, endemic, endangered, and invasive species.

eDNA techniques appear as the least employed monitoring technology by the schemes in the sample. This is possibly because these are emerging methods (Hoban *et al*., 2021; 2025) and thus can be proposed as complementary alternatives to non-genetic methods (Holderegger *et al*., 2019). Holderegger *et al*. (2019) show that the most common conservation actions in genetic conservation are barcoding and metabarcoding for identifying species from environmental samples.

However, the literature also indicates they can be integrated to explain broad-scale biodiversity patterns, such as spatial patterns of species richness (Schmidt *et al*., 2021) and population-level genetic variability (Andres *et al*., 2023). Allen *et al*. (2024) argue that eDNA technologies could significantly improve biodiversity monitoring in reforestation and restoration activities.

Indeed, not all schemes have their own technologies and resources to operate or finance monitoring, implying a management and utilization approach of external data, metrics, and methods, either freely accessible or through partnerships with other organizations. Different studies show that the management and planning stage is essential in determining intervention priorities, thereby strategically ensuring positive outcomes in the area of interest. Some schemes externalize the responsibility for carrying out measurement and monitoring to those responsible for project development, with the task of verifying and validating the data and other relevant information through the creation of a monitoring plan.

However, while these approaches are pragmatic and allow for scalability, they may not fully capture all dimensions of biodiversity (Ford *et al*., 2024). The choice of measurements and proxies significantly influences which aspects of biodiversity are valued and measured by interventions, demanding careful selection and calibration of monitoring technologies (or external data) to ensure that proxies adequately reflect the overall state of nature, as well as transparency about what is not being measured, especially concerning the baseline assessment (Elmiger *et al*., 2023). Also for Lehtonen *et al*. (2021) the baseline against which the outcomes are compared influences the assessment results. In our sample, schemes rarely consider a specific evaluation period for the baseline assessment, preferring to establish it at the project's inception (Figure 13).

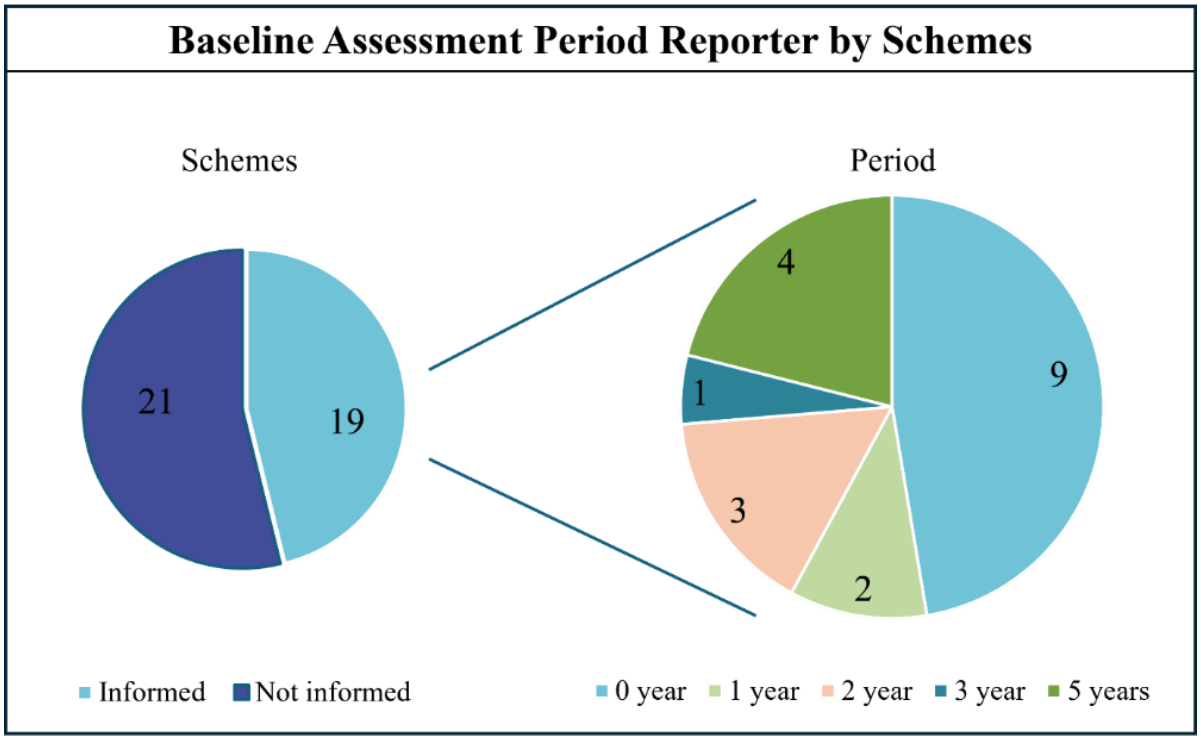

Figure 13: *Baseline assessment period reporter based on all 39 Voluntary Biodiversity Credits organizations / schemes.*

Only 19 schemes report the time frame considered for baseline assessment, with project initiation being established in nine cases. This panorama shows a fragility in the voluntary market, which may call into question the effectiveness of these monitored changes and ecological results, since the lack of temporality may make it difficult to characterize changes in biodiversity (Primack *et al*., 2018). The aim of requiring an effective baseline assessment before project initiation is to safeguard against a temporal loss of conservation values, increasing the efficacy of monitoring tools by accounting for potential natural seasonal fluctuations and the impacts of biogeophysical factors and can contribute to optimizing analytical time and resources in monitoring programs (Lindenmayer & Likens, 2010; Ruaro *et al*., 2020).

Table 6: *MRV Technologies employ by Voluntary Biodiversity Credit schemes*

In-situ Monitoring Technologies		Remote Sensing Technologies		Data Management and Analysis Tools		Genetic and Molecular Methods	
Grouping	**Schemes**	**Grouping**	**Schemes**	**Grouping**	**Schemes**	**Grouping**	**Schemes**
Acoustic monitoring, recording and live (e.g., Audio records; Bioacoustics sensors; Point-counts acoustic sampling; Soil acoustics)	3Bee; EraBrazil; InvestConservation; LandBanking Group; Natural State; Plan Vivo; Recelio; Savimbo; SLU; ValueNature; Verra; Wallacea Trust; Winderlands	Remote-Sensing (general citation) (e.g., Imagery, data, photographs)	BioCarbon; EraBrazil; GreenCollar; Natural State; OBC; Recelio; Single.Earth	Geospatial engineering index and tools (e.g., Forest Removal monitoring Tool; Normalized Difference Vegetation Index; Residual Trap Catch Index)	Biota; Climate Action Company; CreditNature; GreenCollar; New Atlantis Labs; Single.Earth	eDNA (e.g., DNA extraction, amplification, sequencing, Metabarcoding)	BeZero Carbon; Climate Action Company; EraBrazil; New Atlantis Labs; OpenEarth; Plan Vivo; Recelio; Savimbo; SLU; ValueNature; Wallacea Trust
Fields observation, measures or surveys (e.g., Birth dens and nest observation; Collection of existing flora species; Footprint; Pollinator Field Monitoring; Water and Soil samples)	3Bee; BeZero Carbon; BioCarbon; BMV Global; Climate Action Company; CreditNature; CreditNature; EraBrazil; GreenCollar; LandBanking Group; Natural State; OBC; Savimbo; Verra; Winderlands	High-altitude Orbital Sensors (e.g., Orthophotography; Satellites imagery; Synthetic-Aperture Radar (SAR), Laser scanning)	Biota; BMV Global; CreditNature; InvestConservation; LandBanking Group; Natural State; OpenEarth; Recelio; Single.Earth; SLU; ValueNature; Wallacea Trust	Local, National, International and Global databases (e.g., Biomass inventory and/or Specific carbon assessments; Global conservation priorities; National biodiversity; Standard taxonomic approaches; Weather data)	Biota; BMV Global; Invest; OpenEarth; Recelio; Wallacea Trust		
Photopoint monitoring (e.g., Camera trap; Photography; Underwater camera)	BMV Global; Cercabono; EraBrazil; GreenCollar; InvestConservation; LandBanking Group; Natural State; Plan Vivo; Savimbo; Single.Earth; SLU; ValueNature; Wallacea Trust; Winderlands	Especially multispectral and hyperspectral imagery (e.g., LiDAR imagery)	Biota; OpenEarth; Single.Earth	Bibliographic or management documents (e.g., Clearing permits; Elicitation from property owners/mangers; Tax invoices; Forest and vegetation registries)	BioCarbon; Biota; GreenCollar		
Sensor-based observations (spaceborne or ground-based) (e.g., Internet-of-things sensors; Motion sensor cameras; Selectively tagged animals) and Evidence recorded (e.g., Audio; calls, hair, faces; tracks and scats)	3Bee; Cercabono; Climate Action Company; EraBrazil; Natural State; OpenEarth; Single.Earth; Winderlands	Low-altitude Aerial Sensors (e.g., Drones; UAVs)	Biota; CreditNature; CreditNature; EraBrazil; Natural State; Plan Vivo; Wallacea Trust	Artificial Intelligence and Machine Learning (ML) methods	LandBanking Group; Natural State; OpenEarth; Recelio; Single.Earth		
Smart devices (e.g., Cellular technology; Digital cameras; GPS collars; Radio collars)	Cercabono; EraBrazil; Natural State; Plan Vivo; Recelio			Land use and land cover maps (e.g., vegetation, cartography, geologic, Reef structures; topographic and soil maps)	BeZero Carbon; BioCarbon; Biota; GreenCollar; Wallacea Trust		
Traps (e.g., Baited pitfall trapping; Chew cards; DOC Traps; Fur-traps; Malaise; Moto-lures; Pitfall trapping Winkler extractor; Tracking tunnels)	Climate Action Company; EraBrazil; Verra; Wallacea Trust						

4.3. Typologies of Voluntary Biodiversity Credit Schemes

4.3.1. General characterization and similarity analysis

The frequency analysis of the 15 methodological variables (Figure 14) reveals a Voluntary Biodiversity Credit (VBC) market undergoing a process of schematic maturation yet exhibiting notable heterogeneity. A predominant pattern observed is the asymmetry stemming from a lack of transparency in high-integrity criteria. For instance, 62% of schemes (n=24) do not report the baseline assessment period, and 45% (n=17) do not specify project permanence. The Leakage variable also presented a considerable information gap, being reported by only 38% (n=15) of the schemes. Furthermore, the VBC is predominantly composed of schemes that less frequently include a reference site (50%) for comparing the ecological conditions of the project area.

Other variables display a bimodal distribution, indicating the coexistence of distinct profiles and a fragmentation that suggests the market has not yet converged on a dominant standard for these aspects. Regarding the development status, the market is divided between "Fully operational" schemes (n=13) and those "In development" without pilot projects (n=15). This market division is also evident in the consideration of other natural credits within the same project area. double-counting permission divides schemes, with 25% (n=10) allowing it and 41% (n=16) not, which highlights the necessity of a debate surrounding the bundling of ecosystem services.

Concerning aspects with defined profiles, the majority ecological domain of assessment is individually terrestrial, accounting for 66.6% (n=26) of schemes. At the biodiversity organization level, 41% of schemes operate with species assessment combined with the ecosystem level (n=16), followed by 21% of assessments occurring at the species and landscape levels (n=8). The predominant spatial scale is habitat, with 31% (n=12) occurring individually.

As previously discussed, the consideration of significance presented a wide range, as did payment approach and issuance mechanisms. This high variability demonstrates considerable diversity and an apparent lack of standardization in the selection and application of these aspects, which is justified by the complexity, diversity of components, and different approaches to biodiversity assessment.

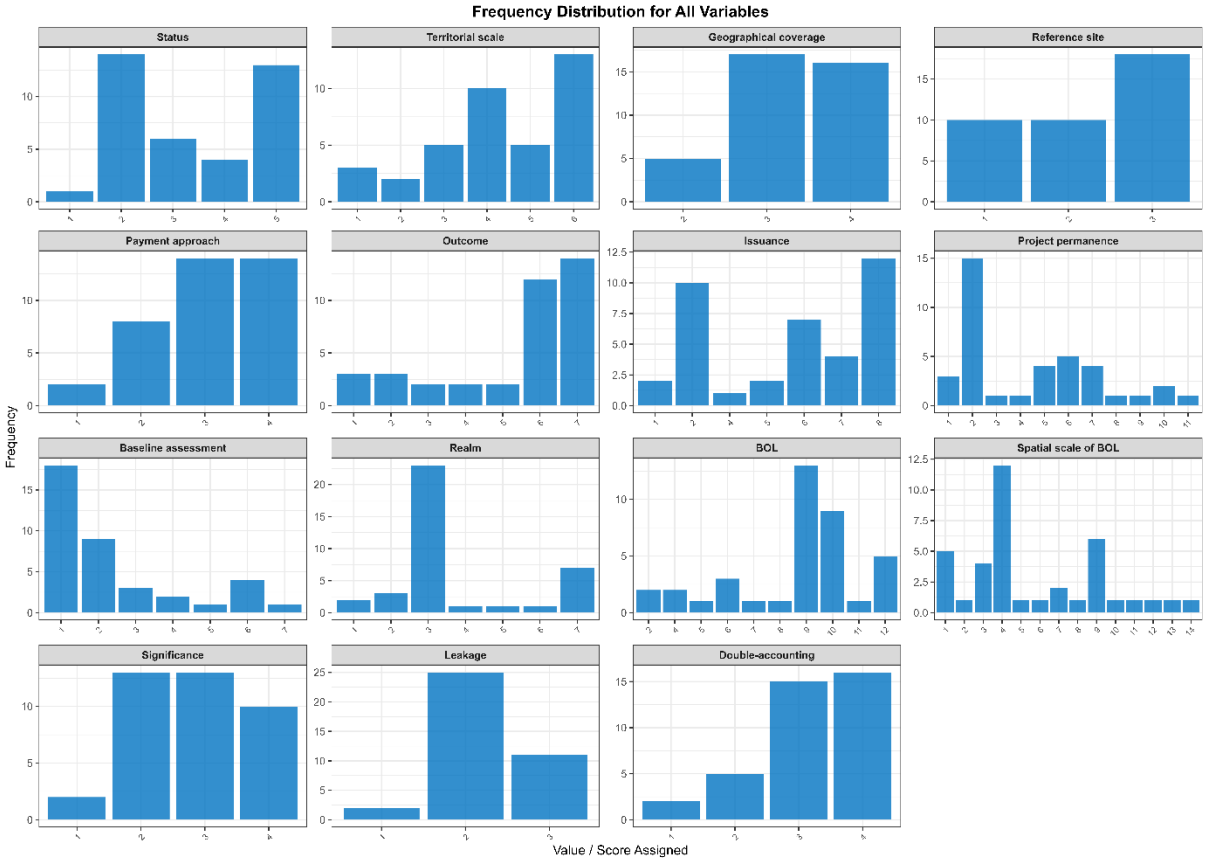

Figure 14: *Frequency distribution of the 15 selected variables relative to the 38 Voluntary Biodiversity Credits schemes.*
Note: Categories in the horizontal axis correspond to the codes in Table 3.

The association network analysis (Figure 15), based on the chi-squared test ($p<0.05$), illustrates the interdependencies that structure these schemes. The strongest connections in the network, represented by thick red/orange lines, indicate associations with greater strength and statistical significance ($p<0.05$). The p-value results are presented in Table 14, Appendix F.

The centrality and strength of these connections reveal a dense core comprising four variables: Payment Approach, Leakage, Significance, and Double-counting. Other notably strong associations include that of the Realm – BOL (Biological Organization Level) axis, which is anticipated given that both variables exhibit well-established profiles.

A distinct observation, not directly within the primary network associations, is that all organizations defining the baseline at the beginning of the project (n=9) measure biodiversity at the species level, either individually (n=2) or in association with the ecosystem or landscape levels (n=3). For a one retroactive year baseline, the landscape is the predominant BOL (n=2). For two- and five-year baselines, the species level combined with the ecosystem-level is predominant (n=6), with only one case being in association with the landscape level.

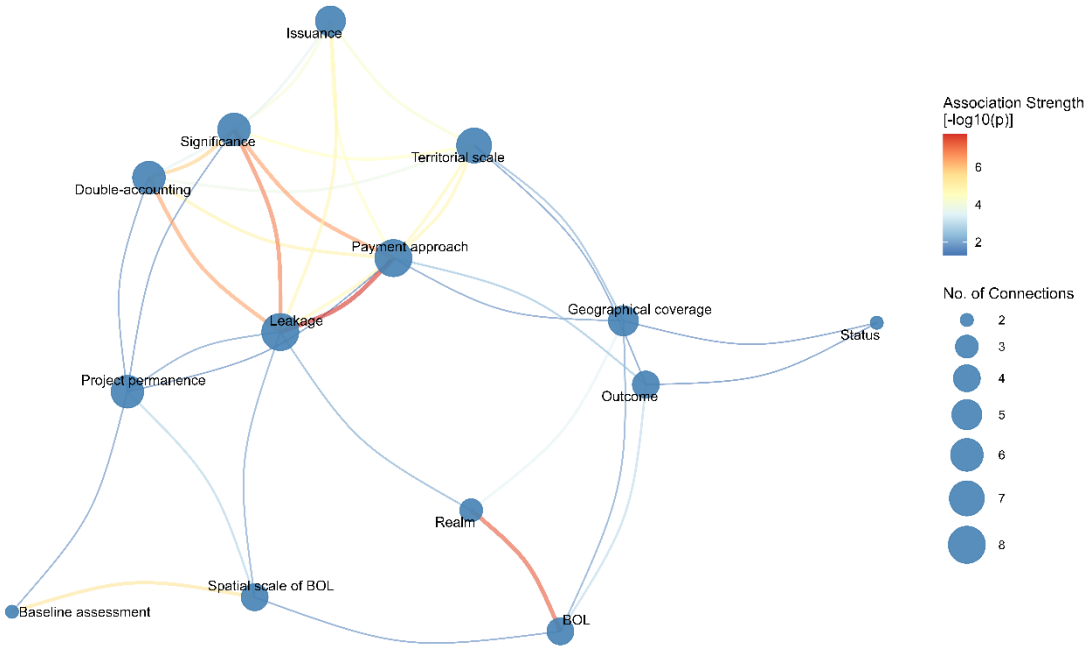

Figure 15: *Chi-square association network between the 15 variables ($p<0.05$) relative to the 38 Voluntary Biodiversity Credits schemes*.
Note: The number of connections represents the centrality and influence of the variable within the network and the strength of the association represents the significance of the association.

The strong association between the payment approach and the consideration of leakage, for example, indicates that all ten schemes accounting for impacts outside the project area utilize outcome/performance-based payments. In three of these cases, this approach is combined with action/effort-based elements. The relationship between payment approach and territorial scale further reveals that outcome/performance-based and combined payment types primarily appear at larger territorial scales.

The Sankey Diagram (Figure 16) reinforces this logic, showing a dominant flow where outcome/performance-based and combined payment approaches lead to similarly combined ecological outcomes, whereas action/effort-based approaches tend toward individual outcomes. Both of these are then verified ex-post and on a regular basis, outlining the model currently in practice, suggesting a higher degree of integrity from these schemes.

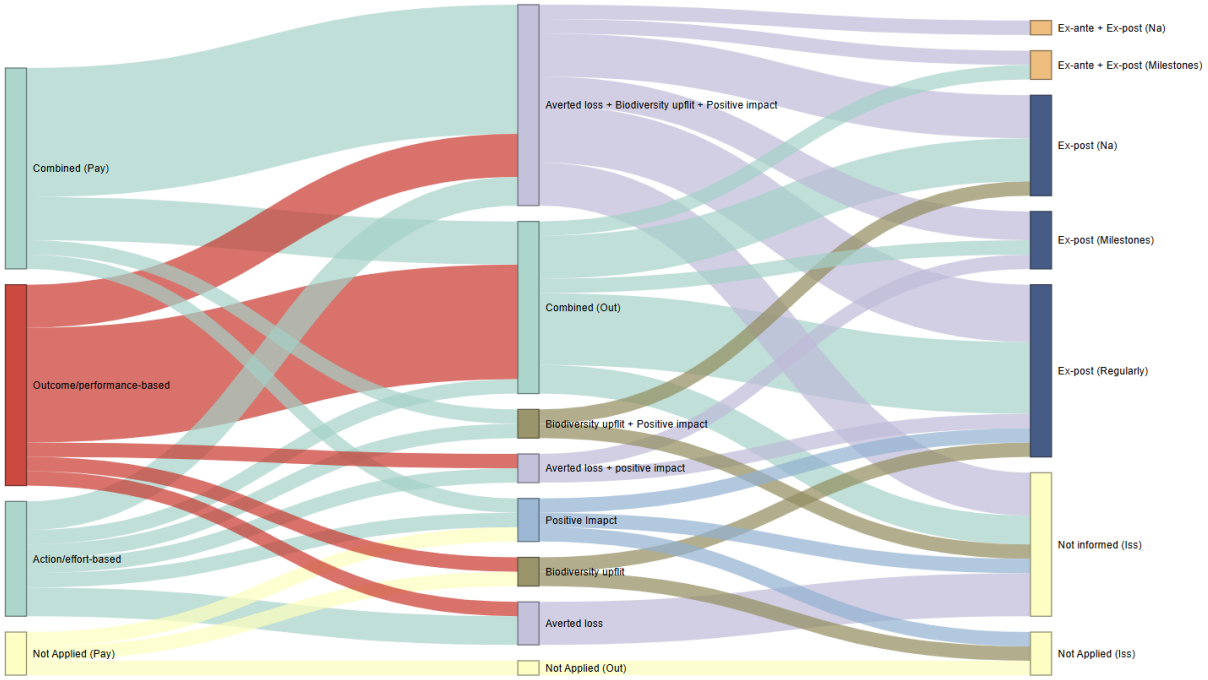

Figure 16: *Sankey diagram for the relationship of economic variables relative to the 38 Voluntary Biodiversity Credits schemes.*
Note: The elements in the first column on the left refer to the types of payments resulting from interventions implemented by the schemes. The middle column refers to the expected ecological outcomes and their possible combinations. The column on the right encompasses the possible issuance mechanisms for credit release.

4.3.2. Non-hierarchical clustering analysis – K-Medoids/PAM

The cluster analysis of the 38 organizations was based on the dissimilarity matrix between the 15 methodological variables, formed using the Gower Distance coefficient, and visualized through a heatmap (Figure 17). In the heatmap, color intensity represents the degree of dissimilarity, where blue tones indicate a low Gower distance, and thus high similarity in scoring patterns, while red tones represent high distance and, consequently, high methodological dissimilarity. The map reveals the conceptual relationships between the 15 variables and is organized by a hierarchical clustering dendrogram, which groups the most similar variables into closely related branches.

A cohesive block of high similarity (in blue) confirms the core of interrelated variables identified in the network analysis, indicating that they are frequently designed in combination. It is essential, however, to distinguish this conceptual dissimilarity from statistical dependence. Although the heatmap indicates that BOL and Realm are not redundant, the network analysis revealed one of the strongest associations between them. This indicates that, despite being unique dimensions, choices in one are strongly conditioned by those in the other.

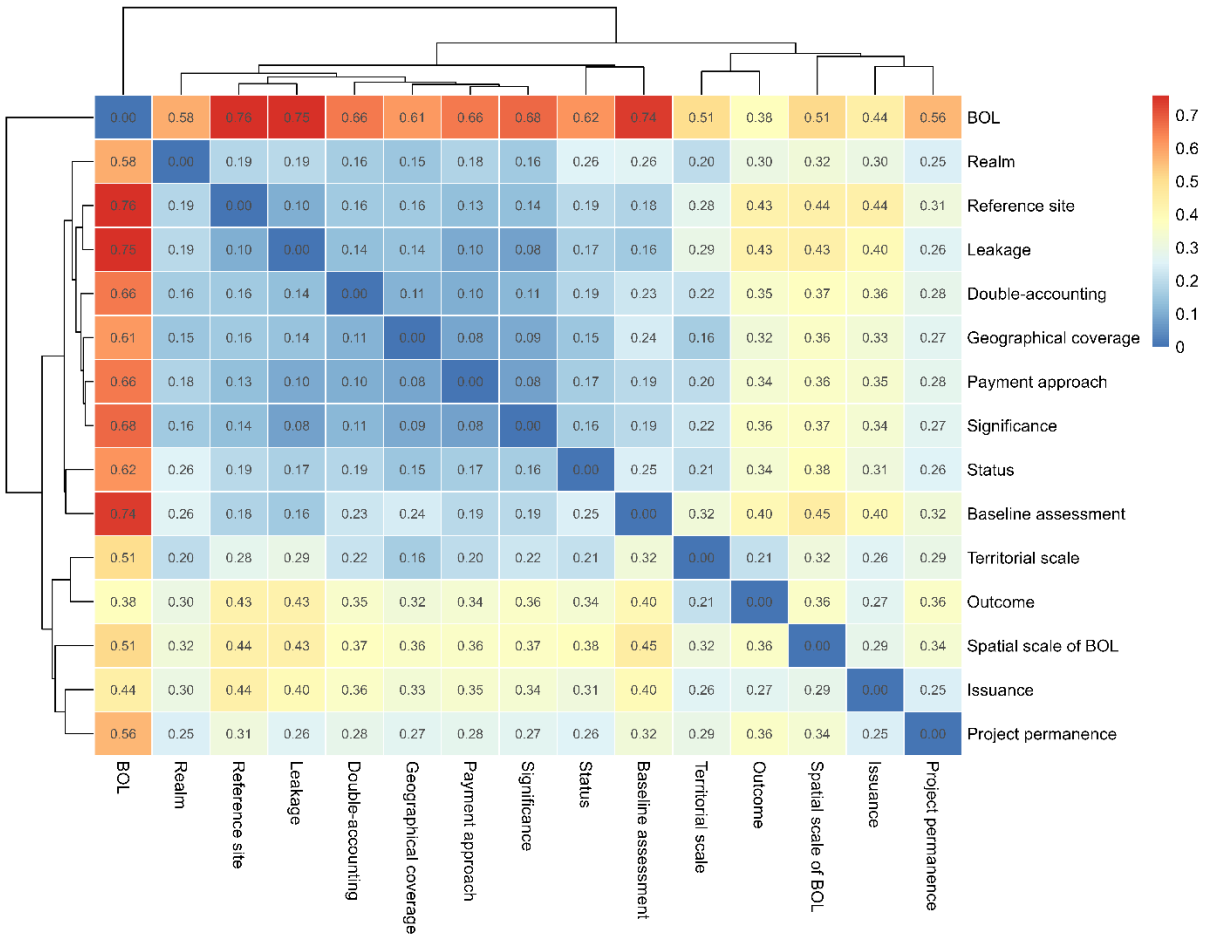

Figure 17: *Heat-map of Gower Distance with a dendrogram for visual representations relative to the 38 Voluntary Biodiversity Credits schemes.*
Note: Red colors represent high dissimilarity, and blue colors have high similarity.

The projection of the 38 schemes into a two-dimensional space (Figure 18) via K-Medoids/PAM reveals the market structure. The horizontal axis (MDS1) can be interpreted as a gradient of methodological robustness and comprehensiveness. To the left, with negative scores, are positioned Clusters 4 and 2, which incorporate more integrity criteria. To the right, with positive scores, are Clusters 1 and 5, representing more focused, niche, or initial phase approaches. The vertical axis (MDS2) differentiates the internal profiles of each cluster.

The identification of Medoids for each cluster demonstrated five distinct profiles, which are organized and presented in Table 7, facilitating the understanding of the different methodological philosophies and practices existing in the market.

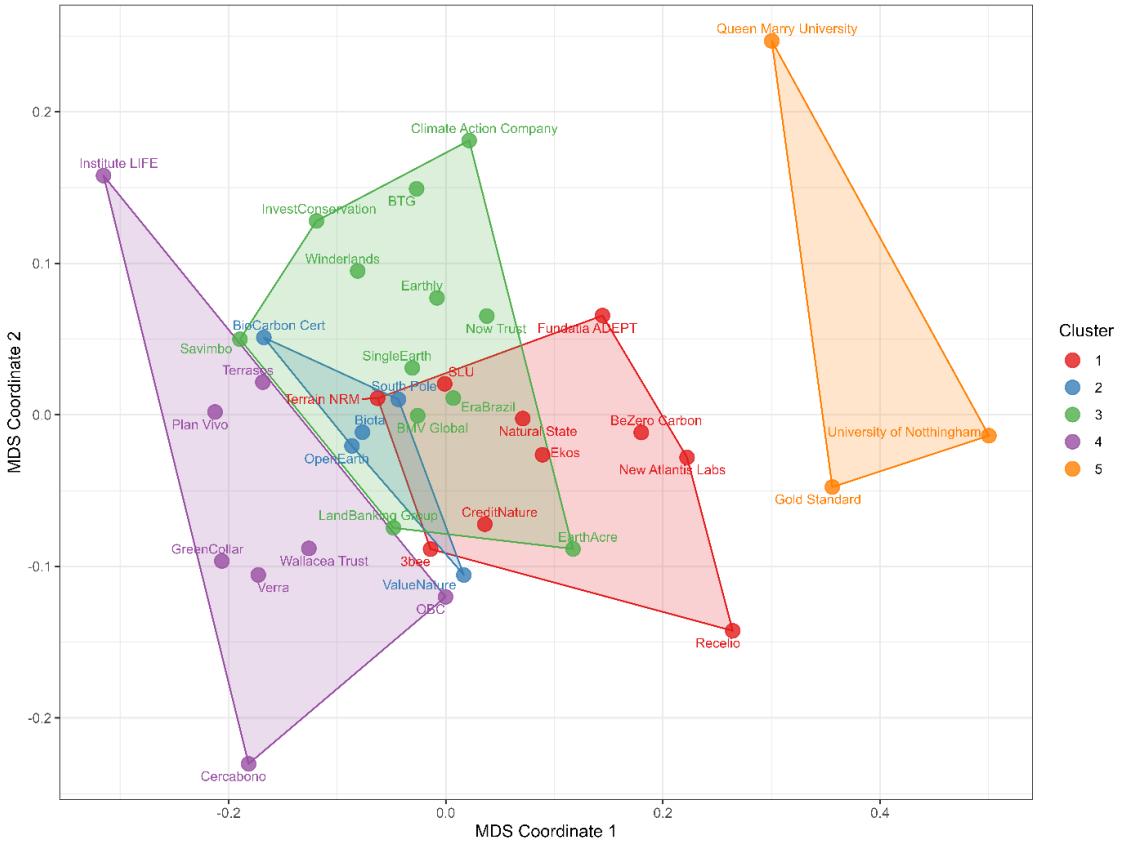

Figure 18: *Multidimensional Scaling (MDS) plot based on the K-Medoids(PAM) algorithm relative to the 38 Voluntary Biodiversity Credits schemes*.
Note: MDS1 (horizontal axis) represents the largest source of variation among the scheme profiles, while MDS2 (vertical axis) represents the second largest source of variation. Points correspond to organizations. The colors are arbitrary representations.

Table 7: *Organizations in each of five Voluntary Biodiversity Scheme clusters established based on the Non-hierarchical analysis*

Cluster 1		Cluster 2		Cluster 3		Cluster 4		Cluster 5	
Id	**Organization**	**Id**	**Organization**	**Id**	**Organization**	**Id**	**Organization**	**Id**	**Organization**
1	3bee	3	BioCarbon	5	BMV Global	8	Cercabono	16	Gold Standard
2	BeZero Carbon	4	Biota	6	BGCI	16	GreenCollar	27	Queen Marry University
9	CreditNature	23	OpenEarth	7	Climate Action Company	17	Institute LIFE	35	University of Notthingham
12	Ekos	31	South Pole	10	EarthAcre	24	OBC		
14	Fundatia ADEPT	35	ValueNature	11	Earthly	25	Plan Vivo		
20	Natural State			13	Era Brazil	33	Terrasos		
21	New Atlantis Labs			18	Invest Conservation	36	Verra		
26	Queen Mary University			19	LandBanking Group	37	Wallacea Trust		
28	Recelio			28	Savimbo				
30	SLU			29	Single.Earth				
33	Terrain			38	Winderlands				

Note: The values correspond to the order of the 38 organizations used in the multivariate analysis, with the exclusion of organization number 2 - AfN. This results in a numerical difference of -1 when compared to the initial list, except for 3bee (Table 2).

4.3.3. Cluster typologies characterization

Cluster 1 consists of 11 schemes predominantly in initial development phases, with some pilot projects underway, though CreditNature is already fully operational. It presents a heterogeneous methodological profile focused on specific niches, operating primarily in the terrestrial domain, with the exception of New Atlantis Lab, which addresses marine domain measurement.

These schemes tend to operate at a lower geographical scale, either national or local/regional, with geographical restrictions on their application. It is characterized by gaps in integrity criteria such as Leakage and baseline period definition, and credit release type. However, it shows a strong inclination towards technological innovation, having the highest adoption of eDNA and other MRV technologies, such as acoustic and photopoint monitoring. Other unmentioned variables do not exhibit a defined profile, as indicated by the boxplot (Fig. 19).

The schemes profile is more practical and field-focused. The proposed interventions are concrete, including “Enhancement of Degraded Ecosystem Conditions” and “Restoration of Specific Ecosystems”. The approach to biodiversity assessment occurs at the species level, with combined outcomes and the consideration of positive impacts, often combined with ecosystem and/or landscape levels. They demonstrate very low utilization of significance indicators, with the exception of “Protected Areas” categories and “Red List of threatened species”.

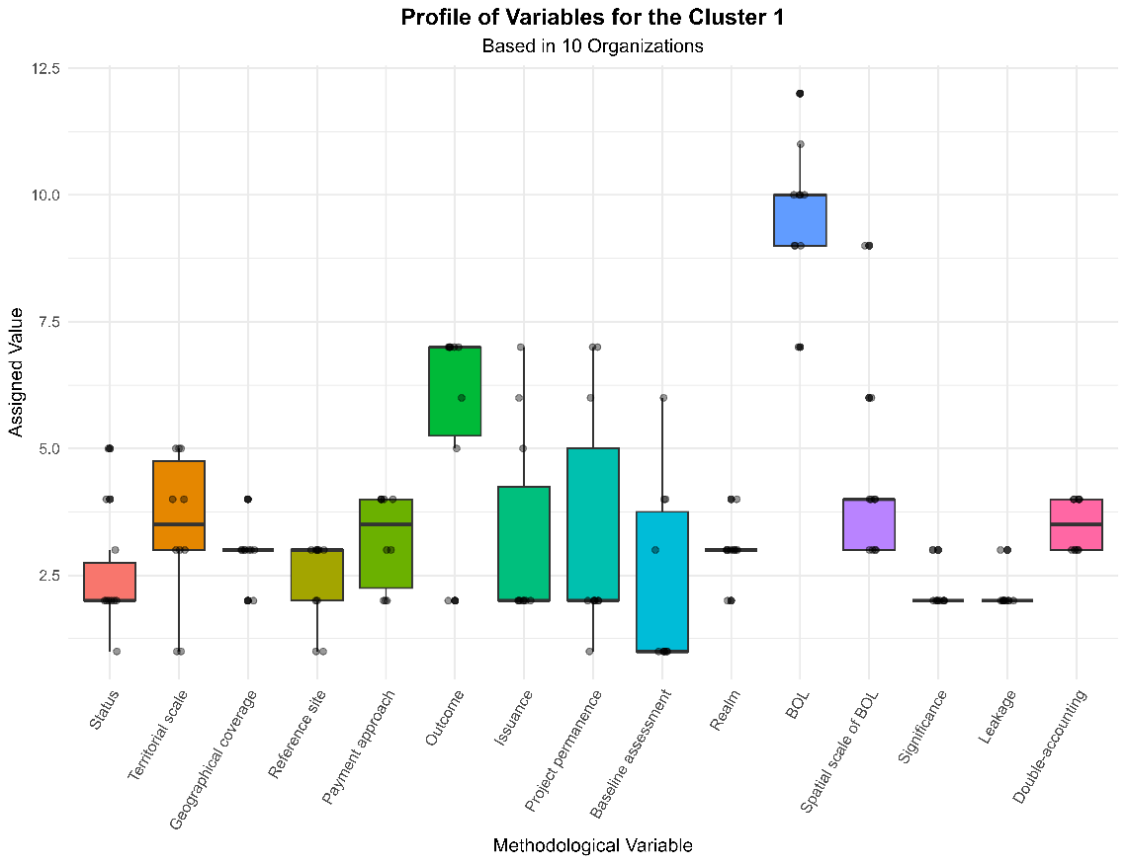

Figure 19: *Boxplot profile of 15 schematics variables presents on Cluster 1 based on 11 Voluntary Biodiversity Credits schemes.*
Note: The vertical axis and dots represent the code value for each aspect as present in table 3.

Cluster two comprises five organizations and is characterized by operating at international or intercontinental territorial scales without geographical restriction. The schemes are in the development phase or are pilot projects in operation with credit negotiation and do not consider a reference site. The measurement approach occurs in the terrestrial domain considering the species level, in combination with the ecosystem and landscape level, with the exception of Open Earth, which operates in the marine domain.

However, none of the schemes in these groups communicate the inclusion of Leakage and the temporal aspects are also not well defined, indicating a lack of transparency or schematic development that is not mature due to the lack of information availability, as indicated by the boxplot (Fig. 20).

The cluster is characterized by presenting schemes that combine payment types, combined ecological outcomes (or combined outcomes considering Positive Impact), with ex-

post credit release. The listed interventions are comprehensive, and MRV technologies relies more on "Data management and analysis tools" and models than on intensive field monitoring.

Significance indicators are used in the equation, with the exception of Value Nature, which utilizes significance indicators for management purposes and employs outcome/performance-based payment.

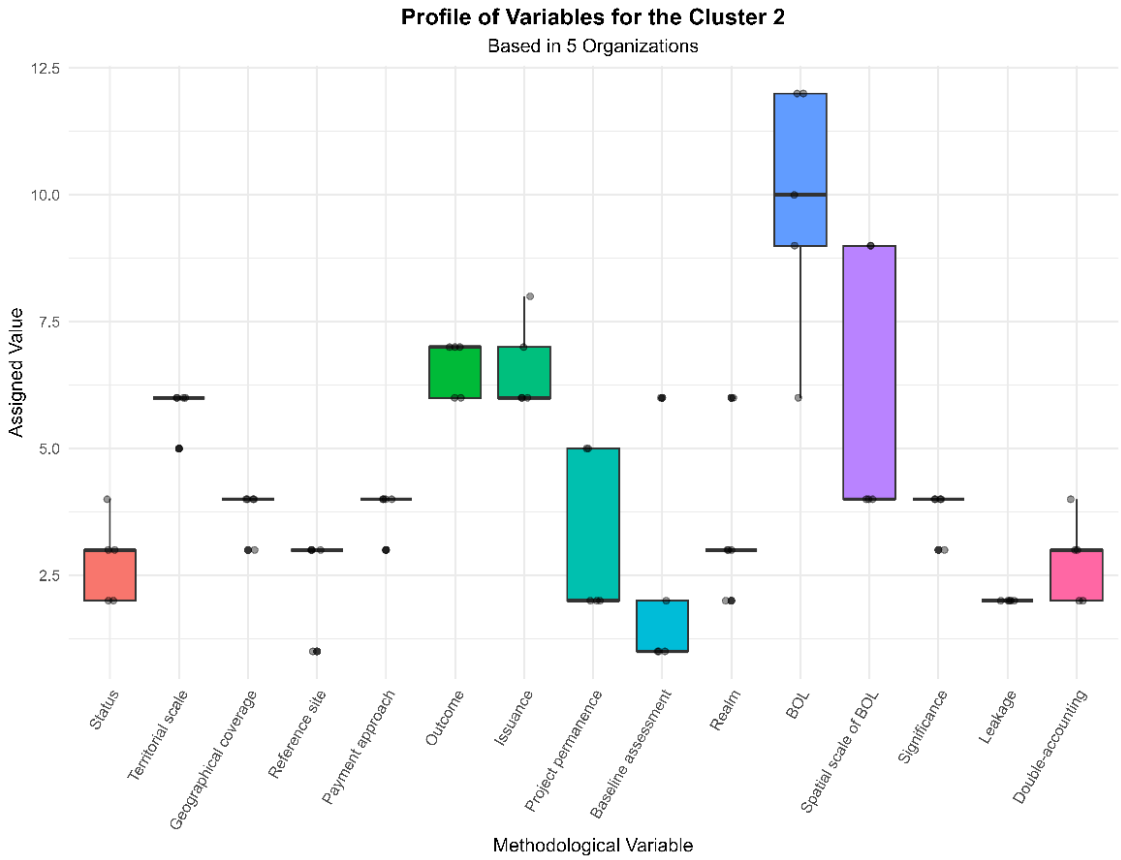

Figure 20: *Boxplot profile of 15 schematics variables presents on Cluster 2 based on 5 Voluntary Biodiversity Credits schemes*.
Note: The vertical axis and dots represent the code value for each aspect as present in table 3.

Cluster 3 comprises eleven organizations and exhibits a broader range in organizational profiles, as demonstrated in the boxplot in Figure 21. This group is predominantly composed of fully operational schemes with a practical and targeted focus, with only three in the pilot phase involved in credit negotiation.

The schemes have more niche scopes, with all assessments occurring in the terrestrial domain, but with operational geographical restrictions. The operational scale is predominantly “National” or “Local/Regional”, which reinforces its specialized nature within specific ecological and social contexts. All schemes in this cluster conduct their measurements at the

species level, either individually or combined with the ecosystem or landscape level. Their approach to Significance is management-oriented, with all schemes utilizing some form of classification for Threatened/Endangered species and protected or priority conservation area categories. Due to their more niche focus, this cluster has the most interventions centered on species-focused interventions and Threat Management and Mitigation.

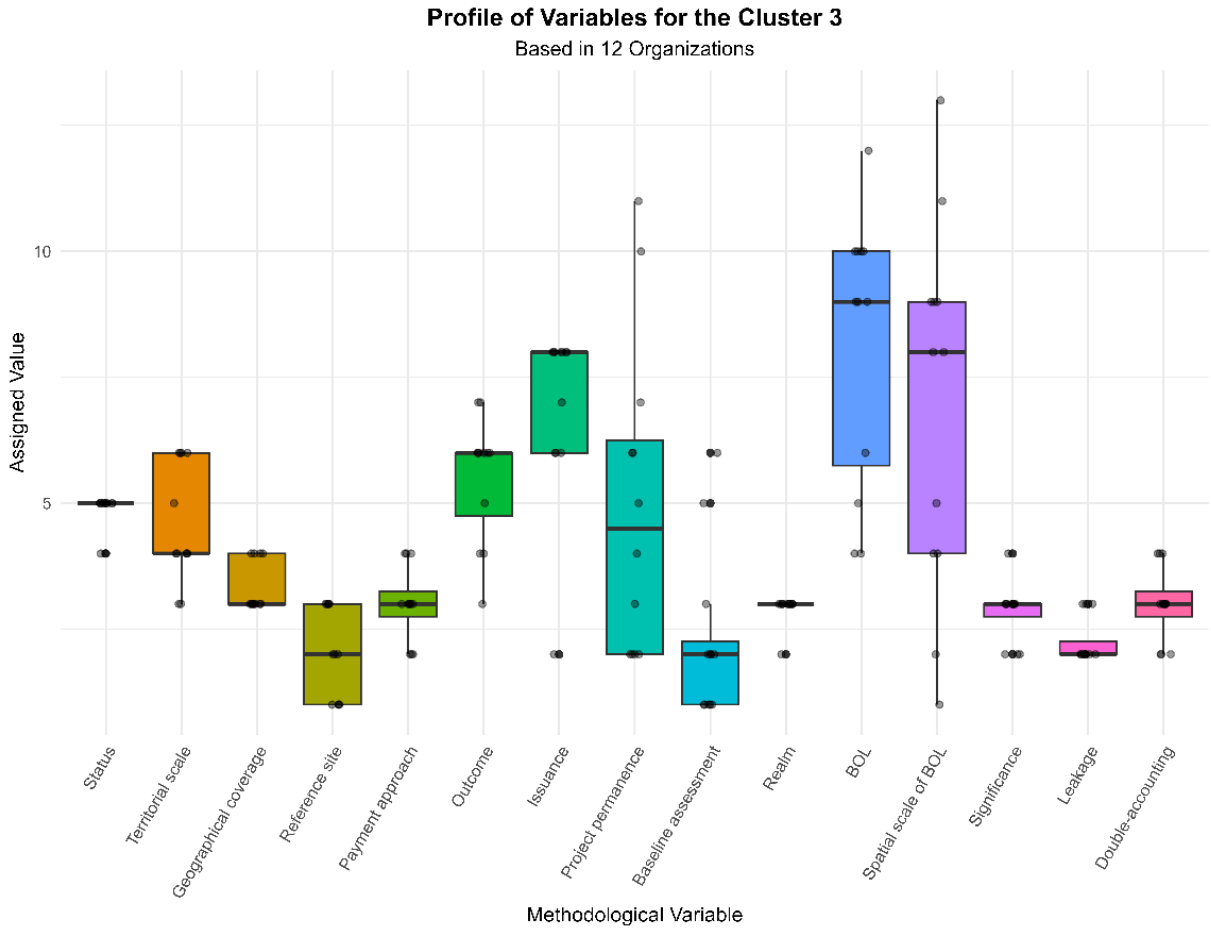

Figure 21: *Boxplot profile of 15 schematics variables presents on Cluster 3 based on 11 Voluntary Biodiversity Credits schemes*.
Note: The vertical axis and dots represent the code value for each aspect as present in table 3.

Less practice in on-site conservations interventions than Cluster 3, Cluster 4 consists of eight organizations and represents the group with the most robust and comprehensive theoretical schematic structure among all identified clusters regarding the composition of integrity aspects. With the exception of OBC, all schemes account for impacts outside the project area, tend to operate in multiple ecological domains, and exhibit no lack of transparency

or information availability, especially regarding temporal assessment aspects, as demonstrated in the boxplot in Figure 22.

The credit definition is based on “Results or ecological impacts”, with this grouping featuring schemes that lean towards a management-oriented approach, balancing theory and practice. They propose the most diverse portfolio of interventions, ranging from “Restoration” to “Sustainable Management”, primarily in the Global South.

The schemes in this cluster utilize a broader variability of “Data Management and Analysis Tools” compared to other clusters, integrating remote sensing data with in-situ validation. This dynamic also extends to their significance indicators, with all significance categories having at least one indicator cited by an organization. Furthermore, this outsourced and integrated approach allows them to operate at multiple scales, being either national or intercontinental, generally exhibiting no geographical restriction.

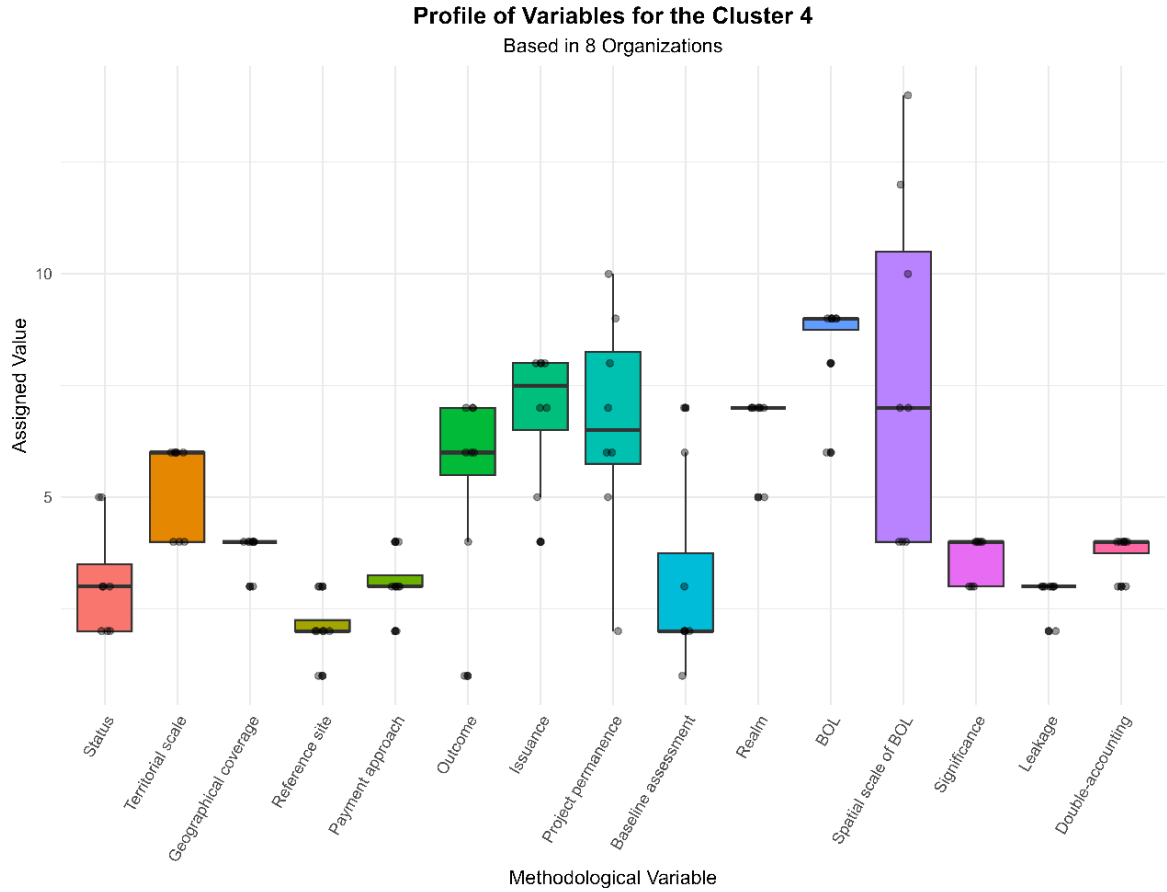

Figure 22: *Boxplot profile of 15 schematics variables presents on Cluster 4 based on 8 Voluntary Biodiversity Credits schemes*.
Note: The vertical axis and dots represent the code value for each aspect as present in table 3.

Cluster 5 comprises three organizations, representing initiatives in a conceptual stage of development. The almost complete absence of detailed methodological information suggests that their frameworks have not yet been publicly disseminated or finalized. Their presence on the map, therefore, serves to illustrate the dynamic nature of the VBC market, which continues to attract novel participants and foster the development of future approaches.

4.3.4. Limitations and gaps

Conducting a study on a multidisciplinary and complex thematic such as VBC, with a large composition of organizations/schemes including other aspects and more extensive theoretical depth within the duration of a double-degree master's dissertation would be unfeasible. However, this study discusses an overview of the current landscape of VBC, in terms of characterizing the main concepts of the different areas of knowledge and seeks to contribute with initial clarifications and with the future development of this market.

Our analysis identified five distinct typological groups of voluntary biodiversity credit schemes. The spectrum ranges from niche schemes, at different stages of development, data availability and information transparency. These groups show varying compositions based on the analyzed aspects and structural composition and different approaches to performance.

Due to this diversity, it is necessary to state that the organizations and schemes present across the clusters do not necessarily represent the entirety of schemes operating in the voluntary biodiversity credit market. Rather, they constitute the schemes included based on information extracted during this research, attributed through interpretation and pre-established criteria applied up to March 4, 2024. It is also pertinent to acknowledge that the *Google Search* algorithm may present subtle differences, even with the application of specified filters and search parameters. Furthermore, the documents incorporated into these analyses may not strictly reflect their current versions, given that organizations periodically update their materials. Consequently, some analyzed articles may no longer be in active circulation.

The results and limitations of this study should be interpreted by considering that it was not possible to access all documents and information from every organization. This was due to either a lack of available data or insufficient transparency from the entities themselves. Another factor to consider is the potential for conceptual differences between this study and the organizations, especially regarding the inclusion of landscape as a level of biological organization, considering that a large portion of the literature and organizations still adhere to

the inclusion concept presented by international regimes in the last century, which primarily consider only genetic, species, and ecosystem levels (UNEP, 1992).

Although subjective interpretations could have been used, especially concerning the aspects selected for the documentary research and the assignment of numerical value to aspects, this study deliberately selected a limited number of organizational, socioeconomic, and techno-environmental perspectives and aspects from the schemes. This choice was made to target a smaller dataset that would still address a variety of biases to produce rigorous results. Given the fact this study applied a typology approach, incorporating new schemes and/or complementary information from the included schemes would inevitably change both the scores and the rankings of the applied aspects, consequently altering the groupings.

Therefore, it would be recommended that involved stakeholders, particularly private certification schemes, genuinely seek to ensure the high integrity promulgated within the natural credit market. This approach would, in turn, permit comparisons among different schemes of similar approaches and foster an understanding among dissimilar ones. Such clarity would facilitate better comprehension for all potential interested in the emerging VBCs.

However, this necessitates higher transparency in information disclosure, and the organizations should endeavor to align data and communication with scientific literature to coordinate advancements and future developments in their schematic structures with the scientific community, local communities, and traditional peoples, primarily because these initiatives are fundamentally established for biodiversity conservation, not economic gain (Vardon & Lindenmayer, 2023).

5. CONCLUSIONS

This study is one of the pioneering works that seeks to establish a typology to understand and characterize the Voluntary Biodiversity Credit schemes. Through a mixed methodology and application of a Systematic Review Protocol, our study mapped the fragmented and heterogeneous landscape of these instruments and identified the organizations and schemes in a democratic way, also characterizing the structural factors that define their robustness and the integrity challenges that threaten their credibility and effectiveness for conservation.

The results of this work indicate that the market for VBC is at an early stage of establishment and that the existing schemes are at different stages of maturity, robustness and methodological development and applicability, ranging from similarities and dissimilarities in its philosophy, schematic design and biodiversity measurement objectives. As stressed in the analysis, one of the main current challenges to understand the state and composition of the VBC market is lack of transparency and the way organizations make available and approach the data and information about the methodological and governance aspects that characterize their schemes.

Given that the VBC market is emerging in the wake of constant skepticism regarding the credibility and integrity of other voluntary nature markets, especially in ensuring the effectiveness of ecological outcomes, as seen in the carbon market (Fletcher *et al*., 2016; West *et al*., 2023), it would be expected that organizations would design their schemes and frameworks with high levels of transparency and methodological rigor to avoid repeating past systemic failures (Swinfield *et al*., 2024; Zu Ermgassen *et al*., 2025). However, as this research demonstrates, the observed lack of transparency and the heterogeneity in the available data are particularly concerning. This suggests that the challenges may be systemic and inherent to such voluntary markets, pointing to a disconnect between the proclaimed objectives of high integrity (Manez & Clifton, 2024; BCA, 2025) and the pressures of a market that demand simplicity and scalability with ecological rigor in the assessment (Ford *et al*., 2024; Wauchope *et al*., 2024).

In general, the biophysical aspects included in the analysis of the schemes do not show major variations in their approaches, demonstrating a current market preference. The results show that the Terrestrial domain and the Habitat spatial scale are the main focuses of the schematic models analyzed (34 considerations), with a predominance of assessments based on the species level (27 considerations) combined with the ecosystem level or the landscape level. Although the landscape level is considered in 18 schemes, the various schemes analyzed include

it only as part of a combination (14 consideration) and not as the central organizing principle (3 consideration), often precisely because they do not understand and consider the landscape as a level of biological organization. Paradoxically, many schemes propose interventions that, in addition to being generic, are inherently at the landscape scale, such as the “creation and restoration of ecological corridors” or the “improvement of the condition of the degraded natural landscape” and include in their methodologies schematic aspects appropriate to the landscape-level assessment.

Regarding the VBC geographic dynamics observed in the headquarters countries and operating countries, it was possible to perceive a clear division between the Global North and South. According to the results achieved, the vast majority of organizational headquarters and, consequently, intellectual and financial capital and demand, are concentrated in countries in Europe and North America. In contrast, the interventions that generate the credits, occur predominantly in regions rich in biodiversity, which overlap geographic regions with the distribution of threatened species richness, hotspots and forest areas with greater biodiversity significance, especially located in South and Central America and the African continent.

This structure is similar to the dynamics established in global markets for other commodities, where countries in the Global South are considered the "producer" of the raw material and the Global North as the main center of consumption, financing and market regulation (Nkurunziza *et al*., 2017; UNCTAD, 2023), directly aligning with the theoretical perspective of the "neoliberalization of nature" and its process of valuing and commoditizing nature addressed in the state of the art.

This dynamic raises questions about the principle of national sovereignty and governance over biological resources, a pillar of the Convention on Biological Diversity (CBD) (UNEP, 1992) and imposes the need for national governments, especially in the Global South, to play a central role in regulating national voluntary markets to ensure control over the flow of financing in natural credit markets, requiring consideration of both the role of national schemes and the role of foreign organizations. This regulation needs to ensure an integrated policy so that VBCs schemes interventions align with National Biodiversity Strategies and Action Plans, ensure transparency in transactions and establish fair mechanisms for sharing benefits with Indigenous Peoples and local communities and the government itself, thus fostering market credibility and revenue could strengthen national legislation and improve environmental compensation mechanisms for biodiversity (offset).

Aligned with this, our biodiversity significance analysis indicates that well-designed and correctly applied criteria and indicators of biodiversity significance can effectively channel financing towards the conservation of areas of great ecological value, primarily maximizing the ecological outcome. This capacity is crucial to support national governments in ensuring that VBC schemes and their proposed interventions are aligned with national biodiversity strategies.

Regarding the analysis of the interventions attributed to the organizations/schemes, a preference for restoration and regeneration projects was observed, specifically the enhancement of degraded areas, whose scale and complexity are directly influenced by the payment model adopted and, mainly, by the spatial scale and territorial location. The research shows that outcome/performance-based and/or combined payment approach target combined ecological outcomes and occurs predominantly in schemes that develop their interventions at higher territorial scales and exhibit fewer geographical restrictions on the implementation of the proposed interventions, while action/effort-based approaches tend to focus on individual outcomes at lowers spatial scales with geographic restriction. The alignment between territorial location and market preference is reflected in a functional divide in the execution of these interventions, where large-scale projects occur more frequently in the Global South and sustainable management initiatives in the Global North.

Notably, the diversity and lack of detail in the set of proposed interventions and monitoring requirements and technologies by organizations also function as an indicator of methodological range and robustness. However, this heterogeneity of approaches poses significant operational challenges, especially in demonstrating additionality. Our results show that there is a lack of transparency and availability of data in the evaluation and dissemination of the established period of permanence to guarantee the effectiveness of interventions in generating the proposed outcomes, as well as in the period of establishment of the initial conditional assessment. These two temporal aspects are available in only half of the organizations, the 20–30-year range interval and the baseline assessment established at the project initiation are the most commonly used periods.

The typological analysis allowed the grouping of organizations by schematic similarities but also contributed to synthesizing the qualitative analysis. Thus, the typology resulted in the understanding that schematic robustness and the structure to ensure additionality and long-term ecological benefits are associated with an assessment in multiple ecological domains, as well as the generation of multiple types of results with combined payment approaches, considering impacts outside the project area and not considering double counting with other natural credits,

long-term monitoring permanence program and consideration of a retroactivity period from the start of the project in the initial evaluation. Crucially, the results suggest a central challenge for the maturation of the VBC market, the need to merge the scalability and governance of robust theoretical frameworks with the tangible effectiveness of direct, on-the-ground conservation actions.

The analysis focused primarily on technical and ecological aspects, necessitating future investigations into social aspects such as the participation of IPLCs, social safeguards, benefit-sharing mechanisms, stakeholder engagement processes, and detailed economic analyses, such the market dynamics, credit pricing, alignment with non-market values. These areas represent important avenues for future research. Exploring the practical implementation challenges and the effectiveness of different interventions, metrics, and MRV technologies employed by each scheme would also be valuable. Additionally, investigating the governance structures, certification processes and their auditing processes could provide further insights.

Fundamentally, the current scenario of the market and actors of Voluntary Biodiversity Credits face uncertainty, which requires them to rethink their structures to ensure an effective future progress. While they have the potential to channel private capital into conservation, their real contribution will depend on a commitment to transparency, scientific rigor, and inclusion of socio-environmental governance principles. Without this, they risk becoming yet another financial tool that, under a facet of sustainability, fails to address effective positive outcomes that actually contribute to all fronts of biodiversity conservation.

REFERENCES

Abdelaal, M., Zoss, A., Szafir, D. A., & Keefe, D. F. (2020). Time-aligned edge plots for dynamic graph visualization. In 2020 24th International Conference Information Visualisation (IV) (pp. 248-257). IEEE. New York, NY, USA: 10 pages.

Addison, P. F., Bull, J. W., & Milner-Gulland, E. J. (2019). Using conservation science to advance corporate biodiversity accountability. Conservation Biology, 33(2), 307-318.

Alkemade, R., van Oorschot, M., Miles, L., Nellemann, C., Bakkenes, M., & ten Brink, B. (2009). GLOBIO3: A framework to investigate options for reducing global terrestrial biodiversity loss. Ecosystems, 12(3), 374-390.

Allen, M.C., Lockwood, J.L., Ibanez, R. et al. eDNA offers opportunities for improved biodiversity monitoring within forest carbon markets. Commun Earth Environ 5, 801 (2024).

Allen, M., Gweon, H. S., Hotham, P., MacGillivray, M., & Durance, I. (2024). eDNA offers opportunities for improved biodiversity monitoring within forest carbon markets. Communications Earth & Environment, 5, Article 801.

Andeltová, L., Juutinen, A., & Mäntymaa, E. (2015). Action-based versus outcome-based payments for environmental services - An experimental auction for tree planting contracts in Kenya. (BioEcon-NetWork Working Paper Series 16). Department of Economics and Policy in Agriculture and Forestry, Humboldt-Universität zu Berlin. Berlin, Germany: 26 pages.

Andres, K., Stepien, C. A., & Tiffan, D. (2023). Environmental DNA reveals the genetic diversity and population structure of an invasive species in the Laurentian Great Lakes. Proceedings of the National Academy of Sciences of the United States of America, 120(37), e2307345120.

Armsworth, P. R., & Banerjee, S. (2012). How should we incentivize private landowners to "produce" more biodiversity? Oxford Review of Economic Policy, 28(1), 155-172.

Arponen, A. (2012). Prioritizing species for conservation planning. Biodiversity and Conservation, 21(4), 875-893.

Azevedo, J. C., Moreira, F., & Castro, J. P. (2014). Forest landscape ecology and global change: An introduction. In J. C. Azevedo, A. F. T. Pinto, & J. M. C. Pereira (Eds.), Forest landscapes and global change: Challenges for research and management (pp. 1-27). Springer, New York, NY, USA.

Bakker, K. (2005). Neoliberalizing nature? Market environmentalism in water supply in England and Wales. Annals of the Association of American Geographers, 95(3), 542–565.

Basile, M., Aszalós, R., & Oberegelsbacher, S. (2021). Abundance, species richness and diversity of forest bird assemblages – The relative importance of habitat structures and landscape context. Ecological Indicators, 133, 108402.

Baynham-Herd, Z., Brooks, T. M., van der Meer, L. J. C., Mace, G. M., & Redman, C. H. (2018). Governance explains variation in national responses to the biodiversity crisis. Environmental Conservation, 45(4), 407-418.

Bellwood, D. R., Streit, R. P., Brandl, S. J., & Tebbett, S. B. (2019). The meaning of the term 'function' in ecology: A coral reef perspective. Functional Ecology, 33(6), 948-961.

Beyerlin, U. (2006). Bridging the North-South divide in international environmental law. Zeitschrift für ausländisches öffentliches Recht und Völkerrecht, 66(2), 259-296.

Bezombes, L., Dangles, O., Teyssèdre, A., & Bas, Y. (2019). Do biodiversity offsets achieve no net loss? An evaluation of offsets in a French department. Biological Conservation, 237, 24-29.

Biodiversity Credit Alliance. (2023a). Communities and nature markets: Building just partnerships in biodiversity credits. World Economic Forum. Geneva, Switzerland: 18 pages.

Biodiversity Credit Alliance. (2023b). Demand-side sources and motivation for biodiversity credits (Issue Paper No. 1). World Economic Forum. Geneva, Switzerland: 15 pages.

Biodiversity Credit Alliance. (2024a). Review mechanisms for supply-side quality and integrity in the biodiversity credit market (Issue Paper No. 2). World Economic Forum. Geneva, Switzerland: 20 pages.

Biodiversity Credit Alliance. (2024b). Definition of a biodiversity credit (Issue Paper No. 3). World Economic Forum. Geneva, Switzerland: 14 pages.

Biodiversity Credit Alliance. (2024c). High-level principles to guide the biodiversity credit market. World Economic Forum. Geneva, Switzerland: 14 pages.

Borrini-Feyerabend, G., N. Dudley, T. Jaeger, B. Lassen, N. Pathak Broome, A. Phillips e T. Sandwith (2017). Governança de Áreas Protegidas: da compreensão à ação. Série Diretrizes para melhores Práticas para Áreas Protegidas. IUCN, No. 20, Gland, Switzerland: 124 pages.

Boucher, M. A., & Davies, A. B. (2023). Predicting bird diversity with lidar-derived vegetation structure [Preprint]. EcoEvoRxiv.

Boulton, C. A., Lenton, T. M., & Nobre, C. A. (2022). Pronounced loss of Amazon rainforest resilience since the early 2000s. Nature Climate Change, 12(3), 271-278.

Bowgen, K. M., Peace, K. A., O'Brien, D., & McClean, C. J. (2022). Conservation interventions can benefit species impacted by climate change. Biological Conservation, 269, 109524.

Brancalion, P. H., Niamir, A., Broadbent, E., Crouzeilles, R., Barros, F. S. M., Almeyda Zambrano, A. M., Baccini, A., Aronson, J., Goetz, Scott., Reid, J. H., Strassburg, B. B. N., Wilson, S & Chazdon, R. L. (2019). Global restoration opportunities in tropical rainforest landscapes. Science Advances, 5(7), eaav3223.

Brancalion, P. H., & Holl, K. D. (2024). Upscaling ecological restoration by integrating with agriculture. Frontiers in Ecology and the Environment, 23(1), e2812.

Brancalion, P., Hua, F., Joyce, F., Antonelli, A., Holl, K. (2025). Moving biodiversity from an afterthought to a key outcome of forest restoration. Nature Reviews Biodiversity, 1, 248-261.

Brics Policy Center. (2018). Radar Socioambiental: Reunião do C20 - Ação conjunta para enfrentar os desafios globais. Rio de Janeiro, Brazil: 11 pages

Briscoe, S. (2023). Feasibility and desirability of screening search results from Google Search exhaustively for systematic reviews: A cross-case analysis. Research Synthesis Methods, 14(3), 427-437.

Brunetti, I., Salgado, R., & Souto, T. (2023). A spatial model for biodiversity offsetting. Ecological Modelling, 481, 110364.

Buchadas, A., Verburg, P. H., Gil, A., & Leitão, P. J. (2023). Tropical dry woodland loss occurs disproportionately in areas of highest conservation value. Global Change Biology, 29(17), 4880-4897.

Bulé, M., & Sørensen, H. (2024). Medoid splits for efficient random forests in metric spaces. Computational Statistics & Data Analysis, 198, 107995.

Bull, J. W., Gordon, A., Law, E. A., Suttle, K. B., & Milner-Gulland, E. J. (2016). Seeking convergence on the key concepts in 'no net loss' policy. Journal of Applied Ecology, 53(6), 1686-1693.

Bull, J. W., Worcester, E., Tytel, M., St-Laurent, G. P., Palmer Fry, B., & Strange, N. (2022). Analysis: The biodiversity footprint of the University of Oxford. Nature, 604(7906), 420-424.

Burgess, N. D., Ali, N., Bedford, J., Bhola, N., Brooks, S., Cierna, A., Correa, R., Harris, M., Hargey, A., Hughes, J., McDermott-Long, O., Miles, L., Ravilious, C., Rodrigues, A. R., van Soesbergen, A., Sihvonen, H., Seager, A., Swindell, L., Vukelic, M., Durán, A. P., Green, J. M. H., West, C., Weatherdon, L. V., Hawkins, F., Brooks, T. M., Kingston, N., & Butchart, S. H. M. (2024). Global metrics for terrestrial biodiversity. Annual Review of Environment and Resources, 49.

Business and Biodiversity Offset Programme. (2009). Biodiversity offset design handbook. Forest Trends. Washington, DC, USA: 102 pages.

Butchart, S. H., et al. (2010). Global biodiversity: Indicators of recent declines. Science, 328(5982), 1164-1168.

Calvet, C., Le Tixier, M., & Napoléone, C. (2015). The biodiversity offsetting dilemma: Between economic rationales and ecological dynamics. Sustainability, 7(6), 7357-7378.

Capellesso, E. S., Ganade, G., Melo, F. P., & Peres, C. A. (2022). Habitat amount is a driver for biodiversity, but not for the carbon stock in post-logging natural regenerating areas in Tropical Atlantic Forest. Biological Conservation, 273, 109673.

Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., Narwani, A., Mace, G. M., Tilman, D., Wardle, D. A., Kinzig, A. P., Daily, G. C., Loreau, M., Grace, J. B., Larigauderie, A., Srivastava, D. S., & Naeem, S. (2012). Biodiversity loss and its impact on humanity. Nature, 486(7401), 59-67.

Castro-Pardo, M., del Campo, A., & Calvo, J. F. (2022). A new composite indicator to assess and monitor performance and drawbacks of the implementation of Aichi Biodiversity Targets. Ecological Economics, 201, 107567.

Cazalis, V., Princé, K., Mihoub, J. B., Kelly, J., Kpéra, G. N., & Gauthier-Clerc, M. (2020). Effectiveness of protected areas in conserving tropical forest birds. Nature Communications, 11(1), 4461.

Chase, J. M., McGill, B. J., Thompson, P. L., Adamowicz, L., Jenkins, R. M., & Weitz, S. (2020). Ecosystem decay exacerbates biodiversity loss with habitat loss. Nature, 584(7820), 238-243.

Chen, C., Chen, T., Jin, L. (2024). Companies' preferences and willingness to pay for ecosystem services credits through an online-marketplace. Ecosystem Services, 69, 101662.

Chen, S., Böhme, S., & Wüstemann, H. (2021). Voluntary carbon offsets: An empirical market study. SSRN, 22.

Climate Policy Initiative. (2012). The landscape of climate finance 2012. CPI. San Francisco, CA, USA: 40 pages.

Convention on Biological Diversity. (2000). Cartagena Protocol on Biosafety to the Convention on Biological Diversity: Text and annexes. Secretariat of the Convention on Biological Diversity. Montreal, Canada: 29 pages.

Convention on Biological Diversity. (2011). Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity: Text and annexes. Secretariat of the Convention on Biological Diversity. Montreal, Canada: 37 pages.

Convention on Biological Diversity. (2020). Global Biodiversity Outlook 5. Secretariat of the Convention on Biological Diversity. Montreal, Canada: 208 pages.

Convention on Biological Diversity. (2021a). Proposed headline indicators of the monitoring framework for the Post-2020 Global Biodiversity Framework. Secretariat of the Convention on Biological Diversity. Montreal, Canada: 23 pages.

Convention on Biological Diversity. (2021b). Estimation of resources needed for implementing the Post-2020 Global Biodiversity Framework. Secretariat of the Convention on Biological Diversity. Montreal, Canada: 20 pages.

Convention on Biological Diversity. (2022). Nations adopt four goals, 23 targets for 2030 in landmark UN biodiversity agreement. Secretariat of the Convention on Biological Diversity. Montreal, Canada.

Convention on International Trade in Endangered Species of Wild Fauna and Flora. (2023). Appendices I, II and III. CITES Secretariat. Genebra, Switzerland: 65 pages.

Curkovic, M. (2019). Need for controlling of the filter bubble effect. Science and Engineering Ethics, 25, 323–324.

Dallimer, M., Martin, T. M., & Bullock, J. M. (2020). Taking stock of the empirical evidence on the insurance value of ecosystems. Ecological Economics, 167, 106451

Damiani, M., Fantke, P., Verones, F., & Laurent, A. (2023). Critical review of methods and models for biodiversity impact assessment and their applicability in the LCA context. Environmental Impact Assessment Review, 101, 107134.

Damiens, L., Maron, M., & Bull, J. W. (2021). Governing for “no net loss” of biodiversity over the long term: Challenges and pathways forward. One Earth, 4(1), 60-74.

Dauguet, B. (2015). Biodiversity offsetting as a commodification process: A French case study as a concrete example. Biological Conservation, 192, 533-540.

D’Alberto, R., Zemo, K. H., Musshoff, O., & Zander, K. (2024). A European perspective on acceptability of innovative agri-environment-climate contract solutions. Land Use Policy, 141, 107120.

Dehling, D. M., Barreto, E., & Graham, C. H. (2022). The contribution of mutualistic interactions to functional and phylogenetic diversity. Trends in Ecology & Evolution, 37(9), 768-776.

Dennis, M., Huck. J. J., Holt. C. D., Bispo. P. da Conceição. , McHenry. E., Speak. A., & P. James, p. (2024). Land-cover gradients determine alternate drivers of mammalian species richness in fragmented landscapes. Landscape Ecology, 39, 146.

Di Bitetti, M. S., & Ferreras, J. A. (2017). The effect on citation rate of using languages other than English in scientific publications. Ambio, 46(1), 121-127.

Dias, A. P., Guerra, C. A., Carvalheiro, L. G., & Pereira, H. M. (2023). Using essential biodiversity variables to assess forest ecosystem integrity. Frontiers in Forests and Global Change, 6, 1113081.

Di Sacco, A., Hardwick, K. A., Blakesley, D., Brancalion, P. H. S., Breman, E., Ceccon, E., ... & Smith, P. (2021). Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. Global Change Biology, 27(7), 1328-1348.

Doswald, N., Couto, T., & Baker, J. (2012). Biodiversity offsets voluntary and compliance regimes: A review of existing schemes, initiatives and guidance for financial institutions. UNEP-WCMC, Cambridge, UK. UNEP FI, Geneva, Switzerland: 24 pages.

Ducros, A., & Steele, P. (2022). Biocredits to finance nature and people: Emerging lessons. International Institute for Environment and Development, London, UK: 25 pages.

Dudley, N., Parish, J., & Stolton, S. (2010). The revised IUCN protected area management categories: The debate and ways forward. Biodiversity, 11(3-4), 5-7.

Dudley, N., & Stolton, S. (2014). Applications of Key Biodiversity Areas: End-user consultations. IUCN, Cambridge, UK and Gland, Switzerland: 107 pages.

Eftec, IEEP, Ecologic, & GHK. (2010). The use of market-based instruments for biodiversity protection – The case of habitat banking. European Commission. London, UK: 269 pages.

Elmiger, B., Luka, H., Pfister, S. C., Jacot, K., & Herzog, F. (2023). Biodiversity indicators for result-based agri-environmental schemes – Current state and future prospects. Agricultural Systems, 204, 103538.

Estes, L. D., ARC Centre of Excellence for Environmental Decisions, Baek, J., Blevins, C., Brand, A. C., Braun, D. W., ... & Zilli, M. (2018). The spatial and temporal domains of modern ecology. Nature Ecology & Evolution, 2(5), 819-826.

European Parliament & Council of the European Union. (2022). Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting. Official Journal of the European Union, L 322/15, 15-80. Luxembourg: 66 pages.

Fankhauser, S., Smith, S. M., Allen, M., Axelsson, K., Hale, T., Hepburn, C., ... & Wetzer, T. (2022). The meaning of net zero and how to get it right. Nature Climate Change, 12(1), 15-21.

Félix, M. (2022). Financer la nature et la biodiversité. Banque européenne d'investissement. Luxembourg: 104 pages.

Finance for Biodiversity Initiative. (2020). Aligning global finance with nature needs: A framework for systemic change. Finance for Biodiversity Initiative. Washington, DC, USA: 102 pages.

Fletcher, R., Büscher, B., & Kolinjivadi, V. (2016). Questioning REDD+ and the future of market-based conservation. Conservation Biology, 30(3), 663-673.

Fletcher, R. (2020). Neoliberal conservation. In Oxford Research Encyclopedia of Anthropology. Oxford University Press. Oxford, Uk.

Food and Agriculture Organization of the United Nations. (2020a). Emissions due to agriculture: Global, regional and country trends 2000–2018 (FAOSTAT Analytical Brief Series, No. 18). FAO Press. Rome, Italy: 16 pages.

Food and Agriculture Organization of the United Nations. (2020b). Global Forest Resources Assessment 2020: Key findings. FAO Press. Rome, Italy: 16 pages.

Ford, H., Healy, J. R., Mac Aodha, O., & Jones, K. E. (2024). A technological biodiversity monitoring toolkit for biocredits. Journal of Applied Ecology, 61(9), 2007-2019. https://doi.org/10.1111/1365-2664.14695

Forest Europe. (2020). State of Europe's forests 2020. Ministerial Conference on the Protection of Forests in Europe, Liaison Unit Bratislava. Ministerial Conference on the Protection of Forests in Europe - FOREST EUROPE. Bratislava, Slovakia: 392 pages.

Fortini, L. B., & Schubert, O. E. (207). Beyond exposure, sensitivity and adaptive capacity: A response-based ecological framework to assess species climate change vulnerability. Climate Change Responses, 4, Article 2.

Fortunato, S., & Newman, M. E. J. (2022). 20 years of network community detection. Nature Physics, 18(8), 848-850.

Fournier, B., Burel, F., & Baudry, J. (2017). Contrasting processes drive alpha and beta taxonomic, functional and phylogenetic diversity of orthopteran communities in grasslands. Agriculture, Ecosystems & Environment, 242, 43-52.

Fox, J., S. N. S., & Kanter, D. (2011). Stacking opportunities and risks in environmental credit markets. Environmental Law Reporter, 41, 10530.

Franke, T. M., Ho, T., & Christie, C. A. (2012). The Chi-Square Test: Often used and more often misinterpreted. American Journal of Evaluation, 33(3), 448-458.

Gantioler, S., Rayment, M., & GHK. (2010). Costs and socio-economic benefits associated with the Natura 2000 Network (Final report, Contract No. ENV.B.2/SER/2008/0038). Institute for European Environmental Policy. London, UK: 181 pages.

Gardner, T. A., Brownlie, S., Bull, J. W., & Anstee, S. (2013). Biodiversity offsets and the challenge of achieving no net loss. Conservation Biology, 27(6), 1254-1264.

Garibaldi, L. A., Naylor, R. L., Andersen, H. M., August, P. V., Barral, M. P., Bascompte, J., ... & Daily, G. C. (2021). Working landscapes need at least 20% native habitat. Conservation Letters, 14(2), e12773.

Gibbons, J. M., Zammit, C., Young, J., & Brook, B. W. (2011). Should payments for biodiversity conservation be based on action or results? Journal of Applied Ecology, 48(5), 1218-1226.

Gil, A. C. (2017). Como elaborar projetos de pesquisa (6th ed.). Rio de Janeiro, Brazil: 128 pages.

Gino, H. A. R., Felippe, R. M., & Moro, M. M. (2023). Exploratory analysis on market basket data using network visualization. In Proceedings of the 12th Brazilian Workshop on Social Network Analysis and Mining (pp. 19-30). Sociedade Brasileira de Computação. Porto Alegre, Brazil: 12 pages.

Global Inventory of Biodiversity Offset Policies. (2019). World view: A snapshot of national biodiversity offset policies. IUCN. Gland, Switzerland.

Gómez-Baggethun, E., & Ruiz-Pérez, M. (2011). Economic valuation and the commodification of ecosystem services. Progress in Physical Geography: Earth and Environment, 35(5), 613-628.

Gonzalez, A., Germain, R. M., Srivastava, D. S., Filotas, E., Dee, L. E., Gravel, D., ... & Isbell, F. (2020). Scaling-up biodiversity-ecosystem functioning research. Ecology Letters, 23(5), 757-771.

González-Ávila, S., García-Llamas, P., Suárez-Seoane, S., & Taboada, A. (2024). Relationships between amount and configuration indicators in real-world landscapes: Novel references for the assessment of forest cover in the Iberian Peninsula. Ecological Indicators, 159, 111634.

Gower, J. C. (1985). Properties of Euclidean and non-Euclidean distance matrices. Linear Algebra and its Applications, 67, 81-97.

Gann, G. D., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., ... & Dixon, K. W. (2019). International principles and standards for the practice of ecological restoration. Restoration Ecology, 27(S1), S1-S46.

Group on Earth Observations Biodiversity Observation Network Secretariat. (2015). Global biodiversity change indicators (Version 1.2). GEO BON Secretariat. Leipzig, Germany: 29 pages.

Guijarro, F., & Tsinaslanidis, P. (2020). Analysis of academic literature on environmental valuation. International Journal of Environmental Research and Public Health, 17(24), 9170.

Hahn, T., McDermott, C. L., Ituarte-Lima, C., & Schultz, M. (2015). Purposes and degrees of commodification: Economic instruments for biodiversity and ecosystem services need not rely on markets or monetary valuation. Ecosystem Services, 16, 74–82.

Hahn, T., Koh, N, S., & Elmqvist, T. (2022). No net loss of biodiversity, green growth, and the need to address drivers. One Earth, 5(6), 612-614.

Haines-Young, R., & Potschin, M. B. (2018). Common International Classification of Ecosystem Services (CICES) V5.1: Guidance on the application of the revised structure. Fabis Consulting Ltd. Nottingham, UK: 53 pages.

Han, M., & Zhu, B. (2020). Changes in soil greenhouse gas fluxes by land use change from primary forest. Global Change Biology, 26(5), 2656-2667.

Han, Q., Wang, Y., Zhang, Y., & Li, X. (2023). Identifying the relationships between landscape pattern and ecosystem services value from a spatial-temporal variation perspective in a mountain-hill-plain region. Forests, 14(12), 2446.

Hansen, A. J., Noble, B. P., Veneros, J., East, A., Goetz, S. J., Supples, C., M. Watson, J. E., Jantz, P. A., Pillay, R., Jetz, W., Ferrier, S., Grantham, H. S., Evans, T. D., Ervin, J., Venter, O., & S. Virnig, A. L. (2021). Toward monitoring forest ecosystem integrity within the post-2020 Global Biodiversity Framework. Conservation Letters, 14(4), e12822.

Hill, S. L., Arnell, A., Maney, C., Butchart, S. H., Ciciarelli, C., Davis, C., Dinerstein, E., Purvis, A., & Burgess, N. D. (2019). Measuring Forest Biodiversity Status and Changes Globally. Frontiers in Forests and Global Change, 2, 464096.

Hoban, S., Campbell, C. D., Da Silva, J. M., Ekblom, R., Funk, W. C., Garner, B. A., Godoy, J. A., Kershaw, F., MacDonald, A. J., Mergeay, J., Minter, M., O'Brien, D., Vinas, I. P., Pearson, S. K., Pérez-Espona, S., Potter, K. M., Russo, I. M., Segelbacher, G., Vernesi, C., . . . Hunter, M. E. (2021). Genetic diversity is considered important but interpreted narrowly in country reports to the Convention on Biological Diversity: Current actions and indicators are insufficient. Biological Conservation, 261, 109233.

Hoban, S., Hvilsom, C., Aissi, A., Aleixo, A., Bélanger, J., Biala, K., Ekblom, R., Fedorca, A., Funk, W. C., Goncalves, A. L., Gonzalez, A., Heuertz, M., Hughes, A., Ishihama, F., Stroil, B. K., Laikre, L., McGowan, P. J. K., Millette, K. L., O'Brien, D., Paz-Vinas, I., … da Silva, J. M. (2024). How can biodiversity strategy and action plans incorporate genetic diversity and align with global commitments?. Bioscience, 75(1), 47–60.

Holderegger, R., Schmidt, B.R., Grünig, C. et al. Ready-to-use workflows for the implementation of genetic tools in conservation management. Conservation Genet Resour 12, 691–700 (2020).

Hrabanski, M. (2015). The biodiversity offsets as market-based instruments in global governance: Origins, success and controversies. Ecosystem Services, 15, 143-151.

Hughes, T. P., Kerry, J. T., Álvarez-Noriega, M., Álvarez-Romero, J. G., Anderson, K. D., Baird, A. H., ... & Bridge, T. C. L. (2017). Global warming and recurrent mass bleaching of corals. Nature, 543(7645), 373-377.

Intergovernmental Panel on Climate Change. (2018). Summary for Policymakers. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), Global warming of 1.5°C: An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Cambridge University Press. Cambridge, UK: 24 pages.

Intergovernmental Panel on Climate Change. (2022). Climate Change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, UK: 3056 pages.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services. In S. Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. A. Brauman, S. H. M. Butchart, K. M. A. Chan, L. A. Garibaldi, K. Ichii, J. Liu, S. M. Subramanian, G. F. Midgley, P. Miloslavich, Z. Molnár, D. Obura, A. Pfaff, S. Polasky, A. Purvis, J. Razzaque, B. Reyers, R. R. Chowdhury, Y. J. Shin, I. J. Visseren-Hamakers, K. J. Willis, & C. N. Zayas (Eds.), Global assessment report on biodiversity and ecosystem services. IPBES Secretariat Press. Bonn, Germany: 56 pages.

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services & Intergovernmental Panel on Climate Change. (2021). Co-sponsored workshop report on biodiversity and climate change (Version 2). IPBES Secretariat Press. Bonn, Germany: 250 pages.

International Energy Agency. (2021). Net zero by 2050: A roadmap for the global energy sector. IEA Press. Paris, France: 224 pages.

International Union for Conservation of Nature. (2015). Net positive impact on biodiversity: The conservation case. IUCN Press. Gland, Switzerland: 15 pages.

International Union for Conservation of Nature. (2016a). A global standard for the identification of Key Biodiversity Areas, Version 1.0. First Edition. IUCN. Gland, Switzerland: 32 pages.

International Union for Conservation of Nature. (2016b). Conservation actions needed classification scheme , Version 2.0. IUCN Press. Gland, Switzerland: 32 pages.

International Union for Conservation of Nature. (2018). Invasive alien species and sustainable development. IUCN. Gland, Switzerland: 24 pages.

International Union for Conservation of Nature. (2022). Species richness and rarity-weighted richness data. IUCN Press. Gland, Switzerland. https://www.iucnredlist.org/resources/spatial-data-download

International Union for Conservation of Nature. (2024). Renewable energy and implications for protected and conserved areas downgrading, downsizing, degazettement, and delisting: Guidance to address climate change and biodiversity loss synergistically (Technical Note). IUCN Press. Gland, Switzerland: 20 pages.

International Union for Conservation of Nature, WWF-Brasil, & IPÊ. (2011). Metas de Aichi: Situação atual no Brasil. Brasília (IUCN e WWF) e Nazaré Paulista (IPÊ), Brazil: 68 pages.

Jacobson, A. P., Riggio, J., Tait, A. M., & Baillie, J. E. M. (2019). Global areas of low human impact ('Low Impact Areas') and fragmentation of the natural world. Scientific Reports, 9, 15336.

Jaureguiberry, P., Titeux, N., Wiemers, M., Bowler, D. E., Cos, M., Baert, J. M., ... & Díaz, S. (2022). The direct drivers of recent global anthropogenic biodiversity loss. Science Advances, 8(45), eabm2982.

Jin, X., & Han, J. (2011). K-Medoids. In C. Sammut & G. I. Webb (Eds.), Encyclopedia of machine learning. Springer. Boston, MA, USA: 2 pages.

Johnson, M. G., Pokorny, L., Dodsworth, S., Botigué, L. R., Cowan, R. S., Devault, A., ... & Forest, F. (2019). A universal probe set for targeted sequencing of 353 nuclear genes from any flowering plant designed using k-medoids clustering. Systematic Biology, 68(4), 594-606.

Karpiński, J. (1980). Methodological schemes. The Polish Sociological Bulletin, (50), 35-44.

Kashwan, P. (2017). Inequality, democracy, and the environment: A cross-national analysis. Ecological Economics, 131, 139-151.

Kasso, M., & Balakrishnan, M. (2013). Ex situ conservation of biodiversity with particular emphasis to Ethiopia. ISRN Biodiversity, 2013, Article 985037.

Katic, P., Kennedy, E., & Addison, P. F. (2023). Mainstreaming biodiversity in business decisions: Taking stock of tools and gaps. Biological Conservation, 277, 109831.

Keck, F., Peller, T., Alther, R. et al. The global human impact on biodiversity. Nature 641, 395–400 (2025).

Keith, D. A., et al. (2013). Scientific foundations for an IUCN Red List of Ecosystems. PLoS ONE, 8(5), e62111.

Keith, D. A., Elith, J., & Faber-Langendoen, D. (2015). The IUCN Red List of Ecosystems: Motivations, challenges and applications. Conservation Letters, 8(3), 214–226.

Keith, D.A., Ferrer-Paris, J.R., Nicholson, E. and Kingsford, R.T. (eds.) (2020). The IUCN Global Ecosystem Typology 2.0: Descriptive profiles for biomes and ecosystem functional groups. IUCN, Gland, Switzerland: 192 pages.

Keith, D. A., Ferrer-Paris, J. R., Nicholson, E., Bishop, M. J., Polidoro, B. A., Ramirez-Llodra, E., Tozer, M. G., Nel, J. L., Mac Nally, R., Gregr, E. J., Watermeyer, K. E., Essl, F., Faber-

Langendoen, D., Franklin, J., Lehmann, C. E. R., Etter, A., Roux, D. J., Stark, J. S., Rowland, J. A., Brummitt, N. A., … Kingsford, R. T. (2022). A function-based typology for Earth's ecosystems. Nature, 610(7932), 513–518.

Kettunen, M., Illes, A., Rayment, M., Primmer, E., Verstraeten, Y., Rekola, A., Ring, I., Tucker, G., Baldock, D., Droste, N., Santos, R., Rantala, S., Ebrahim, N. and ten Brink, P. (2017) Summary report - Integration approach to EU biodiversity financing: evaluation of results and analysis of options for the future. Final report for the European Commission (DG ENV) (Project ENV.B.3/ETU/2015/0014), Institute for European Policy (IEEP), Brussels, Belgium /London, UK: 105 pages.

Kettunen, M., ten Brink, P., Newman, S., & Mutafoglu, K. (2014). Financing Natura 2000 guidance handbook: Part I – EU funding opportunities in 2014-2020. Institute for European Environmental Policy. Luxembourg: 88 pages.

Kujala, H., Maron, M., Jantke, K., Bull, J. W., Wintle, B. A., Gordon, A., ... & Evans, M. C. (2022). Credible biodiversity offsetting needs public national registers to confirm no net loss. One Earth, 5(6), 650-662.

Kuramochi, T., Nascimento, L., Moisio, M., den Elzen, M., Forsell, N., van Soest, H., ... & Höhne, N. (2023). Greenhouse gas emission scenarios in nationally determined contributions. Nature Climate Change, 13(5), 443-449.

Lammerant, J., Houdet, J., & EU Business @ Biodiversity Platform. (2021). Assessment of biodiversity measurement approaches for businesses and financial institutions (Update Report 3). European Commission, Brussels, Belgium: 261 pages.

Leclère, D., Obersteiner, M., Barrett, M., Butchart, S. H. M., Chaudhary, A., De Palma, A., ... & Young, L. (2020). Bending the curve of terrestrial biodiversity needs an integrated strategy. Nature, 585(7826), 551-556.

Lehtonen, E., Pouta, E., Rämö, A. K., & Rekola, M. (2021). What does FSC forest certification contribute to biodiversity conservation in relation to national legislation? Journal of Environmental Management, 299, 113606.

Levin, S. A. (Ed.). (2013). Encyclopedia of biodiversity (2nd ed., Vols. 1-7). Elsevier. Waltham, MA, USA: 5498 pages.

Li, S., Xiao, W., Zhao, Y., & Lv, X. (2021). Integrating ecosystem services modeling into effectiveness assessment of national protected areas in a typical arid region in China. Journal of Environmental Management, 297, 113408.

Lindenmayer, D. B., & Likens, G. E. (2010). The science and application of ecological monitoring. Biological Conservation, 143(6), 1317-1328.

Liu, Y., Zhao, M., Liu, Z., Zhang, J., & Li, Z. (2023). Integrative analysis of biodiversity, ecosystem services, and ecological vulnerability can facilitate improved spatial representation of nature reserves. Science of The Total Environment, 879, 163096.

Loreau, M., & de Mazancourt, C. (2013). Biodiversity and ecosystem stability: A synthesis of underlying mechanisms. Ecology Letters, 16(S1), 106–115.

Lovejoy, T. E., & Nobre, C. (2018). Amazon tipping point. Science Advances, 4(2), eaat2340.

Mair, L., Bennun, L. A., Brooks, T. M., Butchart, S. H. M., Bolam, F. C., Burgess, N. D., ... & Rodrigues, A. S. L. (2021). A metric for spatially explicit contributions to science-based species targets. Nature Ecology & Evolution, 5(6), 836-844.

Maiorano, L., Falcucci, A., Garton, E. O., & Boitani, L. (2007). Contribution of the Natura 2000 network to biodiversity conservation in Italy. Conservation Biology, 21(6), 1433-1444.

Maher, C., Byrne, D., Astrain, C., Beaufoy, G., Berastegi, A., Bleasdale, A., Copland, A., Dunford, B., Edge, R., Iragui, U., Jones, G., Lopez, F., Mcloughlin, D., Moran, J., & O'Donoghue, B. (2018). What are results-based payments for biodiversity and when and where should they be used?. 10.13140/RG.2.2.12561.48487.

Mamo, A. (2023). Biodiversity organization, threats and conservation methods. Global Science Research Journals, 2(1), 1-12.

Manez, K. S., & Clifton, J. (2024). Biodiversity credits: A new currency to support nature conservation? Oryx, 58(3), 263-264.

Marco-Fondevila, M., & Álvarez-Etxeberría, I. (2023). Trends in private sector engagement with biodiversity: EU listed companies' disclosure and indicators. Ecological Economics, 210, 107864.

Marco-Fondevila, M., Lizarralde, I., & Rasanen, K. (2018). CSR and green economy: Determinants and correlations of firms' sustainable development. Corporate Social Responsibility and Environmental Management, 25(5), 817-832.

Marconi, M. de A., & Lakatos, E. M. (2022). Fundamentos de metodologia científica (9th ed.). Atlas. Rio de Janeiro, Brazil: 312 pages.

Marino, D., & Pellegrino, D. (2018). Can payments for ecosystem services improve the management of Natura 2000 sites? A contribution to explore their role in Italy. Sustainability, 10(3), 665.

Maseyk, F. J. F., Maron, M., Gordon, A., Bull, J. W., & Evans, M. C. (2020). Improving averted loss estimates for better biodiversity outcomes from offset exchanges. Environmental Conservation, 47(3), 193-201.

Maxwell, S. L., Fuller, R. A., Brooks, T. M., & Watson, J. E. M. (2016). Biodiversity: The ravages of guns, nets and bulldozers. Nature, 536(7615), 143-145.

McCarthy, J., & Prudham, S. (2004). Neoliberal nature and the nature of neoliberalism. Geoforum, 35(3), 275-283.

McClanahan, T. R., & Rankin, P. S. (2016). Geography of conservation spending, biodiversity, and culture. Conservation Biology, 30(5), 1089–1101.

McGowan, J. K., Traylor-Holzer, K., & Leus, K. (2017). IUCN Guidelines for Determining When and How Ex Situ Management Should Be Used in Species Conservation. Conservation Letters, 10(3), 361-366.

McHugh, M. L. (2013). The Chi-square test of independence. Biochemia Medica, 23(2), 143-149.

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., ... & Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Systematic Reviews, 4(1), 1.

Moreno-Mateos, D., Meli, P., Vara-Rodríguez, M. I., & Aronson, J. (2015). The true loss caused by biodiversity offsets. Biological Conservation, 192, 552–559.

Mothapo, N. V., Chen, H., & Shi, W. (2015). Phylogenetic, taxonomic and functional diversity of fungal denitrifiers and associated N_2O production efficacy. Soil Biology and Biochemistry, 84, 160-175.

Mucina, L. (2019). Biome: Evolution of a crucial ecological and biogeographical concept. New Phytologist, 222(1), 97–114.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403(6772), 853–858.

National Academies of Sciences, Engineering, and Medicine. (2019). Evaluating the taxonomic status of the Mexican Gray Wolf and the Red Wolf. The National Academies Press, Washington, DC, USA: 104 pages.

Nature Finance. (2023a). Colocando os mercados de natureza para funcionar: Como moldar uma economia global da natureza no século 21. Taskforce on Nature Markets Secretariat. Geneva, Switzerland : 102 pages.

Nature Finance. (2023b). Rendre les marchés de la nature plus responsables: Façonner une nouvelle économie mondiale pour le 21e siècle. Taskforce on Nature Markets Secretariat. Geneva, Switzerland : 104 pages.

Nature Finance, & United Nations Environment Programme World Conservation Monitoring Centre. (2022). Climate nature nexus: An investor guide. Taskforce on Nature Markets Secretariat. Geneva, Switzerland: 28 pages.

Nature Finance, & Vivid Economics. (2022). Global nature markets landscaping study. Taskforce on Nature Markets Secretariat. Geneva, Switzerland: 48 pages.

Rachel A. Neugarten, Penny F. Langhammer, Elena Osipova, Kenneth J. Bagstad, Nirmal Bhagabati, Stuart H. M. Butchart, Nigel Dudley, Vittoria Elliott, Leah R. Gerber, Claudia Gutierrez Arrellano, Kasandra-Zoica Ivanić, Marianne Kettunen, Lisa Mandle, Jennifer C. Merriman, Mark Mulligan, Kelvin S.-H. Peh, Ciara Raudsepp-Hearne, Darius J. Semmens, Sue Stolton and Simon Willcock2018). Tools for measuring, modelling, and valuing ecosystem services: Guidance for Key Biodiversity Areas, natural World Heritage sites, and protected areas. IUCN. Gland, Switzerland: 70 pages.

Neuteleers, S., & Engelen, B. (2015). Talking money: How market-based valuation can undermine environmental protection. Ecological Economics, 117, 253-260.

Newbold, T., Oppenheimer, P., Etard, A., & Williams, J. J. (2020). Tropical and Mediterranean biodiversity is disproportionately sensitive to land-use and climate change. Nature Ecology & Evolution, 4(12), 1630-1638.

Newman, Z .E., Steele, P and Ducros, A (2023). Biocredit catalogue: A collection of biocredit developers and schemes. IIED. London, Uk: 19 pages.

Nicholson, E., Fulton, E. A., Brooks, T. M., Blanchard, R., Leadley, P., Metzger, J. P., Mokany, K., Stevenson, S., Wintle, B. A., Woolley, S. N. C., Barnes, M., Watson, J. E. M., & Ferrier, S. (2019). Scenarios and Models to Support Global Conservation Targets. Trends in ecology & evolution, 34(1), 57–68.

Nkurunziza, J., Tsowou, K., & Cazzaniga, S. (2017). Commodity Dependence and Human Development. African Development Review, 29, 27-41. 10.1111/1467-8268.12231.

Noss, R. F. (1990). Indicators for monitoring biodiversity: A hierarchical approach. Conservation Biology, 4(4), 355-364.

Nunes, B., Bennett, D. J., & Ryding, J. (2016). Modelling sustainability performance to achieve absolute reductions in socio-ecological systems. Journal of Cleaner Production, 132, 32-44.

Office Français de la Biodiversité. (2024). Rethinking the role of multilateral funds in the global biodiversity financial landscape. OFB. Vincennes, France: 60 pages.

Oliveira, L. de. (2016). Percepção do meio ambiente e geografia. OLAM: Ciência & Tecnologia, 16(2), 1-18.

Olenin, S., Daunys, D., & Zaiko, A. (2017). Biological invasions. In P. Snoeijs-Leijonmalm, H. Schubert, & T. Radziejewska (Eds.), Biological oceanography of the Baltic Sea. Springer. Dordrecht, Netherlands: 37 pages.

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., ... & Kassem, K. R. (2001). Terrestrial ecoregions of the world: A new map of life on Earth. BioScience, 51(11), 933-938.

Open Earth Foundation. (2022). Marine ecosystem credits. San Francisco: 18 pages.

Organisation for Economic Co-operation and Development. (2020). A comprehensive overview of global biodiversity finance (OECD Environment Policy Papers, No. 22). OECD Publishing. Paris, France: 104 pages.

Organisation for Economic Co-operation and Development. (2021). Biodiversity, natural capital and the economy: A policy guide for finance, economic and environment ministers (OECD Environment Policy Papers, No. 26). OECD Publishing. Paris, France: 88 pages.

Organisation for Economic Co-operation and Development. (2023). Assessing biodiversity-related financial risks: Navigating the landscape of existing approaches (OECD Environment Policy Papers, No. 36). OECD Publishing. Paris, France: 72 pages.

Park, C. (2012). A dictionary of environment and conservation. Oxford University Press. Oxford, UK: 544 pages.

Park, H.-S., & Jun, C.-H. (2009). A simple and fast algorithm for K-medoids clustering. Expert Systems with Applications, 36(2), 3336-3341.

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., ... & Yagi, N. (2017). Valuing nature's contributions to people: The IPBES approach. Current Opinion in Environmental Sustainability, 26-27, 7-16.

Pelicice, F. M., Azevedo-Santos, V. M., Vitule, J. R. S., Orsi, M. L., Lima-Junior, D. P., Magalhães, A. L. B., ... & Agostinho, A. A. (2021). Human impacts and the loss of Neotropical freshwater fish diversity. Neotropical Ichthyology, 19(1), e210134.

Pereira, H. M., Ferrier, S., Walters, M., Geller, G. N., Jongman, R. H. G., Scholes, R. J., ... & Costello, M. J. (2016). Monitoring essential biodiversity variables at the species level. In M. Walters & R. J. Scholes (Eds.), The GEO handbook on biodiversity observation networks (pp. 173-205). Springer. Cham, Switzerland: 33 pages.

Peterson, M. J., Hall, D. M., Feldpausch-Parker, A. M., & Peterson, T. R. (2010). Obscuring ecosystem function with application of the ecosystem services concept. Conservation Biology, 24(1), 113-119.

Piasecki, J., Waligora, M., & Dranseika, V. (2018). Google Search as an additional source in systematic reviews. Science and Engineering Ethics, 24, 809-810.

Pilotto, F., Kühn, I., Adrian, R., Alber, R., Alignier, A., Andrews, C., ... & Julliard, R. (2020). Meta-analysis of multidecadal biodiversity trends in Europe. Nature Communications, 11(1), 3486.

Pingali, P., Aiyar, A., Abraham, M., & Rahman, A. (2017). The bumpy road from food to nutrition security – Slow evolution of India's food policy. Global Food Security, 15, 77-84.

Pinto, L. P., & Voivodic, M. (2021). Reverse the tipping point of the Atlantic Forest for mitigation and adaptation. Nature Climate Change, 11(5), 371-372.

Pisani, D., Pazienza, P., Perrino, E. V., Caporale, D., & De Lucia, C. (2021). The Economic Valuation of Ecosystem Services of Biodiversity Components in Protected Areas: A Review for a Framework of Analysis for the Gargano National Park. Sustainability, 13(21), 11726.

Pollination. (2024). State of voluntary biodiversity credit markets: Current supply & demand dynamics. Pollination Foundation. Sydney, Australia: 44 pages.

Porras, I., & Steele, P. (2020). Making the market work for nature: How biocredits can protect biodiversity and reduce poverty (IIED Issue Paper). International Institute for Environment and Development. IIED. London, UK: 32 pages.

Raffard, A., et al. (2019). The community and ecosystem consequences of intraspecific diversity: A meta-analysis. Biological Reviews, 94(2), 648-661.

Ramsar Convention Secretariat. (2025). The list of wetlands of international importance. Retrieved July 23, 2025, from https://www.ramsar.org/

R Core Team. (2024). R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org/

Reale, R., Ribas, L. C., & Magro Lindenkamp, T. C. (2022). Ecosystem services as a ballast to guide sustained economic growth by biodiversity conservation actions. Journal of Cleaner Production, 358, 131846.

Reynolds, A. P., de la Iglesia, B., & Kumbier, K. (2004). The application of K-medoids and PAM to the clustering of rules. In Z. R. Yang, H. Yin, & R. M. Everson (Eds.), Lecture Notes in Computer Science: Vol. 3177. Intelligent Data Engineering and Automated Learning – IDEAL 2004 (pp. 161-166). Springer. Berlin, Germany: 6 pages.

Robertson, M. M. (2004). The neo-liberalization of ecosystem services: Wetland mitigation banking and problems in environmental governance. Geoforum, 35(3), 361–373.

Robertson, M. M. (2006). The nature that capital can see: Science, state, and market in the commodification of ecosystem services. Environment and Planning D: Society and Space, 24(3), 367-387.

Rodrigues, A. S. L., Andelman, S. J., Bakarr, M. I., Boitani, L., Brooks, T. M., Cowling, R. M., ... & Gascón, C. (2004). Effectiveness of the global protected area network in representing species diversity. Nature, 428(6983), 640–643.

Rogelj, J., den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., ... & Meinshausen, M. (2016). Paris Agreement climate proposals need a boost to keep warming well below 2°C. Nature, 534(7609), 631-639.

RPS Group. (n.d.). Biodiversity net gain. Retrieved July 23, 2025. R from https://www.rpsgroup.com/services/environment/biodiversity-ecology-and-arboriculture/biodiversity-net-gain/

Ruaro, R., Gubiani, É. A., & Piana, P. A. (2020). Global trends and challenges in multimetric indices of biological condition. Ecological Indicators, 110, 105847.

Salafsky, N., Salzer, D., Stattersfield, A. J., Hilton-Taylor, C., Neugarten, R., Butchart, S. H. M., ... & Wilkie, D. S. (2008). A standard lexicon for biodiversity conservation: Unified classifications of threats and actions. Conservation Biology, 22(4), 897-911.

Sarkki, S., Heikkinen, H. I., & Tynkkynen, N. (2016). Are national biodiversity strategies and action plans appropriate for building responsibilities for mainstreaming biodiversity across policy sectors? The case of Finland. Journal of Environmental Planning and Management, 59(8), 1377-1396.

Satorra, A., & Bentler, P. M. (2010). Ensuring positiveness of the scaled difference chi-square test statistic. Psychometrika, 75(2), 243-248.

Scheffer, M., Carpenter, S., Foley, J. A., Folke, C., & Walker, B. (2001). Catastrophic shifts in ecosystems. Nature, 413(6856), 591-596.

Shaw, R. E., Farquharson, K. A., Bruford, M. W., Coates, D. J., Elliott, C. P., Mergeay, J., Ottewell, K. M., Segelbacher, G., Hoban, S., Hvilsom, C., Ruņģis, D., Aravanopoulos, F., Bertola, L. D., Cotrim, H., Cox, K., Ekblom, R., Godoy, J. A., Konopiński, M. K., Laikre, L., . . . Grueber, C. E. (2025). Global meta-analysis shows action is needed to halt genetic diversity loss. Nature, 638(8051), 704-710.

Shi, J., Westeen, E., Katlein, N., Dumont, E., & Rabosky, D. (2018). Ecomorphological and phylogenetic controls on sympatry across extant bats. Journal of Biogeography. 45. 10.1111/jbi.13353.

Schmidt, C., Dray, S., & Garroway, C. J. (2022). Genetic and species-level biodiversity patterns are linked by demography and ecological opportunity. Evolution; international journal of organic evolution, 76(1), 86–100.

Sil, Â., Azevedo, J.C., Fernandes, P.M. et al. Will fire-smart landscape management buffer the effects of climate and land-use changes on fire regimes?. Ecol Process 13, 57 (2024).

Silva, E., Guerrero-Moreno, M. A., & Oliveira, F, B., & Juen, L. J., & Carvalho, F, G., & Oliveira Junior, J, M, B., (2024). The importance of traditional communities in biodiversity conservation. Biodiversity and Conservation. 34. 685-714. 10.1007/s10531-024-02999-3.

Simkins, A. T., Beresford, A. E., Buchanan, G. M., Crowe, O., Elliott, W., Izquierdo, P., Patterson, D. J., & Butchart, S. H. (2023). A global assessment of the prevalence of current and potential future infrastructure in Key Biodiversity Areas. Biological Conservation, 281, 109953.

Simpson, K. H., de Vries, F. P., Dallimer, M., Armsworth, P. R., & Hanley, N. (2022). Ecological and economic implications of alternative metrics in biodiversity offset markets. Conservation biology : the journal of the Society for Conservation Biology, 36(5), e13906.

Skrindo, H. (2024). Empirical analysis of the voluntary carbon market: Impact of project characteristics on carbon credit projects [Master's thesis, Norwegian School of Economics]. NHH Brage Institutional Repository. Bergen, Norway, 87 pages. https://openaccess.nhh.no/nhh-xmlui/handle/11250/3128453

Smith, Greg, S., Ascui, F., & O'Grady, A, P., & Pinkard, E. (2024). Indicators for measuring and reporting corporate nature-related impacts, dependencies, and risks. Environmental and Sustainability Indicators. 22. 100351. 10.1016/j.indic.2024.100351.

SPA-RAC. (2020). Protocol concerning Specially Protected Areas and Biological Diversity in the Medirerranenan. Convention on Biological Diversity, 1992. Specially Protected Areas Regional Activity Centre. Tunes, Tunisia: 52 pages.

Svadlenak-Gomez, K., Clements, T., & An, D. (2007). Paying for results: The WCS experience with direct incentives for conservation. In K. H. Redford & E. Fearn (Eds.), Protected areas and human livelihoods (WCS Working Paper No. 32, pp. 117-129). Wildlife Conservation Society. Bronx, NY, EUA: 13 pages.

Sun, Z., Scherer, L., Tukker, A., & Behrens, P. (2022). Shared and environmentally just responsibility for global biodiversity loss. Ecological Economics, 194, 107339.

Spilker, G., & Nugent, N. (2022). Voluntary carbon market derivatives: Growth, innovation & usage. Borsa Istanbul Review, 22(Suppl 2), S109-S118.

Swinfield, T., Shrikanth, S., Bull, J. W., Madhavapeddy, A., & Zu Ermgassen, S. O. (2024). Nature-based credit markets at a crossroads. Nature Sustainability, 7(10), 1217-1220.

The Biodiversity Consultancy. (2022). Exploring design principles for high integrity and scalable voluntary biodiversity credits. Cambridge, UK: 41 pages.

The Nature Conservancy. (2024). TNV View: Biodiversity credits. https://www.nature.org/en-us/what-we-do/our-insights/perspectives/tnc-view-biodiversity-credits/

The SURE Collaboration. (2011). SURE guides for preparing and using evidence-based policy briefs (Version 2.1). Geneva, Switzerland: 28 pages.

Thomsen, M. S., Altieri, A. H., Angelini, C., Bishop, M. J., Bulleri, F., Farhan, R., Frühling, V. M. M., Gribben, P. E., Harrison, S. B., He, Q., Klinghardt, M., Langeneck, J., Lanham, B. S., Mondardini, L., Mulders, Y., Oleksyn, S., Ramus, A. P., Schiel, D. R., Schneider, T., Siciliano, A., Silliman, B. R., Smale, D. A., South, P. M., Wernberg, T., Zhang, S., & Zotz, G. (2022). Heterogeneity within and among co-occurring foundation species increases biodiversity. Nature Communications, 13(1), 1-9.

Timmermans, J., & Daniel Kissling, W. (2023). Advancing terrestrial biodiversity monitoring with satellite remote sensing in the context of the Kunming-Montreal global biodiversity framework. Ecological Indicators, 154, Article 110773.

Tisdell, C. (2014). Human values and biodiversity conservation: The survival of wild species. Edward Elgar Publishing. Cheltenham, UK: 272 pages.

Tree Conservation Fund. (n.d) Our work - Tree Conservation Fund. https://treeconservationfund.org/tree-conservation-fund/

Turner, M., Gardner, R. (2015). Landscape Ecology in Theory and Practice Pattern and Process. Springer. New York, NY, USA: 401 pages.

United Nations (UN). (2019). Resolution adopted by the General Assembly on 1 March 2019 (A/RES/73/284). New York, NY, USA: 5 pages.

United Nations (UN). (2015). Transforming Our World: The 2030 Agenda for Sustainable Development. Resolution Adopted by the General Assembly on 25 September 2015, A/RES/70/1, 1-1. New York, NY, USA: 35 pages.

United Nations Conference on Trade and Development (UNCTAD) (2023). State of Commodity Dependence 2023. United Nations Conference on Trade and Development. Geneva, Switzerland: 102 pages. ISBN: 978-92-1-300053-3.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2022). Technical guidelines for Biosphere Reserves. Secretariat of the Man and Biosphere Programme. Paris, France: 140 pages.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2024). Basic Texts of the 1972 World Heritage Convention. Edition December 2024. Secretariat of the World Heritage Programme. Paris, France: 30 pages.

United Nations Environment Programme (UNEP). (1992). Convention on Biological Diversity. United Nations Secretary-General. Nairobi, Kenya: 30 pages.

United Nations Environment Programme (UNEP). (1992). Non-legally binding authoritative statement of principles for a global consensus on the management, conservation and sustainable development of all types of forests. United Nations Secretary-General. Nairobi, Kenya: 7 pages.

United Nations Environment Programme (UNEP). (2021). Making peace with nature: A scientific blueprint to tackle the climate, biodiversity and pollution emergencies. United Nations Secretary-General. Nairobi, Kenya: 168 pages.

United Nations Environment Programme (UNEP)., Food and Agriculture Organization of the United Nations (FAO). (2021). Tornando-se #GeraçãoRestauração: Restauração de ecossistemas para pessoas, natureza e clima. Nairobi, Kenya: 44 pages.

United Nations Environment Programme - World Conservation Monitoring Centre (UNEP-WCMC)., International Union for Conservation of Nature (IUCN). (2016). Protected Planet Report 2016. UNEP-WCMC and IUCN. Cambridge, UK: 26 pages.

United Nations Environment Programme - World Conservation Monitoring Centre, Capitals Coalition, Arcadis, ICF, & WCMC Europe. (2023). Measuring ecosystem condition – A primer for business, aligning accounting approaches for nature. European Commission. Brussels, Belgium: 36 pages.

United Nations Environment Programme - World Conservation Monitoring Centre (UNEP-WCMC). (2024). State of the World's Migratory Species. UNEP-WCMC, Cambridge, UK: 348 pages.

University of Cambridge Institute for Sustainability Leadership (CISL). (2020). How businesses measure their impact on nature: A gap analysis. Cambridge, UK: 31 pages.

Van der Sluijs, J. P. (2020). Insect decline, an emerging global risk. Current Opinion in Environmental Sustainability, 46, 39-44.

Vardon, M., Lindenmayer, D. (2023). Biodiversity market doublespeak. Science, 382,491-49.

Vargas, M., Rodrigues, D. (2009). Regime internacional de mudanças climáticas e cooperação descentralizada: o papel das grandes cidades nas políticas de adaptação e mitigação. In D. J. Hogan & E. Marandola Jr. (Orgs.), População e mudança climática: Dimensões humanas das mudanças ambientais globais (pp. 205-222). Ed. Unicamp. Campinas, Brazil: 17 pages.

Verschuuren, B., Wild, R., McNeely, J., & Oviedo, G. (Eds.). (2010). Sacred natural sites: Conserving nature and culture. Earthscan. London, UK: 384 pages.

Wauchope, H. S., zu Ermgassen, S. O. S. E., Jones, J. P. G., Carter, H., Schulte to Bühne, H., & Milner-Gulland, E. J. (2024). What is a unit of nature? Measurement challenges in the emerging biodiversity credit market. Proceedings of the Royal Society B: Biological Sciences, 291(2014), 20232749.

West, T. A. P., Wunder, S., Sills, E. O., Börner, J., Rifai, S. W., Neidermeier, A. N., Frey, G. P., & Kontoleon, A. (2023). Action needed to make carbon offsets from tropical forest conservation work for climate change mitigation. Science, 381(6660), 873-877.

Wildlife Conservation Society Canada. (2024). Connecting Canada's 2030 nature strategy to the Global Biodiversity Framework. Toronto, Canada: 23 pages.

Wong, J. Y., Huang, Y.-C., & Chen, C. A. (2018). Comparing patterns of taxonomic, functional and phylogenetic diversity in reef coral communities. Coral Reefs, 37(3), 737-750.

World Bank Group (WBG). (2016). Biodiversity Offsets: A User Guide. WBG. Washington, DC, USA: 112 pages.

World Bank Group (WBG). (2022). Nature and Development Brief: Scaling Up Finance for Nature. WBG. Washington, DC, USA: 112 pages.

World Business Council for Sustainable Development (WBCSD). (2021). What does nature-positive mean for business?. WBCSD. Geneva, Switzerland: 8 pages.

World Economic Forum (WEF). (2020). Nature risks rising: Why the crisis engulfing nature matters for business and the economy. WEF. Geneva, Switzerland: 33 pages.

World Economic Forum (WEF). (2022). The Global Risks Report 2022. WEF. Geneva, Switzerland: 124 pages.

World Economic Forum (WEF). (2023). The Global Risks Report 2023. WEF. Geneva, Switzerland: 107 pages.

World Rainforests. (2023). Countries with the highest biodiversity. World Rainforests. https://worldrainforests.com/03highest_biodiversity.html

World Wildlife Fund (WWF). (2022). Relatório Planeta Vivo 2022 – Construindo uma sociedade positiva para a natureza (R. E. A. Almond, M. Grooten, D. Juffe Bignoli, & T. Petersen, Eds.). WWF-Brasil. Brasília, Brazil: 156 pages.

Wu, J. (2007). Scale and scaling: A cross-disciplinary perspective. In Key topics in landscape ecology (pp. 115-142). Cambridge University Press. Cambridge, UK: 27 pages.

Wu, J., Jelinski, D. E., Luck, M., & Tueller, P. T. (2000). Multiscale analysis of landscape heterogeneity: Scale variance and pattern metrics. Geographic Information Sciences, 6(1), 6-19.

Wuepper, D., & Huber, R. (2022). Comparing effectiveness and return on investment of action- and results-based agri-environmental payments in Switzerland. American Journal of Agricultural Economics, 104(5), 1585-1604.

Wunder, S. (2015). Revisiting the concept of payments for environmental services. Ecological Economics, 117, 234-243.

Wunder, S., Fraccaroli, C., Bull, J. W., Dutta, T., Eyres, A., Evans, M. C., Thorsen, B. J., Jones, J. P. G., Maron, M., Muys, B., Pacheco, A., Olesen, A. S., Swinfield, T., Tegegne, Y. T., White, T. B., Zhang, H., & zu Ermgassen, S. O. S. E. (2024, September 10). Biodiversity credits: learning lessons from other approaches to incentivize conservation.

Yang, R., Cao, Y., Hou, S., Peng, Q., Wang, X., Wang, F., Tseng, T.-H., Yu, L., Carver, S., Convery, I., Zhao, Z., Shen, X., Li, S., Zheng, Y., Liu, H., Gong, P., & Ma, K. (2020). Cost-effective priorities for the expansion of global terrestrial protected areas: Setting post-2020 global and national targets. Science Advances, 6(37), eabc3436.

Yang, Z., & Chen, Y. (2018). A technique for the identification of biodiversity priority areas at the county level. PLOS ONE, 13(2), e0192569.

Yin, D., Zhao, Q., Zheng, D., & Liu, J. (2021). Habitat loss-biodiversity relationships are influenced by assembly processes and the spatial configuration of area loss. Forest Ecology and Management, 496, 119452.

Zellweger, F., Braunisch, V., Baltensweiler, A., & Bollmann, K. (2013). Remotely sensed forest structural complexity predicts multi species occurrence at the landscape scale. Forest Ecology and Management, 307, 303-312. h

Zoss, A, M., Maltese, A., Uzzo, S. M., & Borner, K. (2018). Network visualization literacy: Novel approaches to measurement and instruction. In: Cramer, C., Porter, M., Sayama, H., Sheetz, L., Uzzo, S. (eds) Network Science In Education. Springer, Cham, Switzerland: 18 pages.

Zu Ermgassen SOSE, Baker J, Griffiths RA, Strange N, Struebig MJ, Bull JW. The ecological outcomes of biodiversity offsets under 'no net loss' policies: A global review. Conservation Letters. 2019; 12:e12664.

Zu Ermgassen, S. O., Howard, M., Bennun, L., Addison, P. F., Bull, J. W., Loveridge, R., Pollard, E., & Starkey, M. (2022). Are corporate biodiversity commitments consistent with delivering 'nature-positive' outcomes? A review of 'nature-positive' definitions, company progress and challenges. Journal of Cleaner Production, 379, 134798.

Zu Ermgassen, S. O., Hawkins, I., Lundhede, T., Liu, Q., Thorsen, B. J., & Bull, J. W. (2025). The current state, opportunities and challenges for upscaling private investment in biodiversity in Europe. Nature Ecology & Evolution, 9(3), 515-524.

APPENDIX A: SYSTEMATIC REVIEW PROTOCOL

Author: André Luiz Ramos Lino

Work

Systematic review protocol of the work entitled: Descriptive-Exploratory Study on Biodiversity Credits: An Analysis of Certification Methodologies.

Additional File 1: Protocol Structure

About the document

This document structures, characterises, and describes the procedures of the steps in search of the identification and classification of the initiatives involved in the theme of biodiversity credits.

1. Objectives

The primary objective of this work is to identify, map, categorise and quantify the national and international initiatives that are related on different fronts to the natural market financial instrument called voluntary biodiversity credits, thus allowing the characterisation of the typologies of the areas of action of the initiatives, with subsequent analysis of the approaches, conditions, of the criteria, premises and considerations presented in the public documents of the initiatives.

2. Primary and Secondary Issue

What are the roles of the initiatives involved in developing the voluntary natural market financial instrument, and what are the proposals for their methodologies for generating biodiversity credits?

3. Research Phase 1 – Search for Initiatives/Organizations

3.1. Keywords

a. The search for keywords will take place in 4 languages, namely Portuguese, Spanish, French and English;
b. The search will take place on the "Google" platform, using in anonymous mode with the selection "all filters", "Safe Search" = Blur explicit images and, with the selection of tools: In any language; Custom break with deadline of the day of application and All results;
c. The forty links found for each keyword will be counted, except in the English language, which will be considered up to eighty links;
d. Chronological order of languages in the search for data: Portuguese language; Spanish language; French language; English language.

Observations:

- The languages were chosen for the author reading ability and comprehension;
- The decision to extend the results to the limits in the English language was based on studies that show that most of the production of content, materials and information takes place in the English language (BITETTI; FERRERAS, 2016);
- The chronological order of languages in the data search has no criteria.

3.2. Cut-off criteria

When an exclusion criterion is assigned to the link, the analysis will end, starting the next line, and no other criteria will be included.

3.2.1 Indicators - Cut 1

- Repeated Links;
- Blocked Links;
- Links Offline.

3.2.2 Indicators - Cut 2

A. No Biodiversity Theme and/or not linked to biodiversity credits;
B. No free access;
C. YouTube/videos platform, Twitter, Linkedin, Google Book and course sales;
D. Directories of files already accounted / similar;
E. Articles, Theses, Academic dissertations, Teaching programs and Academic books

Description

a. Content targeting other types of natural assets or those that are not related to biodiversity;
b. Paid access content or platform that requires registration;
c. Platforms not considered;
d. Directed to avoid duplicates;
e. A previous search was carried out in scientific directories, where no productions involving voluntary biodiversity credits were found.

3.2.3 Indicators - Cut 3

- No initiatives/metrics/methodologies for quantifying biodiversity with the development of biodiversity credits;
- Addresses or presents initiatives for Biodiversity Credits Offset, Payment for Environmental Services Offset;
- Publications and/or directories with repeated documentation that was not explicit in previous links or other languages.

Description

a. The organisations/initiatives to be considered will need to present a direct citation of involvement with the development of the field of voluntary biodiversity credits, excluding the organisations/initiatives present in citations not elucidated to the development of such;
b. The accounting of the number of citations of a particular organisation/initiative will only be considered from the first direct citation, excluding from the accounting previous citations that did not present a link;
c. Home page links that present direct associative content for the development of methodology will be considered, without the need for a direct citation in these cases to account for organisations/initiatives;
d. All organisations/initiatives that are on lists present in links or documents that are associated with the Voluntary Biodiversity Credit will be considered;

APPENDIX B: DOCUMENTS, WEBSITES AND OTHER SOURCES OF INFORMATION FOR THE ORGANIZATION/SCHEMES ANALYZED

Table 8: *Compilation of Voluntary Biodiversity Credit organizations/schemes document available from the organisations used in this study*

Id	Name	Documente name	Version	Date	Reference
2	AfN	NARIA Framework – Terrestrial Ecosystem Condition Method	1.0	April 2024	AfN, 2024
		GreenCollar Native Vegetation Condition Monitoring Method	2.2	November 2023	AfN, 2023
4	BioCarbon	BioCarbon Biodiversity Standard - Ecosystem and Biodiversity Conservation Activities	3.1	May 2024	BioCarbon, 2024c
		Methodological document Biodiversity Conservation Activities	2.0	February 2024	BioCarbon, 2024a
		Certification Manual for Biodiversity Conservation Initiatives	1.0	February 2024	BioCarbon, 2024b
		Tokenization Guidelines	1.0	May 2024	BioCarbon, 2024d
		Sustainable Development Safeguard	1.1	July 2024	BioCarbon, 2024e
5	Biota	BIOTA Biodiversity Credits - Whitepaper		August 2024	Biota, 2024
6	BMV Global	Standard BMV - Programa de Geração dos Ativos Baseados na Conservação da Natureza: Unidades de Créditos de Sustentabilidade – UCS Florestas	2.0	October 2023	BMV Global, 2023
7	BGCI	Biodiversity Impact Credits: Methodologies for Metric Computation	1.0	2023	Rossberg, 2023
8	Cercabono	Cercabono Biodiversity Certification Programme Protocol	1.1.1	May 2024	Cercarbono, 2024a
		Cercarbono Biodiversity Certification Programme Procedures	1.0	May 2024	Cercarbono, 2024b
		Rules of Procedure of the Independent Expert Panel	1.0	June 2024	Cercarbono, 2024c
		Methodology CBCP-01: Indicator Species Biodiversity Methodology - For conservation of intact regional biodiversity using indicator species	1.2	August 2024	Cercarbono, 2024e
		Project Management Plan - Savimbo Biodiversity Putumayo	1.1	September 2024	Cercarbono, 2024f
9	Climate Action Company	Kea Credit Methodology - website			Climate Action Company, 2024a
		Whio Credit Methodology - website			Climate Action Company, 2024b
		Mohua Credit Methodology - website			Climate Action Company, 2024c
10	CreditNature	NARIA Framework – Terrestrial Ecosystem Condition Method	1.0	April 2024	AfN, 2024
11	EarthAcre	Predicting Bird Diversity with lidar-derived vegetation structure	1.0	May 2023	Boucher & Davies, 2023
		EarthAcre website			EarthAcre, 2024
14	Era Brazil	Umbrella Species Stewardship – Biodiversity Crediting Protocol	2.0	October 2024	ERA, 2024a
		Umbrella Species Stewardship – Project & Monitoring Plan	1.0	October 2024	ERA, 2024b
		Umbrella Species Stewardship – Monitoring Report	1.0	October 2024	ERA, 2024c
17	GreenCollar	NaturePlus Standard	1.1	August 2023	GreenCollar, 2023a
		NaturePlus Guide		October 2023	GreenCollar, 2023c
		NaturePlus Claims Guidance		September 2023	GreenCollar, 2023b
		GreenCollar Native Vegetation Condition Monitoring Method	2.2	November 2023	AfN, 2023
18	Institute LIFE	LIFE Standard Business & Biodiversity	4.0-R1	June 2023	LIFE, 2023a
		LIFE Technical Guide 01	1.0-R1	August 2023	LIFE, 2023b
		LIFE Technical Guide – 02	1.0-R1	August 2023	LIFE, 2023c
		LIFE Biodiversity Credits - General Rules for Management and Negotiation	1.0-R1	March 2024	LIFE, 2024

Continues on the following page.

Table 8 (Continued)

Id	Name	Documente name	Version	Date	Reference
19	Invest Conservation	Token Methodology		April 2023	InvestConservation, 2023
20	LandBanking Group	Verifiable Nature Unit			African Park, 2024
		Nature Equity Consultation Paper	1.0	January 2024	LandBanking Group, 2024
23	Now Trust	Funding Niue's Ocean Wide Conservation and Resilient, Sustainable Blue Economy		September 2023	Niue Ocean Wide, 2023
24	OpenEarth	Marine Ecosystem Credits		November 2022	OpenEarth, 2022
		Marine Biodiversity Credits - Protection Category - Technical Framework	1.0	November 2023	OpenEarth, 2023
25	OBC	Towards biodiversity certificates: proposal for a methodological framework		November 2023	OBC, 2023
		Developing an Effective Market supporting the biodiversity strategies of both companies and states to reach Kunming objectives		October 2024	OBC, 2024
26	Plan Vivo	Project requirements	1.0	2023	Plan Vivo, 2023b
		Methodology & data protocol	1.0	2023	Plan Vivo, 2023a
		Validation and Verification requeriments	1.0	2023	Plan Vivo, 2023d
		Procedures Manual	1.0	2023	Plan Vivo, 2023c
		PVBC Calculation Protocol	1.0	2023	Plan Vivo, 2023e
27	Queen M	A metric for tradable biodiversity credits quantifying impacts on global extinction risk		June 2024	Rossberg et al., 2024
		Biodiversity Impact Credits: Methodologies for Metric Computation	1.0	2023	Rossberg, 2023
28	Recelio	Making Biodiversity Investable with the dBT/Dlt Ecosystem	0.9.7	June 2023	Recelio, 2023
29	Savimbo	Indicator-species-based biodiversity crediting	1.3	April 2024	Savimbo, 2024
30	Single.Earth	Using essential biodiversity variables to assess forest ecosystem integrity		November 2023	Dias et al., 2023
		The Scientific background behind the MERIT	1.0	October 2022	Single.Earth, 2022
31	SLU	Biodiversity credits in boreal forest landscapes: rationale, methods and process description		May 2022	SLU, 2022
33	Terrain	Cassowary credit scheme Standard Version 2.0 - Draft	2.0	July 2024	Terrain, 2024
34	Terrasos	Protocol for issuing voluntary biodiversity units	4.0	October 2024	Terrasos, 2024
37	Verra	Nature Framework	2.0	October 2024	Verra, 2024a
		Nature Framework worked examples	1.0	October 2024	Verra, 2024b
38	Wallacea	Methodology for quantifying units of biodiversity gain	3.0	October 2023	Wallacea, 2023
39	Winderlands	Whitepaper: A review of the biological diversity units	1.5	February 2025	Winderlands, 2024

APPENDIX C: RESULTS COMPILATION

Table 9: *Compilation results of the theoretical characterization*

Id	Organization	Credit definition category	Territorial scale of the scheme implementation	Geographical coverage / boundary	Reference site	Payment approach	Outcome	Issuance or credit release	Project permanence	Baseline assessment
1	3bee	Area under specific management	Internacional	No Geographical restriction	Yes	Combined	Combined + Positive impact	Ex-post (Not informed)	Not informed	2 years
3	BeZero Carbon	Not applied	Local / Regional	Not informed	No	Action/efforts-based	Combined	Not informed	Not informed	Not informed
4	BioCarbon Cert	Area under specific management; Based on results or ecological impacts	Intercontinental	No Geographical restriction	No	Combined	Combined + Positive impact	Ex-post (ecological/ management milestones)	10 years	0 year
5	Biota	Area under specific management	International	No Geographical restriction	No	Combined	Combined + Positive impact	Ex-post (Not informed)	Not informed	Not informed
6	BMV Global	Area under specific management; Based on results or ecological impacts; Monitoring cycles and the process of verification	National	No Geographical restriction	Not informed	Combined	Combined + Positive impact	Ex-post (regularly)	25 years	0 year
7	Botanic Garden Conservation Internacional	Area under specific management; Based on results or ecological impacts	Intercontinental	No Geographical restriction	No	Outcome/ performance-based	Biodiversity upflit	Ex-post (regularly)	Not informed	0 year
8	Climate Action Company	Area under specific management; Based on results or ecological impacts; Explicit long-term durations, periodic annual or monthly units	National	Geographical restriction	No	Action/efforts-based	Averted loss + positive impact	Ex-post (regularly)	1 year	0 year
9	Cercabono	Area under specific management; Monitoring cycles and the process of verification	National	No Geographical restriction	Not informed	Combined	Combined + Positive impact	Ex-post (regularly)	10 years	5 years
10	CreditNature	Based on results or ecological impacts; Monitoring cycles and the process of verification	International	Geographical restriction	Not informed	Combined	Combined + Positive impact	Not informed	Not informed	2 years
11	EarthAcre	Area under specific management; Monitoring cycles and the process of verification	Local / Regional	Geographical restriction	Not informed	Outcome/ performance-based	Combined	Not informed	Not informed	Not informed
12	Earthly	Area under specific management; Based on results or ecological impacts	Intercontinental	Geographical restriction	Yes	Combined	Biodiversity upflit + Positive impact	Ex-post (Not informed)	30 years	Not informed

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Table 9 (Continued)

Id	Organization	Credit definition category	Territorial scale of the scheme implementation	Geographical coverage / boundary	Reference site	Payment approach	Outcome	Issuance or credit release	Project permanence	Baseline assessment
13	Ekos	Area under specific management; Based on results or ecological impacts	National	Geographical restriction	No	Combined	Combined + Positive impact	Not informed	Not informed	Not informed
14	EraBrazil	Area under specific management; Based on results or ecological impacts	Local / Regional	Geographical restriction	Yes	Action/efforts-based	Combined + Positive impact	Ex-post (regularly)	5 years	3 years
15	Fundatia ADEPT	Not applied	National	Geographical restriction	No	Action/efforts-based	Averted loss	Not informed	25 years	Not informed
16	Gold Standard	Not applied	Not informed	Not informed	Not informed	Action/efforts-based	Positive Impact	Not informed	Not informed	Not informed
17	GreenCollar	Area under specific management; Monitoring cycles and the process of verification; Explicit long-term durations, periodic annual or monthly units	National	No geographical restriction	Yes	Outcome/ performance-based	Combined	Ex-post (ecological/ management milestones)	25 years	2 - 10 years
18	Institute LIFE	Based on results or ecological impacts; Monitoring cycles and the process of verification	Intercontinental	No geographical restriction	No	Combined	Positive Imapct	Ex-post (regularly)	30 years	1 year
19	InvestConservation	Based on results or ecological impacts; Explicit long-term durations, periodic annual or monthly units	Intercontinental	Geographical restriction	No	Outcome/ performance-based	Combined	Ex-post (regularly)	50 years	0 year
20	LandBanking Group	Area under specific management; Based on results or ecological impacts; Explicit long-term durations, periodic annual or monthly units	International	Geographical restriction	Not informed	Outcome/ performance-based	Combined	Ex-post (Not informed)	Not informed	1 year
21	Natural State	Not applied	International	Geographical restriction	No	Combined	Combined + Positive impact	Not informed	Not informed	Not informed

Continues on the following page.

Table 9 (Continued)

Id	Organization	Credit definition category	Territorial scale of the scheme implementation	Geographical coverage / boundary	Reference site	Payment approach	Outcome	Issuance or credit release	Project permanence	Baseline assessment
22	New Atlantis Labs	Not applied	Not informed	Geographical restriction	Yes	Outcome/performance-based	Averted loss	Not informed	Not informed	Not informed
23	Now Trust	Area under specific management	National	No geographical restriction	Not informed	Action/efforts-based	Averted loss + Positive impact	Ex-post (regularly)	20 years	Not informed
24	OpenEarth	Area under specific management; Based on results or ecological impacts; Explicit long-term durations, periodic annual or monthly units	Intercontinental	Geographical restriction	No	Combined	Combined	Ex-post (regularly)	Not informed	5 years
25	OBC	Not applied	Intercontinental	No geographical restriction	Yes	Action/efforts-based	Combined + Positive impact	Ex-ante / Ex-post (Not informed)	Not informed	Not informed
26	Plan Vivo	Based on results or ecological impacts; Explicit long-term durations, periodic annual or monthly units	Intercontinental	No geographical restriction	No	Outcome/performance-based	Combined	Ex-post (regularly)	10 - 50 years	0 year
27	Queen Marry University	Based on results or ecological impacts; Explicit long-term durations, periodic annual or monthly units	Not applied	No geographical restriction	No	Not applied	Positive Imapct	Not Applied	Not applied	Not informed
28	Recelio	Area under specific management	Not informed	Not informed	Not informed	Action/efforts-based	Biodiversity upflit + Positive impact	Not informed	Not applied	Not informed
29	Savimbo	Area under specific management; Based on results or ecological impacts; Explicit long-term durations, periodic annual or monthly units	National	Geographical restriction	No	Outcome/performance-based	Combined	Ex-post (regularly)	10 years	**5** years

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Table 9 (Continued)

Id	Organization	Credit definition category	Territorial scale of the scheme implementation	Geographical coverage / boundary	Reference site	Payment approach	Outcome	Issuance or credit release	Project permanence	Baseline assessment
30	Single.Earth	Based on results or ecological impacts	Intercontinental	Geographical restriction	Yes	Outcome/performance-based	Combined	Ex-post (regularly)	Not informed	Not informed
31	SLU	Based on results or ecological impacts; Monitoring cycles and the process of verification; Explicit long-term durations, periodic annual or monthly units	Local / Regional	Geographical restriction	No	Outcome/performance-based	Combined + Positive impact	Ex-ante + Ex-post (regularly)	20 years	5 years
32	South Pole	Area under specific management; Based on results or ecological impacts; Monitoring cycles and the process of verification	Intercontinental	No geographical restriction	No	Combined	Combined + Positive impact	Ex-post (Not informed)	Not informed	Not informed
33	Terrain NRM	Based on results or ecological impacts	Local / Regional	Geographical restriction	No	Combined	Combined + Positive impact	Ex-post (ecological/management milestones)	25 years	1 year
34	Terrasos	Area under specific management	National	Geographical restriction	Yes	Outcome/performance-based	Averted loss + positive impact	Ex-post (ecological/management milestones)	20-50 years	0 year
35	University of Notthingham	Not applied	Not applied	Not informed	Not informed	Not applied	Not informed	Not Applied	Not applied	Not informed
36	ValueNature	Area under specific management	International	No geographical restriction	Not informed	Outcome/performance-based	Combined	Ex-post (Not informed)	10 years	Not informed
37	Verra	Based on results or ecological impacts; Monitoring cycles and the process of verification	Intercontinental	No geographical restriction	Yes	Outcome/performance-based	Combined + Positive impact	Ex-post (regularly)	20 years	0 year
38	Wallacea Trust	Area under specific management; Based on results or ecological impacts;	Intercontinental	No geographical restriction	Yes	Outcome/performance-based	Combined	Ex-ante + Ex-post (regularly)	20 years	0 year
39	Winderlands	Area under specific management	National	No geographical restriction	No	Combined	Combined	Ex-post (Not informed)	20 years	Not informed

Table 10: *Compilation results of the technical characterization*

Id	Organization	Realm	Biological Organization Level - BOL	Spatial scale of BOL	Significance	Metric and Indicator	Pressure index	Leakage	MRV	Double-accounting
1	3bee	Terrestrial	Species + Ecosystem	Habitat	Not informed	Informed	Yes	Not informed	Informed	No
3	BeZero Carbon	Terrestrial + Wetland	Genetic + species	Ecosystem	Not informed	Informed	No	Not informed	Informed	Not applied
4	BioCarbon Cert	Terrestrial	Species + Landscape	Ecosystem + habitat	Calculation	Informed	Yes	Not informed	Informed	No
5	Biota	Terrestrial + Wetland + freshwater	Landscape	Ecosystem + habitat	Calculation	Informed	Yes	Not informed	Informed	No
6	BMV Global	Terrestrial	Species + Landscape	Biome	Not informed	Informed	Yes	Not informed	Informed	Not informed
7	Botanic Garden Conservation Internacional	Terrestrial	Species	Not informed	Management	Informed	No	Not informed	Not informed	Yes
8	Climate Action Company	Terrestrial	Species	Ecosystem + habitat	Not informed	Not informed	Yes	Not informed	Informed	No
9	Cercabono	All	Species + Ecosystem	Habitat	Calculation	Informed	Yes	Yes	Informed	No
10	CreditNature	Terrestrial	Species + Landscape	Habitat	Management	Informed	No	Not informed	Informed	No
11	EarthAcre	Terrestrial	Landscape + Ecosystem + species	Habitat	Management	Informed	Not informed	Yes	Informed	No
12	Earthly	Terrestrial	Landscape	Habitat	Not informed	Informed	Yes	Not informed	Not informed	Not informed
13	Ekos	Terrestrial + Marine	Species + Ecosystem	Habitat	Not informed	Informed	Not informed	Not informed	Not informed	Yes
14	EraBrazil	Terrestrial	Species + Ecosystem	Biome + Habitat	Management	Informed	Yes	Not informed	Informed	No
15	Fundatia ADEPT	Terrestrial	Species + Landscape	Habitat	Not informed	Informed	Yes	Not informed	Not informed	Not informed
16	Gold Standard	Not informed	Not informed	Not informed	Not informed	Not informed	Not informed	Not informed	Not informed	Yes
17	GreenCollar	All	Species + Ecosystem	Bioregions + landscape + habitat	Management	Informed	No	Yes	Informed	No

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Table 10 (Continued)

Id	Organization	Realm	Biological Organization Level	Spatial scale of BOL	Significance	Metric and Indicator	Pressure index	Leakage	MRV	Double-accounting
18	Institute LIFE	All	Landscape	Ecoregion + ecosystem + species + habitat	Calculation	Informed	Yes	Yes	Informed	No
19	InvestConservation	Terrestrial	Species + Landscape	Ecosystem + habitat	Management	Not informed	Yes	Not informed	Informed	Yes
20	LandBanking Group	Terrestrial	Species + Landscape	Ecoregion + ecosystem + habitat	Management	Informed	Yes	Yes	Informed	Yes
21	Natural State	Terrestrial	Species + Landscape	Ecosystem + habitat	Not informed	Informed	Not informed	Not informed	Informed	Yes
22	New Atlantis Labs	Marine	Genetic + Species + Ecosystem	Ecosystem	Not informed	Informed	Not informed	Not informed	Informed	Yes
23	Now Trust	Marine	Ecosystem	Landscape + Habitat	Management	Not informed	Not informed	Not informed	Not informed	Not informed
24	OpenEarth	Marine	Species + Ecosystem	Habitat	Calculation	Informed	No	Not informed	Informed	Yes
25	OBC	All	Species + Ecosystem	Habitat	Calculation	Informed	Yes	Not informed	Not informed	Yes
26	Plan Vivo	All	Species + Ecosystem	Ecoregion + Habitat	Management	Informed	No	Yes	Informed	No
27	Queen Marry University	Terrestrial	Species + Ecosystem + Landscape	Not informed	Not applied	Informed	Not informed	Not applied	Informed	Not applied
28	Recelio	Terrestrial	Species + Landscape	Ecosystem	Management	Informed	Yes	Not informed	Informed	Yes
29	Savimbo	Terrestrial	Species + Ecosystem	Habitat + Ecologic Niche	Calculation	Informed	Not informed	Yes	Informed	No
30	Single.Earth	Terrestrial	Species + Ecosystem	Landscape + Habitat	Management	Informed	Yes	Not informed	Informed	Yes
31	SLU	Terrestrial	Species + Landscape	Ecosystem	Not informed	Informed	Not informed	Not informed	Informed	No
32	South Pole	Terrestrial	Species + Ecosystem + Landscape	Habitat	Calculation	Not informed	Not informed	Not informed	Not informed	Not informed
33	Terrain NRM	Terrestrial	Species + Ecosystem + Landscape	Bioregions + habitat	Not informed	Not informed	Yes	Yes	Not informed	Yes
34	Terrasos	All	Landscape + Ecosystem	Habitat + Species	Calculation	Informed	Yes	Yes	Informed	No

Continues on the following page.

Table 10 (Continued)

Id	Organization	Realm	Biological Organization Level - BOL	Spatial scale of BOL	Significance	Metric and Indicator	Pressure index	Leakage	MRV	Double-accounting
35	University of Notthingham	Not informed	Not informed	Not informed	Not applied	Not informed	Not informed	Not applied	Not informed	Not applied
36	ValueNature	Terrestrial	Species + Ecosystem + Landscape	Habitat	Management	Not informed	Yes	Not informed	Informed	Yes
37	Verra	All	Species + Ecosystem	Ecoregion + Habitat	Management	Informed	Yes	Yes	Informed	No
38	Wallacea Trust	Terrestrial + marine	Species + Ecosystem	Habitat	Calculation	Informed	Yes	Yes	Informed	No
39	Winderlands	Terrestrial	Species + Landscape	Ecosystem + habitat	Management	Informed	Not informed	Not informed	Informed	Yes

APPENDIX D: SIGNIFICANCE

Table 11: *Significance indicators characterized by Voluntary Biodiversity Credit schemes*

Indicator Name	Definition	Schemes
Geographic Designations and Frameworks		
Priority Area for Conservation Categories (e.g. Int, Nat, Reg, Local / Key Biodiversity Area (KBA), Biodiversity Hotspots, IUCN Sacred Natural Sites / Irreplaceable biodiversity and irrecoverable carbon sites / World Heritage List UNESCO / UNESCO Man and the Biosphere Reserves / SPAMIs)	Site contributing significantly to global biodiversity persistence based on standardized criteria (cultural, geographical restriction, ecological integrity, etc.) (Myers *et al*., 2000 ; Verschuuren *et al.*, 2010; IUCN, 2016a, UNESCO, 2022, 2024; SPA-RAC, 2020)	3bee, Biota, Cercabono; EarthAcre, GreenCollar, InvestConservation, LIFE, Natural State, OBC, OpenEarth, Plan Vivo, Savimbo, ValueNature and Verra;
Protected Areas Categories (Int, Nat, Reg, Local / IUCN Categories I-VI) Legal reserve areas and Ramsar Classification of Wetland Type)	Classification based on primary management objectives (Neugarten *et al*., 2018 ; Ramsar, 2025)	3Bee, BMV Global, Biota, Cercabono, Earthly, Ekos, Fundatia ADEPT; InvestConservation, LandBanking, LIFE, New Atlantis, OBC, Open Earth, Plan Vivo, Single.Earth, SLU; South Pole, Verra and Winderland;
Ecoregion biodiversity Importance	Large land/water unit with distinct natural communities; importance based on richness, endemism, uniqueness (Olson, 2001).	LIFE and Verra;
Biogeographical category	Classification based on shared species distributions and evolutionary history (Olenin *et al*., 2017; Mucina, 2019).	OBC; Winderlands
Deforestation frontier	Area with rapid, expanding forest loss, often linked to specific drivers (Buchadas *et al*., 2023).	InvestConservation;
IUCN Global Ecosystem Typology	Hierarchical classification of all ecosystems based on function and composition (Keith *et al*., 2015; Borrini-Feyerabend *et al*., 2017).	Cercarbono, CreditNature, Savimbo and Verra;
Red List of Ecosystems and/or Habitat (e.g. Int, Nat, Reg, Local / IUCN)	Assessment of ecosystem/habitat collapse risk based on distribution/degradation criteria (Keith *et al*., 2020).	Cercarbono, Climate Action Company, InvestConservation, Plan Vivo, Savimbo and Terrasos;
Forest Conservation Status	Assessment of forest condition/extent/management relative to conservation goals (FAO, 2020b).	Single.Earth;
High Conservation Values (HCVs)	Biological, ecological, social, cultural values of outstanding/critical importance in production landscapes (HCV Network, 2025).	BioCarbon, Biota, BMV Global, InvestConservation, Recelio, Single.Earth and Wilderlands;
Species-Level Characteristics and Status		
Endemic species	Species limited to a specific geographic area, found nowhere else naturally (Levin, 2013).	Cercarbono, Climate, Ekos, LandBanking Group, OpenEarth, Savimbo and South Pole;
Invasive species / Category of Potential (e.g. Int, Nat, Reg, Local / IUCN SSC IAS)	Invasive alien species (IAS) are species introduced into places outside their natural range that have negative impacts on native biodiversity (IUCN, 2018).	BeZero Carbon, LIFE, Plan Vivo and Winderlands;
Red List of Threatened/Endangered species (e.g. Int, Nat, Reg, Local / IUCN / CITES App I, II, III)	Global assessment of species extinction/ endangered risk (Keith *et al*., 2013; CITES, 2023).	3Bee, Biota, BGCI, BioCarbon, Climate, Cercarbono, Earthly, Ekos, ERA Brazil, GreenCollar, LIFE, Landbank, Natural State, Open Earth, Plan Vivo, Recelio, Savimbo, Single.Earth, SLU, South Pole, Terrain, Terrasos, Verra, Wallacea and Wilderlands;

Continues on the following page.

Table 11 (Continued)

Indicator Name	Definition	Schemes
Species-Level Characteristics and Status		
Keystone species	Species with disproportionately large ecosystem effect relative to abundance (Levin, 2013).	Cercarbono, Savimbo and Verra;
Umbrella species	"A species that has a large home range and broad habitat requirements, both of which overlap with other species" (Park, 2007).	Cercarbono, ERA Brazil and Savimbo;
Sentinel species		Cercarbono, Savimbo
Emblematic species		Cercarbono, Savimbo
Trafficked species		Cercarbono, Savimbo
Migratory species	Species whose populations cyclically/predictably cross-national borders (UNEP-WCMC, 2024).	EarthAcre;
Rare species	Species with low abundance, narrow range, or high habitat specificity (Levin, 2013).	BeZero, Cercarbono and Savimbo;
Species with High Conservation Value	Broad term for species prioritized due to threat, endemism, role, legal status (HCV Network, 2025).	Wallacea;
Quantitative Metrics and Indices		
MSA (Mean Species Abundance)	Average abundance of biodiversity relative to undisturbed state (Alkemade *et al.,* 2009).	3Bee, LIFE;
Species Threat Abatement and Restoration (STAR)	Potential contribution of actions (abatement, restoration) at a location to reduce global extinction risk (Mair *et al*., 2021).	OpenEarth;
Species Vulnerability (based on WEGE Index / other frameworks)	Assessment of species susceptibility to decline based on sensitivity, exposure, adaptive capacity (Fortini & Schubert, 2017).	OpenEarth;
Rarity-weighted richness value	Richness metric weighted by range restriction (rarity) for threatened species (IUCN, 2022).	Plan Vivo;
Remnants of preserved native vegetation	Patches of original native vegetation remaining altered landscape (Pinto & Voivodic, 2021).	BMV Global and LIFE;
UNEP Forest Biodiversity Intactness Index	Metric assessing forest biodiversity retention relative to pristine state (GEO BON, 2015)	Cercarbono;

APPENDIX E: ACTIVITIES AND PROJECTS

Table 12: *Interventions proposed by Voluntary Biodiversity Credit schemes*

Category	Description	Interventions	Schemes
Restoration and Regeneration	Comprises the set of deliberate processes and interventions aimed at assisting the recovery of areas that have been degraded, damaged, or destroyed, with the objective of re-establishing, wholly or in part, their structure, function, species composition (biodiversity), and resilience over time (Grann *et al*., 2019).	Reforestation and Revegetation	Biota, BGCI, InvestConservation, LandBanking Group, Natural State, Terrain NRM, Verra and Winderlands;
		Enhancement of Degraded Natural Landscape, Ecosystem, and Habitat Condition	3bee, BioCarbon, Biota; BMV Global, Cercabono, CreditNature, EarthAcre, Earthly, EraBrazil, LIFE, LandBanking Group, OBC, Plan Vivo, Savimbo, Single.Earth, SLU, South Pole, Terrain NRM, Terrasos, ValueNature, Verra, Wallacea Trust and Winderlands;
		Creation and Restoration of Ecological Corridors and Connectivity	BioCarbon, Cercabono, Earthly, LIFE, OBC, Recelio and South Pole;
		Natural Regeneration and Processes (e.g. Forest regeneration; Deliberate creation of dead wood; Carbon regrowth; Promotion of old-growth qualities)	InvestConservation, Natural State and SLU;
		Restoration of Specific Ecosystems (e.g., Marine restoration; Wetland depollution; Peatlands increase carbon uptake and storage; Restoration of buffer zones)	LIFE, OpenEarth, OBC and Single.Earth;
Conservation and Preservation	Refers to the set of direct actions, strategies, and interventions aimed at maintaining existing biodiversity, safeguarding natural landscapes, ecosystems, habitats, and species against loss, degradation, and extinction, and prevent future damage (Kasso & Balakrishnan, 2013; Salafsky, 2007)	Prevention of Deforestation and Degradation in Natural Landscapes, Ecosystems, and Habitats	Fundatia Adept, InvestConservation, LandBanking Group, OBC, ValueNature and Verra;
		Creation, Management, and Strengthening of Protected Areas (e.g., Inclusion of protected areas in IUCN 'Green List Standard; Legal protection of rainforest vegetation)	Cercabono, LIFE, Plan Vivo, SLU and Terrain NRM;
		Maintenance and Protection of Natural Landscapes, Ecosystems, and Habitats	BMV Global, Cercabono, Earthly, EraBrazil, LandBanking Group, OBC, Single.Earth, SLU, South Pole, Terrasos, ValueNature and Winderlands;
		General Conservation/preservation projects and interventions (e.g., Avoided loss projects, Conservation management interventions for land protection, Broadleaf promotion, Reward marine protection)	BioCarbon, Ekos, InvestConservation, OpenEarth, Savimbo, SLU, Terrain NRM and Wallacea Trust;
Sustainable Management	This category involves the integration of ecological principles into production systems to ensure long-term viability, resource conservation, and ecosystem health, aiming to increase biodiversity and ecosystem services within managed landscapes (IUCN, 2024; Mamo, 2023).	Agroforestry and Silvopastoral Systems	Natural State, OBC, Recelio, South Pole and Verra;
		Sustainable and Regenerative Agriculture, Aquaculture and Pasture	BioCarbon, Cercabono, Fundatia Adept, Natural State, OBC, Recelio, South Pole, ValueNature and Verra;
		Sustainable Forest Management (e.g., Improved forest management)	Biota, OBC, SLU and Verra;
		Sustainable Resource Use and Production	BioCarbon, Biota, BMV Global, Single.Earth, South Pole and Terrasos;

Continues on the following page.

Table 12 (Continued)

Category	Description	Interventions	Schemes
Species-Specific Interventions	This category focuses on actions directly aimed at the conservation needs of particular species or groups of species, frequently those that are threatened or of special interest. It includes both *in-situ* actions and *ex-situ* conservation measures (Bowgen *et al*., 2022; McGowan et al., 2016).	Species Conservation and Restoration (e.g., genetic conservation, Ex-situ species conservation, Collection and conservation of crop wild relatives, Conservation of livestock genetics)	Cercabono, EraBrazil, LIFE, LandBanking Group, Natural State and Terrain NRM;
		Habitat Management for Target Species and Climate Change Adaptation (e.g., Interventions in the habitat to enable species' reproduction and survival, Installation of structures that improve access to habitat by native wildlife, Species adaptation to climate change)	Cercabono, LIFE and Terrain NRM;
Threat Management and Mitigation	This category includes actions specifically designed to reduce or eliminate direct threats to biodiversity and ecological health (McGowan *et al*., 2016; Salafsky, 2007).	Invasive Species/Pest Control (e.g., Alien species clearance, Control of non-native/invasive introduced plant and animal species; Installation and maintenance of DOC traps, Purse-seine and other control efforts)	Climate Action Company, Ekos, LIFE, LandBanking Group, Terrain NRM and Winderlands;
		Fire Management and Prevention (e.g., Application of sensors with alerts, Creation of fire breaks, Fire management, Observation towers to detect fire outbreaks, Prescribed burning, Training local fire brigades)	BMV Global, EraBrazil, LIFE, SLU and ValueNature;
		Limitation or Reduction of Direct Impacts/Threats (e.g., Limitation of heavy or destructive machinery/tools, Limitation on entry and/or action of the public/tourists, prevent damage in coastal areas, Reduction of hunting and fishing activities, Removal of the agents causing degradation on the ecosystem, Limitation of agrochemicals or fertilizers; Footprint/ Energy optimization)	BioCarbon, Cercabono, OBC, Recelio, Terrain NRM and Winderlands;
		General Enabling Actions and Policies (e.g., Quantifying human-driven disturbances or threats; Ecosystem adaptation to climate change)	EraBrazil, Ekos, LandBanking and Winderlands;
Education, Legislation and Infrastructure Management	This category includes activities focused on information gathering, knowledge generation, and the evaluation of the state of biodiversity, ecosystems, threats, or the effectiveness of conservation actions, as well as support activities that create the necessary conditions or provide the means for other interventions to be successful (IUCN, 2016; Salafsky, 2007).	Human Capacity Building and Environmental Education (e.g., Human resource recruitment/training activities, Training local fire bridges with equipment available for use, Environmental education strategies raising community awareness, Installation of information panels at strategic points showcasing poaching and fauna interference prohibition)	EraBrazil and LIFE;
		Development of Legal, Financial, and Governance Mechanisms (e.g., Development of surveillance and control programs, Establishment of legal and financial mechanisms that ensure the maintenance of the area)	BioCarbon, EraBrazil, LIFE and Terrasos;
		Implementation and maintenance of infrastructure (e.g., Enforcement, Patrol, and Surveillance Activities, Fire Management and Prevention; Limitation on entry and/or action of the public/tourists to a landscape or ecosystem)	BMV Global, EraBrazil, LIFE, Recelio, Terrasos and ValueNature

APPENDIX F: CHI-SQUARE TEST RESULTS

Table 13: *Chi-square analysis (p-value*)

Variable 1	Variable 2	Statistically X^2	p_Value
Baseline assessment	Spatial scale of BOL	147,1972222	3,65E-06
Baseline assessment	Leakage	19,13050505	0,085427
Baseline assessment	Double-accounting	24,65162037	0,134817
Baseline assessment	Significance	14,13632479	0,720162
Baseline assessment	BOL	34,64026591	0,981318
Baseline assessment	Realm	19,48079135	0,988747
BOL	Double-accounting	38,63996439	0,068289
BOL	Spatial scale of BOL	133,1721368	0,145667
BOL	Leakage	20,76075524	0,291655
BOL	Significance	29,09510848	0,356302
Geographical coverage	Realm	33,58506272	0,000784
Geographical coverage	Payment approach	17,92975315	0,00641
Geographical coverage	BOL	33,72129839	0,013631
Geographical coverage	Issuance	20,07533613	0,065674
Geographical coverage	Reference site	8,760490196	0,067373
Geographical coverage	Significance	10,985181	0,088836
Geographical coverage	Spatial scale of BOL	33,44838235	0,149484
Geographical coverage	Outcome	16,48163515	0,170158
Geographical coverage	Leakage	5,274735294	0,260251
Geographical coverage	Baseline assessment	11,43647876	0,491928
Geographical coverage	Double-accounting	5,160735294	0,523369
Issuance	Leakage	46,53174026	5,62E-06
Issuance	Significance	51,78717949	4,03E-05
Issuance	Double-accounting	47,26664683	0,000193
Issuance	Realm	50,34147688	0,056699
Issuance	Baseline assessment	47,33664021	0,097869
Issuance	Project permanence	73,52095238	0,112762
Issuance	Spatial scale of BOL	76,32571429	0,532485
Issuance	BOL	49,15470899	0,661392
Leakage	Double-accounting	40,49418182	3,64E-07
Outcome	BOL	93,54232804	0,00068
Outcome	Significance	31,4543956	0,02549
Outcome	Project permanence	78,66150794	0,05339
Outcome	Leakage	20,62034632	0,056224
Outcome	Double-accounting	28,1531746	0,059762
Outcome	Realm	39,25411614	0,326133
Outcome	Spatial scale of BOL	79,0234127	0,446332
Outcome	Issuance	34,73424036	0,528721
Outcome	Baseline assessment	24,40343915	0,928975
Payment approach	Leakage	47,2187013	1,69E-08
Payment approach	Significance	49,38434066	1,41E-07
Payment approach	Double-accounting	39,484375	9,42E-06
Payment approach	Issuance	55,60085034	1,03E-05
Payment approach	Outcome	37,52338435	0,004476
Payment approach	Project permanence	44,61607143	0,041894
Payment approach	BOL	32,67002442	0,208178

Continues on the following page.

Table 13 (Continued)

Variable 1	Variable 2	Statistically X^2	p_Value
Payment approach	Spatial scale of BOL	44,08452381	0,265255
Payment approach	Realm	19,36457409	0,369704
Payment approach	Baseline assessment	19	0,391823
Project permanence	Spatial scale of BOL	177,8716667	0,003392
Project permanence	Leakage	35,29163636	0,018605
Project permanence	Baseline assessment	83,81111111	0,022879
Project permanence	Double-accounting	46,64236111	0,026957
Project permanence	Significance	45,1274359	0,037561
Project permanence	BOL	109,3360684	0,081031
Project permanence	Realm	31,57487923	0,999075
Realm	BOL	129,1358497	4,27E-08
Realm	Leakage	25,939345	0,010948
Realm	Significance	26,40906195	0,090766
Realm	Double-accounting	24,6146049	0,135905
Realm	Spatial scale of BOL	60,4905452	0,929032
Reference site	BOL	28,58985755	0,053628
Reference site	Spatial scale of BOL	32,2437037	0,185186
Reference site	Realm	15,39756154	0,220411
Reference site	Baseline assessment	11,75185185	0,465809
Reference site	Payment approach	5,232539683	0,514353
Reference site	Issuance	10,67417989	0,557028
Reference site	Significance	4,157264957	0,655404
Reference site	Leakage	1,877737374	0,758233
Reference site	Project permanence	15,07333333	0,772196
Reference site	Double-accounting	2,522777778	0,86591
Reference site	Outcome	5,237566138	0,94957
Significance	Leakage	43,66545455	8,61E-08
Significance	Double-accounting	41,59051282	3,9E-06
Spatial scale of BOL	Leakage	40,18327273	0,037426
Spatial scale of BOL	Significance	42,6525641	0,31692
Spatial scale of BOL	Double-accounting	37,07902778	0,557761
Status	Geographical coverage	15,96600275	0,042869
Status	Outcome	36,38766789	0,05031
Status	Territorial scale	26,77881093	0,141602
Status	Issuance	29,25869091	0,210547
Status	Reference site	8,575905576	0,379324
Status	Leakage	7,525214785	0,481165
Status	Payment approach	11,47233124	0,488931
Status	Spatial scale of BOL	50,47875458	0,533893
Status	Project permanence	37,46004274	0,585193
Status	Baseline assessment	21,8215812	0,589915
Status	Realm	21,39036395	0,615603
Status	Significance	9,871273598	0,627253
Status	BOL	31,70092984	0,673239
Status	Double-accounting	3,746062271	0,987595
Territorial scale	Payment approach	49,85760073	1,27E-05
Territorial scale	Leakage	40,33633566	1,48E-05

Continues on the following page.

Table 13 (Continued)

Variable 1	Variable 2	Statistically X^2	p_Value
Territorial scale	Significance	48,64824458	2E-05
Territorial scale	Issuance	67,22380952	0,000113
Territorial scale	Double-accounting	43,03053419	0,000156
Territorial scale	Geographical coverage	20,1598454	0,027777
Territorial scale	Outcome	43,31605617	0,054938
Territorial scale	Project permanence	65,71564103	0,067209
Territorial scale	Realm	38,11266656	0,146878
Territorial scale	Baseline assessment	37,93504274	0,151424
Territorial scale	BOL	54,13421872	0,165106
Territorial scale	Spatial scale of BOL	75,37153846	0,177979
Territorial scale	Reference site	7,872820513	0,641258

APPENDIX G: R-SCRIPT FOR FREQUENCIES DISTRIBUTION ANALYSIS

Author: André Luiz Ramos Lino

1. LOADING NECESSARY PACKAGES

```
install. packages (c ("readxl", "dplyr", "ggplot2", "tidyr"))
library(readxl)
library(dplyr)
library(tidyr)
library(ggplot2)
```

2. Data Loading and Preparation

```
dados_raw <- read_excel("tabela.xlsx")
dados <- as.data.frame(dados_raw)
rownames(dados) <- dados[[1]]
dados <- dados[,-1]
ordem_original_variaveis <- colnames(dados)
```

3. Preparing the Data for the Chart

```
dados_long <- Data %>%
  pivot_longer(
    cols = everything(),
    names_to = "Variable",
    values_to = "Value"
  )
dados_long$Variavel <- factor(dados_long$Variavel, levels = ordem_original_variaveis)
```

4. Generating the Frequency Graph in the Correct Order

```
grafico_frequencias_todas <- ggplot(dados_long, aes(x = as.factor(Valor))) +
  geom_bar(fill = "#0073C2FF", alpha = 0.8) +
  # O facet_wrap agora respeitará a ordem do fator 'Variavel'
  facet_wrap(~ Variavel, scales = "free") +
  labs(
    title = "Frequency Distribution for All Variables"
    x = "Value / Score Assigned",
    y = "Frequency"
  ) +
  theme_bw() +
  theme(
    axis.text.x = element_text(angle = 45, hjust = 1, size = 7),
    strip.text = element_text(face = "bold"),
    plot.title = element_text(hjust = 0.5, face="bold"),
    plot.subtitle = element_text(hjust = 0.5)
  )
print(grafico_frequencias_todas)
```

APPENDIX H: R-SCRIPT FOR CHI-SQUARE TEST

Author: André Luiz Ramos Lino

1. LOADING NECESSARY PACKAGES

```
install. packages (c ("readxl", "dplyr", "cluster", "ggplot2", "tibble", “ggraph”, “igraph”))
library(readxl)
library(dplyr)
library(tidyr)
library(cluster)
library(tibble)
library(ggplot2)
library(ggraph)
library(igraph)
```

2. DEFINING PARAMETERS AND FILE NAMES

Input Parameters

```
data_raw <- read_excel("table_data.xlsx")
data <- as.data.frame(data_raw)
rownames(data) <- data[[1]]
data <- data[,-1]
```

3. Chi-Square Association Analysis

```
variable_names <- colnames(data)
num_variables <- length(variable_names)
chi_results <- data.frame(
Variable_1 = character(),
Variable_2 = character(),
Chi_Square_Statistic = numeric(),
p_value = numeric(),
stringsAsFactors = FALSE
)
for (i in 1:(num_variables - 1)) {
for (j in (i + 1):num_variables) {
var1_name <- variable_names[i]
var2_name <- variable_names[j]
temp_table <- table(data[[var1_name]], data[[var2_name]])
temp_test <- suppressWarnings(chisq.test(temp_table))
chi_results <- rbind(chi_results, data.frame(
Variable_1 = var1_name,
Variable_2 = var2_name,
Chi_Square_Statistic = temp_test$statistic,
p_value = temp_test$p.value
))
}}
dados_rede <- resultados_qui %>%
  filter(p_valor < 0.05) %>%
  mutate(forca = -log10(p_valor))
rede <- graph_from_data_frame(d = dados_rede, directed = FALSE)
grau_nos <- degree(rede, mode = "all"
```

```
V(rede)$grau <- grau_nos
rede_plot <- ggraph(rede, layout = 'stress') +
  geom_edge_arc(
    aes(width = forca, color = forca),
    strength = 0.15,
    alpha = 0.6
  ) +
  scale_edge_width(
    range = c(0.5, 1.5),
    name = "Força (-log10(p))"
  ) +

  scale_edge_color_distiller(palette = "RdYlBu", direction = -1) +
    geom_node_point(aes(size = grau), color = "#4682B4", alpha = 0.9) +
  scale_size_continuous(range = c(4, 12), name = "No. of Connections") +
    geom_node_text(aes(label = name), repel = TRUE, point.padding = unit(0.3, "lines"), size = 3.5) +
    guides(
    edge_width = "none",
    color = guide_colorbar(
      title = "Força",
      title.position = "top",
      barwidth = unit(1, "cm"),
      barheight = unit(5, "cm")
    )
  ) +
  theme_graph(base_family = 'sans') +
  labs(title = "Association Network between Variables (p < 0.05)")
print(rede_plot)
```

APPENDIX I: R SCRIPT FOR GOWER DISTANCE AND K-MEDOIDS/PAM ANALYSIS

Author: André Luiz Ramos Lino

1. LOADING NECESSARY PACKAGES

```
install. packages (c ("readxl", "dplyr", "cluster", "ggplot2", "ggrepel", “ggplotify”, “pheatmap”))
library(readxl)
library(dplyr)
library(tidyr)
library(cluster)
library(pheatmap”)
library(ggplot2)
library(ggplotify)
library(ggrepel)
```

2. Loading and Diagnostics of the Dataframe 'Data'

```
data_raw <- read_excel("data.xlsx")
data <- as.data.frame(data_raw)
rownames(data) <- data[[1]]
data <- date[,-1]
# INSPECT THE DATA STRUCTURE
str(data)
# INSPECT THE DATA SUMMARY
summary(data)
# Step 2: Distance matrix
# Gower distance
distance_gower_orgs <- daisy(dados, metric = "gower")
# Heatmap Gowers distance
print("Gower Distance Matrix Between Variables:")
print(round(variable_distance_matrix, 2))
print("Generating the heatmap...")
p <- pheatmap(
variable_distance_matrix,
main = "Heatmap of Gower Distance Between Variables",
clustering_distance_rows = gower_distance_variables,
clustering_distance_cols = gower_distance_variables,
color = colorRampPalette(rev(c("#D73027", "#FC8D59", "#FEE090", "#FFFFBF", "#E0F3F8", "#91BFDB",
"#4575B4")))(100), # Color palette (red-blue)
border_color = "white",
display_numbers = TRUE,
number_format = "%.2f"
)
```

3. Cluster Number and PAM Algorithm Diagnostics

```
k_great <- 5
# Executar o algoritmo PAM
pam_resultado <- pam(distancia_gower_orgs, k = k_great)
str(pam_results)
print(pam_results)
```

4. Calculate Coordinates and Prepare Data

```
# Calculate the coordinates for the graph using MDS
coordinates_mds <- cmdscale(distance_gower_orgs)
# Create the dataframe for the plot
plot_data <- data.frame(
  X = coordinates_mds[, 1],
  Y = coordinates_mds[, 2],
  Cluster = as.factor(pam_results$clustering),
  Organization = rownames(data)
)
```

5. Calculate the Convex Hull Vertices for Each Cluster

```
hull_data <- plot_data %>%
  group_by(Cluster) %>%
  slice(chull(X, Y))
print("Points that form the edge of each cluster:")
print(hull_data)
```

6. Create the Chart with the Boundary Polygons (Fixed)

```
grafico_com_limites <- ggplot(plot_data, aes(x = X, y = Y, color = Cluster)) +
  geom_polygon(data = hull_data, aes(fill = Cluster), alpha = 0.2, show.legend = FALSE) +
  geom_point(size = 4, alpha = 0.8) +
   geom_text_repel(
    aes(label = Organizacao),
    size = 3,
    show.legend = FALSE,
    max.overlaps = 30
  ) +
   labs(
    title = "Cluster visualization (K-Medoids/PAM)",
    subtitle = "Multidimensional Scaling (MDS) based visualization with Convex Hull for each group",
    x = "MDS Coordinate 1",
    y = "MDS Coordinate 2",
    color = "Cluster"
  ) +
  theme_bw() +
  scale_color_brewer(palette = "Set1") +
  scale_fill_brewer(palette = "Set1") # Garante que o preenchimento do polígono tenha a mesma cor
# Print Final graphic
print(graphic_with_bounds)
```

7. GENERATE FACETED BOXPLOT

```
cluster_list  <- sort(unique(data_with_clusters$Cluster))
filter(Cluster == current_cluster)
        variables_to_plot  %
                pivot_longer(
                cols = all_of(variables_to_plot),
                names_to = "Variable",
                values_to = "Value")
        long_data$Variable <- factor(long_data$Variable, levels = variables_to_plot)
        individual_profile_plot <- ggplot(long_data, aes(x = Variable, y = Value, fill = Variable)) +
```

```
        geom_boxplot(show.legend = FALSE, na.rm = TRUE) +
        geom_jitter(width = 0.1, alpha = 0.4, height = 0, na.rm = TRUE) +
        labs(
        title = paste("Profile of Variables for the Cluster", current_cluster), # Dynamic title
        subtitle = paste("Based on", nrow(filtered_data), "Organizations"), # Dynamic subtitle
        x = "Methodological Variable",
        y = "Assigned Value"
        ) +
theme_minimal(base_size = 11) +
theme(
axis.text.x = element_text(angle = 60, hjust = 1, size = 9),
plot.title = element_text(hjust = 0.5, face = "bold"),
plot.subtitle = element_text(hjust = 0.5)
)
print(individual_profile_plot)
```