MISTRA
The Swedish Foundation for
Strategic Environmental Research

Background paper

Aligning Markets with Biodiversity

june 2021

Expert Panel Members:
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Charlie Dixon, Vivid Economics
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1 Background and Mission

According to the statutes of Mistra, research funded by the foundation should "promote the development of strong research environments of the highest international class with importance for Sweden's future competitiveness" (Mistra, 2018[1]). The research should find solutions to important environmental problems and enhance the sustainable development of society. The funding call to be developed by Mistra will be based on this background paper and analysis of the current state of the art of research and knowledge relevant to this domain.

The aim of the funding call is to overcome critical research gaps impeding the alignment of the global economy with the needs of biodiversity. Biodiversity is critical for the functioning of the biosphere (Rocktrom et al, 2009[2]) and thereby long-term human well-being as well as economic prosperity. It is itself a large and complex field. A well-developed body of literature on the human-induced impacts on biodiversity already exists, yet there has been comparatively little focus on the economic systems and financial instruments that incentivize these actions. There is an urgent need for research to identify how global markets have led to pernicious links between global economic activity and biodiversity loss and, most critically, the actions that can be taken to decouple them.

Markets play an important role directing the way in which the world interacts with nature. Human impact on biodiversity is largely defined by our production and consumption patterns. Economic markets have enabled the global population to maximize the benefit it gains from the ecosystem services that the natural environment provides. This extends far beyond food and the extraction of natural resources. We also use, and to some extent pay for, ecosystem services including the supply and filtration of water, the use of fertile agricultural land, and through insurance for flood damage.

Markets are not only failing to preserve global biodiversity, they are incentivizing and financing its destruction. The species extinction rate over the last 50 years has reached 1,000 times its background rate (International Resource Panel, 2019[3]). Species abundance, ecosystem integrity and genetic diversity have all been driven downwards by land-use change, over-exploitation, climate change and pollution. This misalignment reflects fundamental weaknesses and failures in the global economy, including the design of global finance, both private and public.

Policy designed to address the loss of biodiversity has generally been of value, but policy makers have focused on protection and conservation and failed to recognise and trigger the systemic change that is needed. Policy debate concerning biodiversity has tended to focus on either command and control policies to protect areas of high biodiversity value, more or less prescriptive recommendations for how to show concern for biodiversity in different sectors, or raising finance for conservation activities. While these measures have been essential and much of the reason we still have patches of wilderness left, broader, systemic solutions are needed that confront our damaging relationship with biodiversity. In their broader activities, governments maintain the status quo through, for instance, subsidies and procurement regimes that damage biodiversity and the long-term interests of taxpayers and of future generations.

To align the global economy with the needs of biodiversity, we need well-governed and tightly defined biodiversity markets complemented by ambitious protection and management of biodiversity. Biodiversity can no longer solely exist outside of the global economic system. Our dependence on ecosystem services inextricably links biodiversity to global production and consumption. As a result, markets will always have a role to play in the solution to the biodiversity crisis. We must find a way to shape and govern markets so that corporate objectives are aligned with radically reducing our impact. But this must be complemented with protection policies that act as guardrails, protecting the most valuable nature that remains and helping steer the global economy to stay within planetary boundaries.

This first requires an understanding of how biodiversity and the economy interact and how this interaction can be managed and measured. This begins with how businesses, policy makers and citizens across the world make decisions and manage competing objectives. From this, we can identify the entry points for biodiversity and how sufficient value might be attached to it to cause a shift in behaviour. Finally, in order to monitor progress and learn what is successful, we need clear, cost-efficient and standardized methods to track biodiversity outcomes.

But transformative change will not occur until biodiversity and its societal values are material to financial decision-making. Systemic solutions require the transformation of financial markets and public finance, rules established through law, regulations and standards, and the behaviour of citizens and institutions. There is no one 'silver bullet' that can deliver such solutions, and we cannot rely on broad, long-term policy and business commitments alone to catalyse the changes needed.

2 Understanding the Biodiversity-Economy Nexus

2.1 Biodiversity

For the purpose of this background paper, we will align with the UN Convention on Biological Diversity's (CBD) definition of biodiversity:

"'Biological diversity' means the variability among living organisms from all sources 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 of ecosystems."

The paper will explore research concerning the management, measurement and governance of the "biodiversity-economy nexus", using this definition as a guiding frame. The paper will in the first instance be concerned with biodiversity outcomes and their relationship with economic actors, institutions and governance, as well as their representation in relevant metrics, data and analytical techniques. In addition, the paper will consider the health and efficacy of natural support systems and ecosystems and their links with biodiversity depends (such as natural ecosystems), their relationship with economic actors and so on. While rooted in the CBD's definition, this also draws inspiration from the broader range of definitions offered in the literature for biodiversity, nature and natural capital (see Annex I).

Biodiversity depends on natural support systems and many natural systems depend on biodiversity. Both are dynamic and resilient. The health and integrity of biological systems are constantly changing. Their evolution is not linear. Multiple stressors can combine in specific geographies and on specific dimensions of biodiversity leading to rapid and unanticipated change (Bowler et al, 2020[4]). Yet biodiversity and its natural support systems are also regenerative and so in most cases, if left undisturbed, they will reach a new equilibrium, and in some cases strengthen, over time. As a result, global biodiversity outcomes are constantly in flux making their management, measurement and governance complex.

In this paper, we must be pragmatic in defining what we mean by positive biodiversity outcomes. To help orient our focus within this paper, we identify two common goals for global biodiversity that reflect consensus in the field (Locke et al, 2021[5]):

- Species loss should be slowed down to close to the background rate.
- Ecosystem services (see further discussion in section below) should be maintained in a resilient state (including but not limited to climate, water and nutrient regulation, pollination and food).

The attributes of biodiversity and associated data and metrics discussed in this paper should closely reflect performance in delivering positive biodiversity outcomes, as defined above. There is a range of data relevant to the state of biodiversity including species and habitats, the availability and quality of natural capital assets, ecosystem distribution and threat status, site importance and protection

status, and conservation priority. In the use of metrics, we must balance data availability with ensuring the data is meaningful and a true reflection of performance against our defined objectives.

Of particular concern are planetary boundaries or "tipping points" associated with large and irreversible impacts. Tipping points mark a shift for a natural system between two previously stable equilibriums. As (often human-induced) impacts on the natural system accumulate, it moves closer to a threshold, after which an accelerating and irreversible transition to a new equilibrium is triggered. For example, clear lakes can become turbid and dominated by algal blooms, coral reefs become overgrown by macroalgae, fisheries collapse owing to overexploitation, and tropical forests shift to savannah-type ecosystems under high fire intensity (Dakos et al, 2019[6]). The thresholds associated with some of the world's most critical natural systems have been coined planetary boundaries (Rockström et al, 2009 [7]).

2.2 Biodiversity and the Economy

Over the past couple of decades, a substantial body of research has evolved trying to describe the variety of benefits that biodiversity and ecosystems provide human society through goods and services, and the values of these benefits (including economic value, health value and social value). This surge in academic interest was partly a result of the Millennium Ecosystem Assessment (MA) in 2005 – at the time the largest body of social and natural scientists ever assembled to assess knowledge of ecosystems. The MA defined ecosystem services simply as "the benefits that people obtain from ecosystems" (Millennium Ecosystem Assessment, 2005[8]). Importantly, it emphasised that ecosystems provide not only provisioning services such as food, water or timber, but also values that are less visible or not perceived at all, including supporting, regulating and cultural services. These were later categorised and systematised in the Common International Classification of Ecosystem Services (CICES).

Ecosystem services as a concept and as an approach to demonstrate the values of nature has since mushroomed and the thinking has been refined and widely applied. In 2007, the G8 initiated the Economics of Ecosystems and Biodiversity (TEEB) initiative to study the economic benefits of biodiversity and the economic costs of its degradation and loss in order to help mainstream the values of biodiversity and ecosystem services into decision-making at all levels. The second phase of the study was hosted by the United Nations Environment Programme (UNEP) and its final report published in 2010 (TEEB, 2010[9]). In 2019, the OECD prepared a report setting the economic and business case for the G7 and other countries to take urgent and ambitious action to halt and reverse global biodiversity loss, presenting an assessment of current biodiversity-related finance flows (OECD, 2019)[10]. Commissioned by the British government, Partha Dasgupta of St John's College, Cambridge, produced the "Dasgupta Review" of the economics of biodiversity, published in 2021[11].

It is evident from these reviews and seminal reports (which all build on scientific results available at the time) that biodiversity is at the heart of the functioning of ecosystems and thereby of the goods and services that they provide (there is some debate about to what extent biodiversity in itself should be viewed as an ecosystem service. See, e.g. Jax & Heink, 2015)[12]. As described above, biodiversity has more dimensions than simply the number of species of organisms. It includes diversity and abundance of living organisms, the genes they contain and the ecosystems in which they live[13]. Biodiversity affects both biotic and abiotic parts of ecosystems. For the most part, its role in the functioning of ecosystems is carried out in silence and out of sight, performed by tiny organisms.

In 2013, the EU Mapping and Assessment of Ecosystems and their Services (MAES) initiative described and conceptualised these connections (Maes et al,

2013)[14]. According to MAES, biodiversity enhances the efficiency of ecological processes, e.g. through nutrient cycling. Other key determinants of ecosystem functioning that biodiversity provides include functional diversity (the number of functional groups in an ecosystem) and biophysical structures. Biodiversity also has dimensions that are more directly linked to ecosystem services, such as genetic diversity, species richness and biotic interactions. Dasgupta explains these linkages in more detail.

While well-functioning and resilient ecosystems, supported by and in turn supporting rich biodiversity, provide immeasurable value to human wellbeing, on the flipside, degraded, polluted and overexploited ecosystems support lower biodiversity and deliver fewer benefits (Maes et al, 2012b)[15]. They can even increase costs or generate new issues that can instead jeopardise human wellbeing and development. Infectious diseases and zoonosis, such as the COVID-19 pandemic, are a striking example, driven largely by land-use change and species overexploitation (Dasgupta, 2021)[16]. Another example is the degradation of pollination and soil fertility from intensive use, raising the costs of production by requiring additional input of energy, water and chemicals.

In the post-World War II era, quality of life has improved at an astonishing rate for large parts of humanity. This is a remarkable achievement, but it has come at a high price for the environment and for future generations. This rapid development has fuelled an unprecedented demand for natural resources, often used in a linear fashion without retaining the value of products or materials once they reach the end of their intended lifetime. All over the world, natural resources are extracted at a rate that far exceeds the system's ability to replenish them (to the extent replenishment is possible). Our demand directly and indirectly drives pressures such as land-use change, emissions and release of toxic chemicals to the environment, in turn generating a range of environmental impacts, including freshwater depletion and pollution, land degradation – and loss of biodiversity. According to IPBES, there has been a decline in 14 of 18 categories of Nature's services, including purification of water, air quality, and disease regulation, since the early 1970s (IPBES, 2019)[17]. According to the OECD, between 1997 and 2011, the world lost an estimated USD4-20 trillion per year in ecosystem services owing to land-cover change and USD6-11 trillion per year from land degradation (OECD 2019)[18].

IPBES identifies five direct drivers of biodiversity loss or "pressures". These are to a significant extent driven by indirect drivers such as values, demography, innovation, trade & governance (IPBES, 2019). They emerge due to human economic activities (e.g. fisheries, agriculture, logging, harvesting, mining, infrastructure, tourism, transport, restoration). The five categories are as follows[19]:

- **Land/sea use change:** Land-use change is the major human influence on habitats and can include the conversion of land cover (e.g. deforestation or mining), changes in the management of the ecosystem or agro-ecosystem (e.g. through the intensification of agricultural management or forest harvesting) or changes in the spatial configuration of the landscape (e.g. fragmentation of habitats). For terrestrial and freshwater systems these anthropogenic alterations of habitats have been the largest contributor to biodiversity decline in the past decades.
- **Direct exploitation:** This refers to the overexploitation of living organisms through hunting, fishing, logging and similar practices. For marine systems this driver has been the main cause of biodiversity decline.
- **Climate change:** Climate change is currently a major driver of change in nature, with strong direct global impacts, that also affect impacts of other drivers. The effects of all of these changes – temperature, precipitation, and frequency and intensity of extreme weather events – can accumulate and interact for further unexpected non-linear change, with eventually irreversible impacts on nature and ecosystem services.

- **Pollution:** Pollution of air, water and soils through, e.g., untreated urban and rural waste, pollutants from industrial, mining and agricultural activities, oil spills and toxic dumping have negative effects on ecosystem health and lead to declines in biodiversity. While there has been progress in certain pollutants and world regions, other pollution processes, such as plastic pollution in the oceans, show increasingly negative effects on biodiversity. Invasive alien species: The introduction of species through human activities (transport, gardening, etc.) into areas where they are not native has contributed to declines of biodiversity as local species are replaced by the introduced ones. Currently, the rates of species introductions are higher than ever before (Seebens et al, 2017)[20].
- **Invasive alien species:** The introduction of species through human activities (transport, gardening, etc.) into areas where they are not native has contributed to declines of biodiversity as local species are replaced by the introduced ones. Currently, the rates of species introductions are higher than ever before.

By maximising our take-out of primarily provisioning services (often enabled through use of synthetic pesticides, fertilisers and other chemicals), there has been a corresponding loss in the biosphere's overall productivity in terms of regulating, maintenance and cultural services (Dasgupta, 2021)[21].

Restoring lost ecosystem functions may not be possible, or only at enormous costs and very long time scales. In most cases, they cannot be imitated or replaced with hard engineering solutions, or again only at very high costs. If pushed too far, ecosystem degradation can reach a state where its capacity to bounce back is lost altogether (Rockström et al, 2009)[22]. Certainly, once a species is lost, it cannot be recreated.

2.3 Biodiversity Finance

Over the last few decades, academic debate concerning "biodiversity finance" has tended to focus on raising money for conservation activities, through an ever-increasing array of different financing mechanisms. Figure 1 below visualizes the semantic content of scientific articles published since 1970 on the topics of biodiversity finance. The prominence of the terms "management", "conservation" and "protected" illustrate this point.

Yet more recently, there has been a broader discussion regarding how the global economy, the financial sector, and global biodiversity interact. This nexus is concerned with understanding the global economy's impacts on nature as well as its dependencies on nature, and the global financial sector's role in shaping this.

The *concept of risk* has been the core conceptual frame for thinking to date. Several types of biodiversity-related financial risks have emerged (PWC & WWF, 2020): [23]

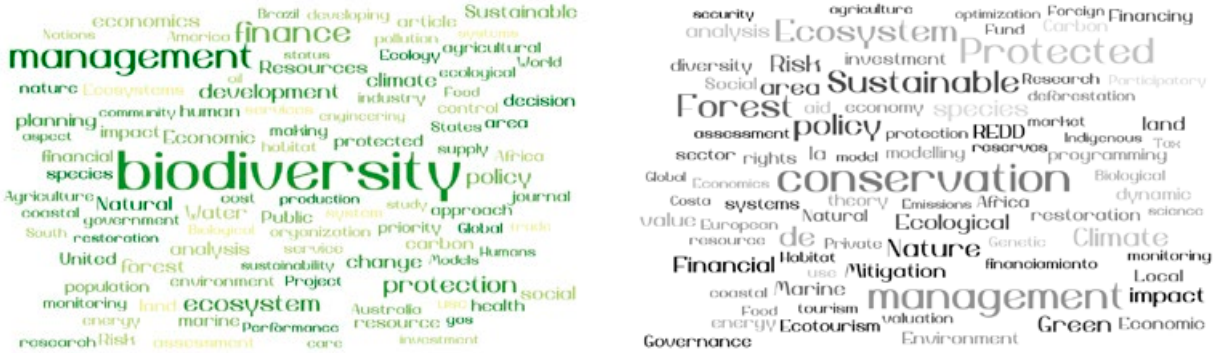

FIG 1 Visualized semantic content of the scientific articles published since 1970 on the topics of biodiversity finance: (left) AI-tagged keywords, based on their frequency in texts, (right) authors' own tags.

1. **Transition risks**, or risks related to the transition to an economy which conserves and restores biodiversity. These types of risks may entail extensive regulatory, legal or liability, technological and market changes and may lead to reputation risks. In order to conserve and restore biodiversity for public benefit, policymakers may use a variety of policy and regulatory tools such as restrictions on access to land and resources, quotas and thresholds, disclosure requirements, compensation costs and taxes, procurement standards, licensing and permitting procedures, or even prohibitions and bans. For affected businesses, this can lead to higher costs, lower revenue and increased litigation risk if their operations are not aligned with the biodiversity-positive transition. Technological innovations towards more sustainable technologies can disrupt markets and changing consumer preferences might shift market demand. These go hand in hand with financial risks such as increased costs of capital or lending requirements, asset write-offs, increased insurance claims, higher premiums, and loss of insurance value. The negative perception of a business is a severe reputational risk and negative press coverage can even lead to a business going bankrupt.
2. **Physical risks**, or risks related to the physical impacts of biodiversity loss causing direct economic and financial losses for businesses and investors. The materialisation of biodiversity risks can damage assets and infrastructure or cause a deterioration in supply chains or business operations (resource dependency, scarcity and quality). Risks can be either acute, because they are event driven such as a natural disaster, or chronic, because they materialise over time such as the depletion of natural resources.
3. **Liability risks**, or risks related to litigation and broader liability claims pertaining to biodiversity loss and breach of the underlying legal frameworks (e.g. case law or reporting breach of biodiversity loss).
4. **Systemic risks**, or risks related to systemic impacts of biodiversity loss. Systemic risks can refer to (i) the risk that a critical natural system no longer functions properly; (ii) risks that arise at portfolio-level (rather than at organization or transaction-level) of a financial institution; and (iii) a risk to system-wide financial stability. Note that both physical risks and transition risks can develop into systemic risks. The financial system can be affected exogenously, such as through a sudden event causing at-scale biodiversity loss, or endogenously due to a failure in banking functions as a result of biodiversity loss.

Not all types of risk or drivers of biodiversity loss ('pressures') will be material, or significantly relevant, for a company. Therefore, financial decision makers are interested in tools and methods which can 'screen' risks and pressures based on how relevant they are to the portfolio of assets that they hold. There are a number of challenges and opportunities for data science and AI to assist in this domain:

- Deployment of the data science techniques to new and existing datasets, including alternative data, to support financial institutions and financial regulators in the transition to global environmental sustainability.
- Analyse the performance of (un)sustainable investments in different asset classes using novel datasets.
- Harness new technologies, including distributed ledgers and smart contracts, to enable the efficient deployment of capital into sustainable investments across different asset classes, sectors, and geographies.
- Ensure greater data quality, consistency, and comparability, including through better data assurance and new data standards.

These innovations can lead to ultra-transparency that can address current imbalances in information that exist between companies and their investors, and

between financial institutions and their regulators. This has potential to help align the financial system with environmental sustainability. At the same time, potential challenges with deploying data science and AI in this domain should not be overlooked, nor should potential unintended consequences related to, for instance, privacy or corporatisation.

3 Managing the Biodiversity-Economy Nexus

3.1 Introduction

To achieve the goals set out in the previous section, we first need to understand how to design an economic system that prioritizes its impact on biodiversity. This requires a combination of proper functioning "biodiversity markets" complemented by effective governance and biodiversity protection. Biodiversity markets can price and trade biodiversity-based products and services (e.g. water and flood protection, sustainably caught fish, etc.) at scale and thereby help demonstrate the value of ecosystem services and biodiversity-relevant assets that are currently left outside of the economic equation. Markets can lead to the development of new nature products and assets on their own, driven entirely by demand, and thus open up new horizons for entrepreneurs and innovators. Markets are essential to organizing collective action – they make it possible to aggregate supply and demand into tradeable packages, to trade complex proxies and product attributes, and to translate broad consumer preference into targeted biodiversity outcomes. Highly complex global crises like the current wave of extinction cannot be overcome without a market exchange that can efficiently match varied demand for biodiversity services with a clear and verifiable source of supply. Biodiversity markets can indeed be one part of the solution and a powerful vehicle for change, but they also need to be carefully governed to avoid the downside of excessive financialization.

3.2 Definition

There are three ways to define biodiversity markets. The narrowest definition is restricted to *those exchanges which create a revenue stream explicitly associated with biodiversity or biodiversity-related transactions.* This includes the pricing and trading of products (e.g. pharma prospecting), product attributes (more sustainably sourced fish) and services (ecotourism). It also includes biodiversity offsets (e.g. wetland trading schemes). These markets are vanishingly small and inconsequential in the big picture – offset markets, their largest component, are valued less than USD 2 billion pa (Madsen, Carroll & Moore Brands, 2010). [24]

A broader definition holds that biodiversity markets include all exchanges in which biodiversity is implicitly or explicitly priced and known to at least one of the transacting parties. For example, if one of the parties of an agricultural land transaction is knowingly pricing in all or part of the upside expected from that land's conversion to regenerative practices, then a biodiversity market exchange has just occurred. By that definition, today's biodiversity markets are quite substantial (e.g. global farmland is worth over USD 1 trillion (Wheaton & Kiernan, 2012)[25]; 5-8 percent of global crop production is directly attributable to natural pollination (IPBES, 2016)[26]; many exchanges involving forest lands, fishery access rights,

water rights, etc. fit this definition). In our view, this definition is most useful – it is grounded in actual exchanges and real values in today's markets.

The broadest definition holds an aspirational view that insists that biodiversity markets include all exchanges in which biodiversity value is exchanged, whether or not that value is currently internalized or externalized, and whether or not it is known to one of the transacting parties. By this definition, biodiversity markets are worth USD trillions, regardless of whether this value is currently monetizable. We do not believe that this definition is particularly practical.

3.3 Current practice

There are a lot of ways to think about biodiversity-related revenue streams. A flourishing mangrove forest ecosystem, for example, should produce revenues from carbon capture, flood protection, fish nursery, bioprospecting, and recreation. However, today's markets are failing that mangrove forest, both on the supply side (the units of trade remain undefined), and on the demand side (citizens have no way to access a "mangrove market"). The biodiversity markets that do exist today are largely restricted to proxy markets such as carbon sequestration – these are typically small, restrictive, and risk-averse, and thus often incapable of monetizing the vast ecosystem services that biodiversity provides.

The notable exceptions, to date, include over 400 "triple bottom line" product certification schemes; the global Marine Stewardship Council (MSC) certified seafood market is forecast to surpass USD18.63 billion by 2025. There is much hope in the air: The 2019 Food and Land Use Commission's "Growing Better" report outlines a multi-trillion-dollar market for biodiversity and nature, and most recently there is much talk of 'nature-based solutions': essentially investable domains that deliver economic benefits, directly or through systemic effects such as reduced carbon emissions or climate adaptation.

Such developments, to the extent they are supported by robust evidence and regular objective evaluation, are to be welcomed and encouraged. Yet biodiversity markets cover a trivial amount of global consumer purchases and often do not deliver change in biodiversity outcomes. Underpinning such results to date is partly the failure to develop revenue-generating markets, or to resolve:

> ***"...why does who pay how much to whom for what..."***
>
> ***"...can enough revenues be generated to pay for sustaining biodiversity and its gifts to us..."***
>
> ***"...can negative unintended consequences of monetarizing biodiversity be mitigated".***

In addressing these fundamental questions, a number of market design issues become critical, including:

- What biodiversity-relevant products and assets could be traded, and what claims may be made about them that create value to the buyer? If the markets themselves "discover" a biodiversity product or asset, what governs the legitimacy of claims?
- How are those claims indexed, verified and tracked in a standardized, trustworthy way?
- Who owns the products to begin with, when multiple and often competing parties assert claims to biodiversity's services?
- Who is able to buy these products, especially when they involve massive, cumulative claims related to human health and welfare?

- How do we design (or adapt) market exchanges to fit the particular demands of biodiversity-based products?

Even when those challenges are met, citizens all too often do not factor in biodiversity in their decisions, whether through lack of accurate and reliable information, because they are too far removed or disempowered from the use of their own money, or other reasons. Governments, far from coming to the rescue, maintain tax, subsidy and procurement regimes that, in their current formation, often undermine biodiversity markets.

Despite these obstacles, it appears that this is a good time to invest in market development. The transactional complexity of these markets is readily harnessed by existing "etailing" (the selling of retail goods on the internet), supply chain management, and remote sensing platforms. The potential supply of discrete and indisputably "owned" biodiversity products and services is growing exponentially as evolving sensing technologies allow precise measurement and verification of biodiversity performance and attributes over time. At the CBD COP in Kunming, there is massive interest in carbon markets, but little to no coherent framing of the market development agenda. REDD+ markets are a top priority for the COP26 in Glasgow in November 2021, with strong potential tie-ins to the biodiversity agenda. Finally, the twin crises of COVID 19 and climate change have sharpened the financial industry's focus on natural risk (such as the direct correlation between wildlife encroachment and pandemic risk).

3.4 The biodiversity market development agenda

It has been claimed that nature is only investable when people engage with it. Foundational to the biodiversity market development agenda is a modern approach to their governance. Nature markets can be plagued by the same goblins that affect traditional commodity markets:

- "Upstream" problems involving the additionality, permanence and leakage of biodiversity claims;
- "Midstream" problems involving the efficiency of the market and/or trading platform; and
- "Downstream" problems involving the avoidance of rent-taking on high-volume transactions, uncontrolled speculation, and obscure derivatives, as well as a host of other unintended consequences.

Many environmental NGOs, for instance, are sceptical of market-based nature solutions ("neoliberalism for nature") if they cannot demonstrate a robust and adaptive set of guard rails to ensure they provide a trustworthy, efficient and truly additional source of financing for a set of equally trustworthy and effective set of biodiversity protection measures.

An array of governance mechanisms is available for trying to address these problems, including:

- Overarching - multi-stakeholder governance; advanced grievance procedures; public policy (including fiscal incentives, all stream); a radical approach to transparency which makes every single trade a public record.
- Upstream - transition planning.
- Midstream - financial regulation.
- Downstream - certification approaches.

Assuming the governance issues can be addressed, there are a number of other domains at the centre of the biodiversity market development agenda:

Regulatory and standard reform will certainly prove catalytic. Today's nature and biodiversity markets are a far cry from the efficient, highly liquid, standardized, well-structured markets we take for granted in the world's great commodity exchanges. Product standardization is in its early stages, as are protocols for quality control, verification, tracking and data access. Digital technology will prove invaluable to measure, register, track, verify, and trade products and their attributes, empower people in making payments, lending and investing, and holding capital accountable. Future standards will need to balance transaction costs and complexity with the demands of trust and transparency.

Supply development: biodiversity product design. Biodiversity products occupy a central link between carbon investments and "pure" nature investments, particularly in the connection between wildlife and carbon. For example, the link between the restoration of elephant populations, healthy forests, and carbon sequestration is now well established, with the carbon value of a single elephant in the realm of USD 1.75 million (Chami et al, 2021).[27] Similar arguments have been developed for the restoration of whales, and essential habitats such as salt marshes, seagrass beds, and mangrove forests. Building these "carbon/biodiversity" products will require a powerful network which can adaptively, creatively, and pragmatically design, test, and evolve these products, especially for application in consumer markets.

Supply development: rethinking ownership. Property rights are fundamental to all markets, and biodiversity/nature rights need a great deal of innovation on the subject of ownership. Expert networks will be required to develop the right claims labelling and verification protocols, and to address the legal issues endemic to "shared" ownership concepts. This is especially important if specific "layers" of biodiversity value (e.g. bio-prospecting, soil productivity, flood control, clean water) are to be traded separately from the underlying land title.

Shaping the proxy markets. Carbon markets, if designed correctly, can be strong proxies for biodiversity benefits (especially in wildlife carbon and REDD++). These markets offer the most immediate opportunities for rapid growth and liquidity – but also the greatest potential for highly consequential design missteps. There is currently considerable momentum in many of these markets, such as Mark Carney's Taskforce on Scaling Voluntary Carbon Markets. Much technical guidance and standard-setting will be required to avoid unintended consequences and to promote the intended co-benefits for biodiversity/nature.

Demand development: Citizens as investors. Biodiversity markets will not scale unless there is a massive expansion of demand for nature products – especially in terms of (non-institutional) consumer demand. Citizens might be able to act as biodiversity investors in their capacity as consumers, savers, policy holders, pension fund investors, and taxpayers – if they are provided with the agency and information to do so. For example, consumers should find it easy to make their pro-nature preferences known on e-commerce platforms, informed by a new, highly identity-tailored narrative about biodiversity and nature markets. Pension fund investors and taxpayers should be empowered to mobilize against biodiversity-destructive uses of their funds.

Demand development: fractional ownership. Today's biodiversity markets tend to sell mainly to small groups of homogenous and powerful buyers – such as corporations seeking nature/carbon or wetland offsets, pharma companies seeking genetic resources, or government agencies seeking to protect exposed shoreline infrastructure. As a result, exchange values tend to be small, the markets are often gamed in favour of the buyers. New concepts like fractional markets (Fractional markets or fractional ownership allow individuals to hold claim to a portion of a given asset or product. In this way, one asset or product can be jointly owned by many different

individuals)[28] can dramatically expand the buyer pool by consolidating the demand of many individual buyers seeking the same package of benefits – such as, a group of city residents seeking to assure the preservation of a treasured near-by forest, or a group of digital payment platform users creatively joining together to re-establish an elephant herd in Ghana. There are many "shared economy" issues to be sorted out, such as licensing, land use law, agency oversight, etc., but this could truly change the game. Such an approach would require working with the local communities and considering the broader legal landscape.

3.5 Bringing it all together

The example of a Mangrove Forest may explain how these biodiversity market development domains come together in one place. Imagining an intact mangrove forest in Bali, Indonesia – the juvenile habitat of uncountable commercially viable marine species, beloved by tourists, a de facto waste-water treatment facility for massive amounts of big city runoff, and a highly efficient carbon sink. The forest is threatened by a shrimp farm conversion that is highly profitable in the short term and the roadbed for a new by-pass throughway.

Biodiversity markets might come to the rescue by offering alternative revenue streams. However, a number of problems need to be solved first. The forest is owned by the Bali Regency and there is no established protocol and precedent for dividing its services into "units of trade" that can be valorised (new nature ownership concepts). The potential services cover different sectors, of which only carbon offers a working exchange that can be accessed by a broad range of buyers (fractional ownership). Even the available carbon exchanges do not offer a trusted additionality protocol for mangrove forests and are thus massively undervaluing the credits (proxy markets). The markets that do offer a trade have significant transaction costs for small volume trades and thus disadvantage any transaction below 100,000 hectares (nature market governance).

This example demonstrates that, without credible and effective market infrastructure, the value that biodiversity markets can help unlock remains unrecognized. As a result, the ecosystem services and the biodiversity asset it is not appropriately valued by the market and it remains threatened by alternative forms of service provision and profit generation. With this infrastructure in place, markets will be able to build trust, grow over time, and attract finance.

4 Making Biodiversity Financially Material

4.1 Introduction

For biodiversity markets – or the consideration of biodiversity in market contexts – to grow, the global financial industry must itself integrate biodiversity considerations into its investment processes. The financial sector holds significant influence over the structure of the real economy and in many cases determines corporate objectives through its investment criteria. As a result, the growth of biodiversity market infrastructure must be accompanied in parallel with the strengthening of the materiality (or significance) of biodiversity to financing decisions. Once established, this dynamic relationship between the financial sector and the real economy will be reinforcing. If the financial sector demands biodiversity-positive investment opportunities, the real economy will shift to supply them; yet equally, if biodiversity markets demonstrate an ability to more robustly monetize biodiversity-related ecosystem services, the financial sector will demand biodiversity-positive investment opportunities.

4.2 Finance – an Inclusive View

Finance is the lifeblood of the global economy, investing the gains from previous economic success in pursuit of beneficial future outcomes. Global finance is a system of actors, norms and rules, markets and flows (Zadek, 2015)[29]. Traditionally, it is understood in terms of 'private' financial and capital markets and their associated actors and governing institutions, managing around US$350 trillion through banks, equities and bond markets, pension funds and insurance companies (BIS 2021)[30]. This includes roughly US$105 trillion in global bond markets and US$95 trillion in global equity market capitalization (Sifma, 2020).[31]

A broader definition of the global finance is adopted here that extends beyond funds and assets intermediated through the world's financial and capital markets to include public finance, financing decisions, including spending, by individual citizens, and illicit financial flows:

- **Public finance:** government spending accounts for roughly 40% of the GDP in OECD countries[32] and can be used as a powerful demand-side incentive for sustainable development. The balance sheets of sovereign and multilateral development assistance/finance institutions are about US$11.2 trillion[33]. Also in this category are current governments' measures to cushion the blow from the pandemic (US$12 trillion globally, IMF 2020[34]), and future (unknown) recovery stimuli, heavily scrutinized for their impacts on poverty, nature and climate outcomes.

- **Central banking:** central banks have responded to global financial crises and the pandemic with large scale "quantitative easing" and other fiscal interventions. The balance sheets of G10 Central Banks now amount to about US$50 trillion, up US$7.5 trillion since the start of the pandemic. They are increasingly drawing closer to financial inclusion and climate/nature goals. Many of them (e.g. European Central Bank) are now greening their monetary operations by purchasing green and sustainability-linked bonds.
- **Citizen's money:** citizens are the ultimate owners and intended beneficiaries of the funds used by private and public intermediaries. They make financing decisions daily in their roles as consumers, savers, borrowers, lenders, the insured, pension policy holders, and tax-payers. Citizens save US$22 trillion annually (Overall households savings rate estimated at 25.2% of GDP; Worldbank, 2019)[35] and spend US$50 trillion p.a. globally (Macrotrends.net, 2021)[36], with about US$4 trillion in food purchases (McNeil, 2011).[37] Citizen's control over the use of their money has been in decline, a concerning trend which is increasingly counteracted by digitalization (UN Digital Financing Taskforce, 2020).[38] Digital finance can connect citizen investors to green projects, standardized and trustworthy green securities (ACMF, 2018; EU Technical Group on Sustainable Finance, 2019; European Commission - EU Taxonomy for Sustainable Activities, 2019;European Union Technical Expert Group on Sustainable Finance, 2019),[39] and green performance (UNEP 2018).[40]
- **Illicit Financial Flows:** these flows, with estimates varying between US$ 1 -3 trillion p.a. (Heine & Thakur, 2011)[41], are best understood as part of the financial system rather than an aberration or something outside of the system. Such flows are critical in parts of the food system, especially linked to unsustainable damage to nature, such as in the context of logging and overfishing.

4.3 Financial Materiality of Biodiversity – a System Condition

The importance of biodiversity to the global economy, and more broadly to well-being and the transition to sustainable development, has been amply demonstrated in previous sections. At the same time, financing decisions, from investment through capital markets to public financing and citizens' spending, rarely take account of biodiversity related value or risks.

Today's convention definitions of materiality are remarkably narrow, set largely by accountants overlooked increasingly by lawyers. The US-based Auditing Standards Board (ASB), for example, alongside the International Accounting Standards Board, uses the decidedly self-referential definition: "*Misstatements, including omissions, are considered to be material if there is a substantial likelihood that, individually or in the aggregate, they would influence the judgment made by a reasonable user based on the financial statements*" (Louis, 2020)[42].

That biodiversity is immaterial in most of today's financial decisions is not a matter of neglect or error (F4B, 2020)[43]. Modern financing, and the business models in which it invests, has evolved as a chain of specialised parts, designed to ignore in practice what happens at the end of the pipeline. At the top end of the pipeline, it narrowly defines the interests of the owners of the world's financial assets, and at the bottom end, it marginalises citizens affected by changes in the natural environment. It creates disincentives for local communities to protect biodiversity and ecosystem services and in the main ignores the young and future generations. Indeed, for investors in specific sectors, financial returns actively depend on continuing free or under-priced access to ecosystem services and extraction of natural resources.

The current system externalises the negative impacts of government as well as businesses on biodiversity. While being guardians of the public interest, they fail to deal with the longer-term consequences of their short-term policies and political interests. Citizens, as consumers, taxpayers, voters and investors, largely choose to turn a collective blind-eye, or are too far removed from and disempowered with regards to the use of their own money.

Biodiversity's perceived immateriality in financial decision-making is, in short, a system-level failure that is created and sustained as a result of incumbent economic and other interests.

This section provides an outline view of recent developments at the nexus of biodiversity and finance, and in particular in the evolution of action to increase the materiality of biodiversity in financial decision-making.

4.4 Manufacturing Materiality

The challenge is therefore not to simply measure materiality as if it has to be discovered or demonstrated (Accountability, 2003)[44]. It is more a matter of creating biodiversity's materiality in financial decision-making. For example, beyond physical risk, the materiality of climate change is a societal rather than a bio-physical phenomenon. Indeed, even physical risks are often mediated through societal constructs in determining their impact on finance. Such constructs can be created by citizens making their views count as consumers, by demanding policies that variously penalise or incentivise those that impact biodiversity, and by ensuring there are consequences for those companies that fall short of expectations.

Under current laws, corporate governance, judges and regulators can only act where the risk is material, which is a fact-based assessment. Material liabilities can be introduced by means including law, regulatory policy, broadening of fiduciary duties, and demonstrating the majority interests of pension members.

- **Governments** have the power to create financial materiality through formal levers of control and through moral suasion. They can create and defend rights, tax, subsidize, oblige and prescribe.
- **Shareholders and lenders** have some powers of control over corporations. They can pass resolutions on policy, write covenants, demand information and appoint directors.
- **Company directors and trustees** have direct involvement in the decisions of their organisations. They have wide executive powers to lay out the vision and objectives, set policy, design processes and allocate resources.
- **Citizens**, as individuals and through organizations enabling their collective action can apply pressure. They can switch supplier, demonstrate and lobby.

Making biodiversity material requires an effective common framework that considers feedback effects that make biodiversity count, in the same way that we are beginning to see for climate. An effective common framework describes the actors, points of control and feedback loops which internalise impacts, and the political economy that underpins this, namely:

- **Values:** so that established cultures of behaviour result in decisions that incorporate impacts on nature and biodiversity. This helps to overcome indifference or complicity in biodiversity loss and activates citizens and consumers, both individually and collectively, in biodiversity-sensitive financing decisions.
- **Influence:** so that influence is wrested away from concentrated interest groups who benefit from the destruction of nature. Consumers, corporate managers and financiers alike may not value nature and biodiversity sufficiently to drive biodiversity value into financial decision-making. These views are reflected

and amplified in the media and subsequently in politics. Influence should be balanced and reflect the values of society.

- **Rights:** so that the public good character of biodiversity is embedded in national and international legal instruments, and so that entitlements to services are clarified, which will underpin more effective markets. It is harder to establish new rights than to enforce existing ones. Goods and services, which are currently missing because they have already been lost, are more likely to be ignored and neither measured nor recorded. Weak rights for consumers of public goods may mean strong de facto rights for others.
- **Governance:** so that the rules governing finance, at the enterprise, product and market level, and at national and international levels, take biodiversity into account. Many factors contribute to weakened or misaligned governance. Most obvious is the interest of incumbents, whose business or political standing depends on a world where biodiversity is not counted.
- **Efficiency:** so that capabilities of data and institutional structures are in place to support biodiversity-sensitive markets and financing decisions. Data may not be readily available or might be too costly or not calibrated to the needs of financial decision making. New capabilities are costly to build and are often resisted by citizens, banks and ministries of finance. Replace the absence of understanding the value of biodiversity.

4.5 Action on Materiality

Practically, creating materiality through varied forms of agency, pathways and instruments is an on-going process that is path dependent as well as responding to new circumstances. Today, for example, we see the emergence of the Task Force on Nature-related Financial Disclosure (TNFD) that aims to direct global financial flows away from nature negative to nature positive outcomes by developing a framework for organisations to report on nature related risk. The TNFD, however, builds on the experience and positive reputation of the Task Force on Climate-related Financial Disclosure (TCFD) established by the G20's Financial Stability Board in 2016 (TCFD, 2016)[45].

Similarly for central banks and financial regulators. The Network of Central Banks for Greening the Financial System (NGFS) was created in 2019, with an aim of ensuring that its members took due account of the financial stability aspects of climate change (NGFS, 2021)[46]. It emerged alongside TCFD with leadership from the French and Dutch central banks, building on the ground-breaking work on climate and green finance championed in its early stages by the Bank of England and the People's Bank of China. Initially it has focused solely on climate, and indeed mainly the impact of emissions reductions. Now, however it is advancing work on how central banks should incorporate biodiversity related risks into their activities (Jun & Robins, 2021)[47].

In response to perceived limitations in today's narrow conception of materiality, some moves are emerging to advance legal definitions, such as the European Commission's attempts to establish the concept of 'double materiality' as considering financial as well as societal and environmental impacts, whilst others have sought to extend time horizons for materiality through the idea of 'dynamic materiality' (Calace, 2020)[48].

For biodiversity, the TNFD has likewise sought to extend the coverage of what is material. Whereas the TCFD has restricted itself to a narrower, more conventional view of financial materiality, the TNFD has framed the concept 'nature related risks', which seeks to extend analysis, disclosure and ultimately responsibility to include nature dependencies and nature impacts (Zadek, 2020)[49]. Such

an approach has been welcomed by many progressive businesses and civil society organisations but has been a source of concern for others. For the latter group, the proposed approach it is felt might open companies to litigation, especially in reporting on impact and especially in litigation intensive jurisdictions such as the US. That said, there are other developments along comparable lines, including for example moves to establish due diligence reporting obligations for corporations and financial institutions regarding deforestation impacts of their activities (Hawes, Mulley & Williams, 2020)[50].

Aspects of biodiversity can be made more material through proxies that are more advanced or easier to measure. Most obviously, work by UNEP-WCMC and others highlight that the materiality of biodiversity and climate are closely related, although not the same (UNEP-WCMC, 2020)[51]. The physical impacts of nature and climate can compound business risks significantly. The strongest examples exist for agriculture, forestry and fishery, as well as built infrastructure and utilities. A multitude of compounding risks can threaten crop yields including lower rainfall, higher temperatures, declining natural pest control, soil degradation, and climate and nature pressures on pollinators. On the transition side, many of the most carbon-intensive activities also have substantial negative impacts on nature including energy, utilities and large built infrastructure.

4.5 Public Finance

Governments act as financial intermediaries in raising and spending money on behalf of their citizens. Most obviously this concerns tax-raising and fiscal spending, but beyond this governments are active across the world's financial markets, especially fixed income markets, in matching the time profile of financial resources to spending requirements. In addition, of course, is the role of central banks as public bodies in shaping monetary and financial outcomes.

Public finance has many impacts on biodiversity. Positively, are publicly-sponsored programmes to support biodiversity conservation and regeneration. Negatively, are agricultural subsidies that in the main are seen as reinforcing biodiversity damaging food production techniques and systems. There have been concerted attempts over several decades to green public procurement (GPP), with the OECD estimating that 69% of OECD member countries are measuring the results of their GPP strategies and practices (OECD, 2021)[52].

Progress has, however, been painfully slow. Early analysis of the National Resilience and Recovery Plans submitted by EU states to access the US$815 billion, Europe-wide Resilience and Recovery Facility (RRF) indicates that only two cents in the euro are planned to benefit biodiversity – a massive, missed opportunity for jobs, economic stimulus, emission reductions and biodiversity gains (Dixson-Declève & Zadek, 2021)[53]. Similar work on the US$15 trillion pandemic-linked stimulus worldwide spending reaches comparable, disappointing findings for the vast majority of G20 and other major countries considered (F4B, 2021)[54].

International development cooperation is increasingly being channelled through the world's 450 development finance institutions, which have a combined balance sheet of US$11.2 trillion. One recent study published by Finance for Biodiversity estimated the "nature dependency risk" of all DFIs worldwide today at US$3.1 trillion (28%of their balance sheet), and the "nature at risk" due to DFI lending activities at US$1.1 trillion annually (F4B, 2020)[55]. Given this, and their public, development mandate, it is disappointing to note that not one of these financial institutions have a commitment, let alone practice, of undertaking comprehensive biodiversity-related stress tests across their balance sheets. At the time of writing, one DFI has made a broad commitment to progress in this direction, but this has not yet been made public.

4.6 Aligning Finance and Biodiversity

The interaction between biodiversity and finance has historically been understood largely in terms of 'mobilizing finance to invest in biodiversity'. Whilst a worthy aim without doubt, this has always concerned a miniscule volume of funds compared to the global financing that impacts biodiversity. Moreover, such a mobilisation lens focuses the mind on 'end of pipeline' flows, rather than shining a light on the systemic features of finance and its relationship to biodiversity outcomes.

It is time to move on, and recent developments are driving forward that broader perspective and the many other possible policy and market levers that have surfaced as a result. The battle over materiality, as this is rightly what it is, is a keystone and sign of what is at stake in shaping materiality in ways that ensures that biodiversity is adequately counted in financial decision-making.

5 Measuring the Biodiversity-Economy Nexus

5.1 Introduction

With a clear understanding of how and why biodiversity is material to investment decision-making, we can then consider which data is required to feed into this process and how that can be collected and verified. For biodiversity markets to grow, we must have robust and trustworthy information on biodiversity benefits and impacts. Much of the uncertainty around the value that biodiversity brings and the feasibility of integration with economic market systems has been driven by a lack of meaningful, accurate and accessible data. Without a detailed and varied range of data, supported by a credible infrastructure, trust in biodiversity markets will not develop. Equally, as long as data remains disparate and inaccessible, corporate actors across the world will not be held to account for their impacts on biodiversity. Even with this data, we must identify efficient ways of using, organizing and disseminating this data to ensure that biodiversity-aware investors are connected with biodiversity-positive investment opportunities.

5.2 Macro-level Impacts on Biodiversity

With the recognition that economic activity has to take place in a setting of limited natural resources and limited sink capacity of the biosphere, approaches have been developed that assess the physical dimension of our economy. One such line of research is based on the concept of socio-economic metabolism (Haberl et al., 2019; Pauliuk & Hertwich, 2015). Here, the economic system (for instance, at the level of a country), is framed as a system that requires physical inflows of material and energy, uses these flows to create economic benefits and produces physical outflows to the natural environment.

Research has developed tools to quantify the material flows needed to sustain economic processes and to look into how the use of, often limited, natural resources as well as outflows from economic systems affect ecosystems from global to local level (Schandl et al., 2018). For instance, EUROSTAT has operationalized economy-wide material flow accounting in their statistical reporting framework (Eurostat, ND)[56].

Environmentally extended multi-regional input-output models (MRIO) have been used to assess the impact different economic sectors exert on the environment. These models look at monetary flows between economic sectors and countries / world regions and assign resource or environmental impacts in proportion to these flows (Peters & Hertwich, 2008). A strength of these macro-level approaches is that they can be implemented at the global level and that they show which activities, product groups and sectors contribute most to overall pressures

on the environment. However, they are less suited for the assessment of granular comparison between products.

Recognizing the need for comprehensive environmental accounts linked to economic activity, the UN has established a System of Environmental-Economic Accounts (SEEA, 2018)[57] , aimed at complementing traditional monetary accounts with comprehensive environmental statistics. The program also increasingly focuses on accounting for biodiversity and ecosystem services, with the aim of providing an accounting basis for new targets in the CBD processes. A recent report outlines the SEEA's relation to and position on biodiversity and natural capital accounting[58] .

The macro-perspectives of how to quantify environmental costs and consequences of economic activity have recently started to look into assessing biodiversity impacts and the contribution of economic sectors to biodiversity decline. Studies have focused on the number of species threats driven by economic activity (Lenzen et al., 2012), potential species loss due to land use for agricultural products (Chaudhary & Kastner, 2016), and impacts of economic sectors on mean species abundance (Wilting et al., 2021).

5.3 Micro-level Impacts on Biodiversity

A granular and micro-perspective is central to life-cycle assessment (LCA) based work, that tries to comprehensively assess the impacts of individual products or processes (Guinée et al., 2011), offering standardized procedures for applications in industry and companies. A major limitation of these kinds of approaches is that their scalability to assess overall flows and impacts is limited. A recent overview of the current state and challenges of biodiversity in LCA research is provided by (Crenna et al., 2020).

Next to such initiatives at the level of international governmental bodies, there has been increased interest of companies in measuring their environmental performance with regards to biodiversity. This has led to a large number of biodiversity indices being developed, aimed at contributing to a more comprehensive natural capital accounting (WWF, 2019)[59]. These measures build largely on research approaches outlined above (material flow accounting, LCA, MRIO) and try to provide numbers tailored to the needs of reporting at the level of companies and organizations.

The EU Business@Biodiversity Platform has published an assessment of biodiversity measurement approaches for businesses and financial institutions in which they list 19 different approaches with their private sector uptake and case studies. Most tools are addressing 'measuring current performance' and 'comparing options'. The tools are mostly applied at product, site and supply chain level and only to a limited extent at corporate level. The maturity level of tools is relatively high for product level measurements which is due to the fact that these approaches are based on life-cycle assessments (LCA) and have strong methodological basis to start from (although proper integration of biodiversity in LCA is challenging and is currently subject of ongoing research). There is much untapped potential as many tools haven't been applied on their full range of potential applications. Some tools cover different organizational focus areas which can be relevant for obtaining corporate figures (aggregation of outcomes over different organizational focus areas).

These efforts are a reflection of the recognition of the importance of biodiversity, but they also highlight that biodiversity is a complex, multidimensional issue that is much harder to frame and measure than e.g. carbon emissions. All of the currently developed approaches struggle with this multi-dimensional nature of biodiversity and have to compromise in terms of aspects covered and the interpretability of the units of such indices. Extent, condition and significance are generally accepted

elements of an appropriate biodiversity metric, i.e. a metric that performs relatively well at reflecting true biodiversity value. Model-based approaches (Globio or ReCiPe based) relying on metrics such as MSA (mean species abundance) and PDF (potentially disappeared fraction of species) have the advantage of allowing aggregation of results over different organizational focus areas, but they lack the 'local dimension' of biodiversity which is inherent to biodiversity ('biodiversity is location specific'). Such a dimension can be provided by a significance parameter which gives higher weights to endemic and more vulnerable species. Approaches incorporating such a significance parameter such as STAR (through accounting for the threat status of threatened species) while still allowing for aggregation of impacts are able to present a refined picture potentially more valuable for conservation, but they overlook biodiversity values that are not covered by the IUCN Threatened Species List, where the relevant information is often available only for vertebrate species. In line with the need to combine biodiversity measurement approaches to cover multiple angles of biodiversity measurement, there will be an increased need for combined biodiversity indicators.

While each individual approach has relative strengths and weaknesses, they highlight some collective weaknesses:

- **Dimensions of biodiversity:** It is clear that the majority of measurement approaches only covers habitats and species. Only four approaches cover ecosystem services too, two of them in a more qualitative way (Agrobiodiversity index and LIFE Methodology) with the other two offering a full monetization approach, i.e. Kering's E P&L approach and LafargeHolcim's approach, not surprisingly approaches developed and applied by businesses who aim to have monetized outcomes. By now, none of the assessed approaches covers genetic biodiversity.

- **Pressures on biodiversity:** Apart from the Product Biodiversity Footprint (PBF), there is no other approach that covers all pressures; PBF only covers products and at this stage it must be acknowledged that coverage of overexploitation and invasive alien species has not been widely applied (see case studies on salmon and shower gel). All approaches cover land use, while the picture for other pressures is mixed. Both Global Biodiversity Score (GBS) and Corporate Biodiversity Footprint (CBF) rely on GLOBIO and are very similar in terms of covered pressures.

- **Setting biodiversity targets:** At the beginning of 2021 new CBD targets are still under consideration and are expected to be central elements of a Global Biodiversity Framework (GBF) to be agreed under the CBD at COP 15. How businesses will be addressed is yet to be defined. However, that businesses will have to become a key part of the solution to global biodiversity in some form is obvious. In this context the science-based targets for nature network has published initial guidance33. More concrete targets will become available soon (announced for 2022). So, 2021 and 2022 will bring more guidance and help corporates to set biodiversity ambitions and targets embedded within internationally accepted frameworks. Based on current indications regarding contents and direction of these biodiversity target frameworks, companies will need to rely on a combination of biodiversity measurement approaches. Today, there is no single tool available that addresses all expected requirements. But also, vice-versa, none of the tools can be qualified yet as not suitable for tracking progress to these targets (albeit partially). The choice is clearer with regard to measuring against a 'No Net Loss' or 'Net Gain' target, as far as land use impacts at site level are considered. In that case suitable tools are the Biological Diversity Protocol (BD) and the Biodiversity Net Gain Calculator (BNGC). Marine biodiversity, covered by SDG 14, is poorly addressed by the assessed biodiversity measurement tools. STAR might be a solution.

5.4 Geolocation, remote sensing and big data

Data science and artificial intelligence (AI) can help the financial system secure much more accurate, consistent, and timely data to inform decision-making, risk pricing and capital allocation. On a practical basis, AI and machine learning can also be used to personalise investment portfolios towards green and sustainable profiles. While their most appropriate application is still being debated (Floridi et al, 2018)[60], over the last decades, digital technologies, such as machine learning and Artificial Intelligence have significantly expanded the breadth of applications which can now be more accurate and granular.

Some of the most known applications of high-resolution satellite imagery and remote sensing data are habitats and species tracking (Duporge et al, 2021; Schrodt et al, 2020; Geller et al, 2017) [61],[62],[63] and land use change mapping to inform local conservation decisions. However, more recent advances in multi-modal data analytics[64] also confirmed that the combination of data with in-situ measurements and the implementation of AI can produce reliable geospatial insights, which are essential for sustainable policymaking[65], conservation programmes development (Palumbo et al, 2017)[66], and other project operations.

Finally, remote sensors are increasingly being used in areas that would originally be outside of its traditional scope, such as autonomous agents or real-time monitoring for environmental compliance and impact tracking. These new opportunities involve the need to develop novel methodologies that adapt the general remote sensing framework, including management of data with high variety, velocity, and volume. Some of the most promising computational techniques for EO data have specialised application angles, and for biodiversity and conservation fields include:

- Change and target detection in single- and multitemporal analysis;
- Weakly supervised learning from single and multiple data sources;
- Large- and global RS data analyses;
- Deep pattern recognition methodologies for RS;
- Near-real time and real-time processing;
- Semantic and image segmentation.

Frontier technologies like AI have proven important to stay ahead of poachers and curb wildlife crimes. Some examples of such approaches include:

- The PAWS (Protection Assistant for Wildlife Security) AI application was created to predict crimes against wildlife and fisheries. It uses game theory to create mathematical and computer models of conflict and cooperation to predict human behaviours and plan optimal approaches for containment. After successful tests in Uganda and Cambodia, PAWS has been integrated into the global collaborative *SMART (Spatial Monitoring and Reporting Tool) patrol information system*.
- A Rainforest Connection uses recycled phones and machine learning to track the sounds of illegal logging in real time. Sounds picked up by sensors, installed on a hidden phone, are uploaded to the cloud and analysed using machine learning. The app then alerts rangers of imminent criminal threats.
- Another real-time *solution* comes from the Zoological Society of London, which aims to help spot poaching threats and monitor wildlife behaviour remotely. Its Instant Detect system uses low-power sensors, camera traps and acoustic sensors to detect humans and wildlife, while satellite technology sends the data in real time to conservationists studying species or to rangers responding to wildlife crimes. The system has already been trialled in Australia, Canada, Kenya and Tanzania, as well as in Antarctica.

- Multiple technologies can be combined to track illegal human activity. The Internet of Things (IoT) has been used by the Connected Conservation Foundation to protect areas around wildlife reserves in parts of Africa. A point-to-point reserve area network (RAN) is set up, with sensors, CCTV cameras and biometric scanning collecting and analysing the data to detect suspicious activities, before informing rangers.

Big data can also help define "essential biodiversity variables" that capture the multiple dimensions and facets of biodiversity (Pereira et al., 2013). Beyond remote sensing (Cavender-Bares et al., 2020; Vihervaara et al., 2017), additional novel ways include environmental DNA metabarcoding (Deiner et al., 2017). These are being developed with the potential to assess large scale biodiversity patterns at costs much lower than through field sampling. However, the robustness of these approaches still has to be improved and their integration into models and indices that assess the biodiversity impacts of economic activity poses additional challenges.

5.5 Verification and blockchain

Specifically, particular role here is expected to be played by the blockchain technologies (Roberts, 2020) [67]. As increasing numbers of forward-looking investors seek to make a positive environmental impact alongside positive financial returns, there are growing expectations for implementation of more credible impact accounting systems. Blockchain technology is beginning to be accepted as a way of revolutionising the storing, management, and transfer of value between digital identities in financial services and has recently made its way into the impact investment community.

One use to take advantage of blockchain's features has given rise to a new category of application referred to as "impact tokens". These tokens represent a UN Sustainable Development Goal-related impact, usually in the form of a quantified, unit-based measurement metric, which is linked to the activity that created it. Some specific industry examples include agro-seed blockchains [68], Genecoins for supply chains[69], Forest Stewardship Blockchains [70] , sustainable fishing blockchains[71], amongst many others.

5.6 Matching investors with opportunities

The current dynamics regarding biodiversity-relevant investment opportunities remains a unidirectional process. This means conservation organisations or originators of broader biodiversity-positive investment opportunities are encouraged to interact with potential investors, either directly or via intermediary stakeholders (depending on the context). Apart from more traditional actors, such as government organisations and departments, procedures of setting up an impact investment pipeline can also include less orthodox intermediaries, such as specialised investment advisory companies that support conservation organisations in filtering and approaching suitable investors. The same companies can also help to advise on the appropriate funding instruments, such as bonds, direct operations or more customised for the case study vehicles. On the other hand, such companies alone (or in their absence, combination of other specialist actors) can help prospective investors to identify appropriate investable assets.

The system is inefficient, imperfect and challenging to scale. Nevertheless, its emergence and existence in its current form are justified by complexities of the local ecosystems and/or socio-economic contexts, which attribute different characteristics to specific conservation investments. Likewise, investors' preferences, restrictions and the regulations that affect them need to be considered on a case-

by-case basis, and it is clear that we have some emerging opportunities here for algorithmic mediation and/or moderation.

Such algorithmic initiatives have been emerging recently in forms of various distributed and anonymised fintech instruments, originally orientated towards retail investors (such as DLTs, 'smart contracts' and SolarCoins, etc.), but which gradually started embracing much wider spectra of B2B applications. Whilst fintech instruments introduced some novel mediation/moderation protocols, they still largely remain as '1-to-1' configurations, and there is still scope for extending their capabilities towards '1-to-many' (e.g., opportunity mapping) and 'many-to-many' instruments (e.g., recommender systems).

It can be argued that in our case a match-making or "recommender" systems approach has potential to enable automatic profile matching of various fund managers against prospective assets, accounting for investors' history, portfolio activities and extents of flexibility to respond to the assets' characteristics. The idea behind recommender systems also shifts impact investing focus from unidirectional approach, where conservation agencies actively seek funding towards bi-directional, where private investors are in the position to take more active role, using broader spectrum of available information - or even multi-directional, where investors are influenced by decisions or rating activity of the similar financial actors. Conceptually, this refocusing also aligns with the future co-design strategies for XAI (explainable AI), underpinned by the idea of augmented collective intelligence with help of AI (Nesta 2020)[72].

Recommender systems are omnipresent in the modern digital sphere, functionally ranging from search engines to internet television platforms and enabling various personal choices for news, products and services. In most cases, they are compiled based on the searching actor's personal data and activity, but increasingly their algorithms have been extended to account for much broader contexts and interactions (i.e., collaborative filtering, content-based and knowledge-based recommenders). They are rarely represented by a single algorithm, rather by collection of programs, which evolve as technology moves forward or to better suit emerging use cases.

While recommenders can be predominantly found in the e-commerce domain, they've been also gradually migrating into the finance sector as well. The most relevant examples of those systems are portfolio selection, where knowledge-based systems are used, and stock recommendations, where combinations of knowledge-based, content-based and networking-based collaborative filtering approaches are used. The most recent studies in GECON 2019[73] reported on prototyping the first 'smart contract' based recommender system, the main advantage of which over traditional recommender lies in that fact that users do not need to trust the underlying platform, because both user ratings and algorithms used to compute the score of the target items are stored on the blockchain and therefore are publicly visible and not alterable.

The potential role of recommender systems in impact investing and specifically in the field of biodiversity finance has not yet been sufficiently explored. Some emerging studies highlighted opportunities for the algorithmic profile matching between investors and early-stage enterprises and start-ups (Ohrfandl et al, 2020)[74]. Authors stress on the growing importance of information filtering techniques based on computational recommendation systems for situations of 'information paradox' faced by potential investors, where a growing number of newly emerging assets is associated with the limited available information about them. In such instances, they argue, it is important to explore in detail the decision-making process of the prominent investors in order to set out requirements for a recommender system.

6 Governing the Biodiversity-Economy Nexus

6.1 Introduction

Biodiversity markets by themselves cannot solve the biodiversity crisis. In fact, without appropriate checks and balances, market incentives can generate significant unintended consequences which can act against the overall objectives set out in this paper. Effective governance plays a critical role in enabling the flow of benefits from biodiversity and ensuring that biodiversity markets and the broader global economy serve these objectives. This is not least because of the multitude of trade-offs involved, for instance between benefits and costs borne by different stakeholders and between short-term and long-term benefits. Monetizing public goods in any context carries a set of risks including but not limited to gaming, poor integrity, and arbitrage. It is important to learn from the rich global experience in environmental governance and biodiversity protection to protect biodiversity assets where these market risks are high. Even policy makers themselves face difficult trade-offs between sustainability goals, such as quickly maximizing carbon sequestration capacity to mitigate climate change (e.g. by planting vast areas of fast-growing trees), while at the same time seeking to halt the loss of and protecting biodiversity (e.g. by gradually managing that same area back to a more natural state) (Hof et al, 2018).[75] These trade-offs must be explicitly recognized and integrated into the design of governance mechanisms.

6.2 Environmental governance in the EU

When the European Union (EU) was founded in 1957 (then the European Economic Community), neither biodiversity nor environment was part of its supranational governance agenda. Over time, however, it has grown to become one of the primary policy areas within its mandate (The EU and its Member States have shared competence for environmental policy). Today, the EU has some of the most progressive environmental policies in the world and the Union has taken on growing leadership also in the global context.

EU environmental governance uses a mix of policy instruments, approaches and strategies to pursue jointly agreed objectives. Some have been adopted to guide environmental decision-making more broadly, for instance the Strategic Environmental Assessment (SEA) Directive[76] and the Environmental Impact Assessment (EIA) Directive[77]. Impact evaluation with respect to ecosystem services is not included in either the SEA or the EIA Directive, however.

The EU habitat and species protection regime – the Birds Directive from 1979 and the Habitats Directive from 1992 – has been essential to the conservation of nature in its Member States (European Commission, 2016)[78]. However, although there has been progress in many areas (Tucker et al, 2019)[79], the predominant

trend is continuing decline (EEA, 2010)[80]. The implementation and enforcement of existing rules has been insufficient and largely underfunded (European Commission, 2016)[81]. Notably, improved implementation is important for biodiversity not only in the field of conservation. EU policies related to water, for instance, are essential for nature and biodiversity and are in need of significant implementation improvements (European Commission, 2019)[82].

The European Commission's economic growth strategy to 2030 – the European Green Deal (EGD) – published in December 2019, is the first time that climate, natural capital and social justice clearly are mentioned as equal goals in an EU-level strategic document of this kind, indicating a more holistic approach. However, the strategy has also been criticised for lacking detail and direction on how the biodiversity crisis can be addressed as well as failing to address the transfer of biodiversity costs to other parts of the world (Fuchs, Brown & Rounsevell, 2021)[83].

As promised in the EGD, the Commission adopted the EU Biodiversity Strategy to 2030 (European Commission, 2020)[84] in 2020. The strategy, supported by all EU Member States[85], includes goals, commitments and actions to put Europe's biodiversity "on the path to recovery" by 2030. The strategy commits the EU to formally protect 30% of land and 30% of sea, whereof 10% strict protection. The Commission also promises to propose before the end of 2021 legally binding targets to restore EU habitats (a step up compared to previous voluntary commitments to restoration). In general, the EU Biodiversity Strategy has a clear focus on the role of nature to human health and to our economies, putting emphasis on the business case of investing in nature. The Commission is also clear that it intends to close the implementation gap related to nature conservation once and for all, a process that is now in motion.

While the current focus in Brussels on climate and biodiversity is a real step-change, it still fails to provide clarity on how to address trade-offs between policy objectives and how to integrate both climate and biodiversity in sectoral policies. The EU treaty establishes that "environmental protection requirements must be integrated into the definition and implementation of all Union policies and activities"[86]. This so-called integration principle has been established as a binding principle through case law from the Court of Justice of the European Union. Further, the Commission recently published guidance on ecosystems and their services in decision-making, which outlines the wide range of benefits that flow from nature, and possible ways to take better account of these benefits in decision-making (European Commission, 2019)[87]. However, the challenge remains how to balance potentially conflicting political sustainability agendas. One example is bioenergy. There is a strong push and political support in Brussels as well as in several Member States (not least Sweden) for increasing bioenergy production. It can be one component in meeting the Union's climate goals. At the same time, this development needs to be carefully managed in order to not increase degradation of ecosystem functions and loss of biodiversity.

6.3 Environmental governance in Sweden

Having been an EU Member State since 1995, a great majority of national political approaches to addressing environmental issues are directly or indirectly based on agreements made in Brussels and Strasbourg. National nature conservation policy has its base in the Swedish Environmental Code, adopted in 1999, the objective of which is sustainable development and enabling the protection and care for valuable natural environments (Ch1, 1§). It implements the EU Nature Directives, for instance, in combination with other acts and regulations. The Swedish 'generational goal'[88] provides the overarching direction of environmental policy, specified by 16 Environmental Quality Objectives (EQOs) which are in turn divided into interim targets adopted by the government and parliament. The objectives cover

climate, air quality, acidification, forest, wetlands, oceans and coasts, lakes, mountains, urban environment, agriculture, toxic substances, radiation, ozone, groundwater and biodiversity. Protection of biodiversity is integrated into the EQOs, for instance the target "A Rich Diversity of Plant and Animal Life".

The Swedish governance system is highly decentralised and higher-level authorities have little mandate to direct sub-national or regional administrative levels. The 21 County Administrative Boards (CABs) are central government agencies acting as the regional competent authorities responsible for, among other things, nature conservation. At the local level, 290 municipalities have an important role in environmental protection, notably through their responsibility for spatial planning.

Sweden has committed to halting the loss of biodiversity through international commitments, the EU targets, the national EQOs and by adopting, for instance, specific protection strategies and action plans for the most vulnerable species and habitats. Major progress has been achieved in some regards, yet, according to the best available information about the state of nature in Sweden, trends are heading in the wrong direction (Naturvårdsverket, 2019a)[89]. The 2019 assessment of the progress with the 16 EQOs indicated that most would be missed (Naturvårdsverket, 2019b)[90]. Also at the national level, lack of funding and continuity of funds are one key factor, for example to carry out mapping, monitoring and evaluation of biodiversity protection. Difficult yet important trade-offs between political agendas, as in most countries, remain a major challenge. The various values of biodiversity to human well-being are not comprehensively recognised or taken into account in prioritisation and decision-making.

6.4 Financial governance for biodiversity

The EU's role in governing finance for nature might be primarily in helping to create the enabling conditions for investors, insurers, businesses, cities and citizens, e.g. on transparency and data availability. Another important role is to provide long-term signals in support of directing financial and capital flows to green investments and nature-based solutions. The latter is part of the European Commission's ambition with the Renewed Sustainable Finance Strategy, to be launched in June 2021.

The EU has come a long way with regard to climate mainstreaming of EU and national budgets. However, although discussed for many years, similar progress is yet to be made in terms of spending on biodiversity mainstreaming (ensuring that biodiversity, and the services it provides, are appropriately and adequately factored into policies and practices that rely and have an impact on it). The European Parliament has called for 10% of the EU long-term budget (Multiannual Financial Framework (MFF)) to be earmarked for biodiversity spending. Following an agreement between the Parliament, the Commission and the Council, the ambition will be to provide 7.5% of annual spending under the MFF to biodiversity objectives in the year 2024 and 10% of annual spending under the MFF to biodiversity objectives in 2026 and 2027.

In the European Green Deal (EGD), the Commission emphasised that public budgets are not sufficient to mobilise enough funds to achieve the block's climate and environmental goals. The Commission wants to channel more private funding in order to contribute to the EGD priorities, funding which currently does not find sufficiently 'bankable' projects. The Sustainable Europe Investment Plan (the financial pillar of the EGD) aims to ensure that financial institutions and private investors have the right tools to identify sustainable investments. In April 2021, the Commission adopted a delegated act under the Taxonomy Regulation that aims to establish a common classification of economic activities that substantially contribute to at least one of the EU's climate and environmental objectives, while at the

same time not significantly harming any of these objectives and meeting minimum social safeguards.

The proliferation of emerging sustainable taxonomies globally will have substantial ripple effects on the way that the financial sector thinks about climate and nature. Japan, Canada, Colombia, China, Malaysia and the UK are all in the process of developing their own taxonomies for sustainable investments, alongside the EU (PWC, 2021; EU Technical Expert Group on Sustainable Finance). [91],[92] The EU's Taxonomy Regulation states that for an activity to be environmentally sustainable it must make a substantive contribution to at least one of the EU's six environmental objectives (of which climate mitigation, climate adaptation and biodiversity are three). Critically, activities must also do no significant harm to any of the others. This represents a step change in thinking, forcing private financial institutions and regulators alike to consider climate and nature together. This thinking will continue to propagate across the financial sector as these taxonomies are translated into standards by the financial community, including by the newly established IFRS Sustainability Board.

In the EGD, the Commission committed to review the Non-Financial Reporting Directive (EU, 2014)[93], with the aim to ensure that companies and financial institutions increase their disclosure on climate and environmental data so that investors are fully informed about the sustainability of their investments.

Meanwhile, work continues in the EU to support the integration of biodiversity in decision-making more broadly. In 2021, the Commission will develop methods, criteria and standards to describe the essential features of biodiversity, its services, values, and sustainable use. These tools will include measuring the environmental footprint of products and organisations on the environment (through, e.g., life-cycle approaches and natural capital accounting) (European Commission, 2020)[94].

The SASB and GRI initiatives have been setting standards that extend companies' obligations to disclose their environmental impact, and some progress has been made in this space. The "Statement of Intent to Work Together Towards Comprehensive Corporate Reporting," published by SASB and GRI, as well as CDP, the Climate Disclosure Standards Board (CDSB), and the International Integrated Reporting Council (IIRC), marks an important step forward. However, very little progress has been done in this space regarding impact to nature in general and biodiversity in particular (Samuel, 2020). [95] Thus, less than one-quarter (23 percent) of companies worldwide at risk from the loss of biodiversity are currently disclosing that risk in their corporate reporting. Various digital technologies are expected to overcome this issue, according to the most recent WEF report (Packer, 2021). [96]

This reflects rising awareness of and attention on biodiversity in the market, as evidenced by the recent launch of the Taskforce for Nature-related Financial Disclosures (TNFD), which will develop a framework for organizations to report and act on evolving nature-related risks. Biodiversity is also picking up speed among regulators. Following the Dutch Central Bank's 2020 assessment of the Dutch financial system's dependency on nature, the Bank of England's remit was updated in March 2021 to consider the relevance of non-climate risks to financial stability. The Network for Greening the Financial System (NGFS), a network of central banks, has also established a biodiversity working group to facilitate collaboration on the topic. Each of these are clear signals of the future direction of financial regulation in this area, raising the likelihood and expected speed at which financial institutions may be required by regulation to consider biodiversity.

7 Investing in Knowledge – Recommendations

The nexus between biodiversity and the economy is rising rapidly in importance to policy makers and market actors, as the preceding sections have amply demonstrated. This development is linked to concerns about the climate crisis, the growing appreciation of nature's contribution to our economic well-being, and of course the increasingly fragile state of biological systems by any and all measures. The increasing interest has been further amplified by both scientific and popular narratives about the COVID pandemic linking the tragedy to our problematic relationship with nature. In Europe, this is to some extent reflected in the EU Biodiversity Strategy for 2030 which all Member States, including Sweden, have committed to delivering.

The preceding chapters have laid out in broad terms the contours of the nexus between biodiversity and economy. They have highlighted in particular the importance of:

- Proper-functioning biodiversity markets as a transformative tool for change.
- Strengthening the materiality of biodiversity in financial decision-making in order to steer global financial flows away from biodiversity-negative outcomes and towards biodiversity-positive outcomes.
- Robust, standardized and verifiable data that both reflects biodiversity outcomes and are accessible by the financial community.
- Effective governance of biodiversity markets to ensure that they provide added value to already ongoing biodiversity conservation and restoration.

With these framing considerations in mind, we identify a number of knowledge gaps that can be closed through strategic, robust research. Our overview of these gaps, set out below, is neither intended to be comprehensive or definitive, but points to gaps that we believe should and can be overcome, and in doing so would open the way to more effective policies and market practices. Note that the knowledge gaps in each of the first four clusters should be combined with the considerations in the fifth and final cluster.

1. **HOW TO ESTABLISH BIODIVERSITY MARKETS:** The development of new markets requires concerted and sustained efforts and should only be pursued where market-models are appropriate tools for biodiversity protection and can be well managed. The proper functioning of biodiversity markets will require trust in the rules that govern those markets as well as accessible and efficient mechanisms of exchange. This cluster explores the associated infrastructure and policies that will be required in order to support the development of well-governed biodiversity markets. Both modelling exercises that include forward-looking scenarios and case studies are relevant here, the latter drawing from the experience of specific jurisdictions, mechanisms or types of biodiversity.
    - **Identification and selection:** Which biodiversity-related ecosystem services can be translated into marketable value and which assets that generate those

services are best suited to market dynamics? From this, which products and services (existing or not existing) linked to the provision of these services have the highest potential to capture biodiversity value? Which services important for human well-being and which biological processes underlying these services cannot be captured by market dynamics so must be addressed in other ways?

- **Legal infrastructure:** What legal mechanisms will be required to develop verification and trust in claims over biodiversity services, biodiversity assets, and broader products and services which claim to have certain biodiversity impacts? The European Commission's ongoing development of a legal proposal mandating the substantiation of environmental claims could be one relevant avenue in this regard.
- **Exchange mechanisms:** How do we design (or adapt) market exchanges to fit the particular demands of biodiversity-relevant products including the use of innovations such as fractional ownership, certification schemes and trading platforms?
- **Policy support:** What policy tools and public finance would be required to manage and support the development of these markets and incentivize early participation? Is there a need for the biodiversity-equivalent of innovations in the carbon space such as emission trading schemes, feed-in tariffs, border carbon adjustments, and how might the impact of these policies play out?

2. **INTEGRATING BIODIVERSITY INTO FINANCE:** While developing biodiversity markets in the first instance is concerned with building trust and methods of exchange between buyers and sellers, their scale up will require demonstrating their value to the financial sector. For climate, research around financial risks and opportunities has helped trigger a rapid increase in global demand for investment opportunities in low carbon assets, both directly and indirectly through the acceleration of granular, climate-related policy. While understanding is growing, awareness of biodiversity in the financial sector remains low. This cluster will examine how the physical impacts of biodiversity loss and the expected policy and consumer response may translate to financial risks and opportunities. Importantly, it will crowd in innovation and forward-looking analysis to understand how biodiversity can be integrated in a more robust, systematic and rapid way than we have seen for climate.
   - **Transition risks:** What financial risks and opportunities will be generated by the development of biodiversity markets, the required policy tools, potential targets under the CBD's Global Biodiversity Framework (GBF) and recognized planetary boundaries? What is a reasonable set of market and policy scenarios for the financial sector to consider, for example reflecting the ongoing efforts in the EU as part of implementing the EU Biodiversity Strategy to 2030?
   - **Systemic risks:** How can systemic biodiversity-related risks (those expected to have system-wide impacts on the economy by 2050) be integrated into financial decision-making? To what extent can these be modelled, understood and managed and how can newly available data streams help to better understand systemic risks and predict potential tipping points within biological systems?
   - **Strengthening materiality:** Are there new ways of defining materiality with greater relevance for biodiversity, and how might these impact financial decision-making? How could changes in regulatory, legal and social norms lead to a shorter causal link between biodiversity impacts and financial risk, drawing from models such as due diligence obligations (DDOs), anti-money laundering (AML) legislation and emerging sustainable finance taxonomies?
   - **Public finance:** How should these concepts be extended to public finance operations? How can we monitor and assess the impact (both positive and negative) of public spending on biodiversity, and how can biodiversity be

mainstreamed within public spending strategy development? For example, how could the EU progress on biodiversity mainstreaming as it has progressed in recent years on climate mainstreaming?

- **Citizen finance:** How can individual and collective citizen action, in particular as savers and investors, be leveraged to increase the materiality of biodiversity in financial decision-making and support biodiversity markets? Which innovations in digital finance have the greatest potential to achieve this rapidly and effectively? What potential caveats or risks of such innovations need to be addressed?

3. **BUILDING BIODIVERSITY INTO ASSET PROFILES:** While there is an already well-developed and growing body of research around ecosystem services, their valuation and the role of biodiversity in ecosystem services, there is still a knowledge gap in connecting this understanding and data to the way in which market systems operate today. The ecosystem services most closely linked to biodiversity, for example, are not consistently or explicitly reflected in pricing systems, nor are the direct or indirect biodiversity impacts of the products and services that we consume. Building from the previous research on how biodiversity can be material to finance, this cluster will explore and elucidate how we can translate existing data and research on biodiversity-derived ecosystem services into the format and standard expected of prospective investments.
   - **Measurement and standardization:** How could new methods of data collection and analysis be deployed to robustly and transparently verify the existence and efficacy of biodiversity-related ecosystem services and hence the value of assets? How could these services be compared and traded? What potential caveats or risks of such solutions would need to be addressed?
   - **Assurance of impact:** How can these markets be constructed, monitored and governed to ensure that their potential growth equates to real and meaningful improvements in critical biodiversity outcomes? What might be suitable structures and levels of governance to oversee and manage these markets? How can the permanence of positive or avoided negative impacts be ensured and assessed?
   - **Digitalization:** How can digital innovations be used to transform the way in which market participants (buyers, sellers, intermediaries, governance institutions) interact and exchange data to better support biodiversity markets? Drawing from the experience in other fields, how could innovations such as recommender systems, blockchain and big data analysis be deployed to support market functionality, and what policy control and support might this require?

4. **THE ROLE OF DATA SCIENCE AND AI IN ENABLING SHIFTS TO NATURE-POSITIVE FINANCE:** This cluster looks into how we can make the best use of the state-of-the-art data science and AI techniques in order to mainstream biodiversity finance. The problems in this area arise from the visible co-evolution trends amongst several disciplines, such as general computer science, quantitative finance and computational ecology. Each of these fields have priority areas, which are defined by their respective disciplinary challenges and methods. The emergence and growth of sustainable finance as the distinct interdisciplinary area, closely related to both finance and ecology, illustrates the need for both adaptation of already existing AI and data science methods, as well as creation of the new ones, native for and specific to this emerging field.
   - **Emergence of domain-specific AI for biodiversity finance:** Methodologies for financial biodiversity indicators and indices: the state of the field, problems and emerging trends? What is the balance between Earth Observation AI and

Natural Language Processing in designing multimodal ESG? How to adapt existing ecological models for various financial institutions?

- **Alternative data:** How suited are current data sources for capturing short- and long-term ESG signals? How to handle low-coverage financial actors? What additional modalities could be beneficial for the new generation ESG and biodiversity scores? What additional ethical problems can arise from multimodal AI for environmental finance applications as compared to already known ones?
- **Handling data gaps, uncertainties and misinterpretations:** What is the role of synthetic data in covering existing data gaps? How can AI assist in dealing with noise, incompleteness and inconsistencies in data streams? How to increase transparency and explainability in AI for sustainable finance applications?
- **Bridging ecological finance with other disciplines via data science:** Emergence of multipurpose models, and how we can ensure their credibility? What benchmark datasets are required for transfer learning? What is the current position of biodiversity finance models in comparison to the broader sustainable finance models and data?

5. **GOVERNING MARKET-BASED APPROACHES (CROSS-CUTTING):** This cluster cuts across each of the four clusters above, which each help to build a synergy between traditional conservation measures and mainstreaming biodiversity considerations. Market-based approaches can unlock productive innovations and much needed finance, as well as better aligning existing markets and financial flows to nature positive outcomes. Yet they can also lead to unintended, unwanted / negative consequences. We must learn from the rich body of research and experience in trying to internalize environmental considerations into market systems as well as with conservation schemes, policy and finance in order to avoid this. A careful balance is needed between the scalability provided by markets and the control provided by management and protection. Not least the issue of comparing future benefits with present costs is essential in this regard. This cluster will explore this balance, drawing boundaries around where a market-based approach might be appropriate and where not, and how such approaches can be effectively combined to not interfere with robust public policies. These considerations should be integrated into all research on the biodiversity-economy nexus.
   - **Governing nature markets:** What the strengths and weaknesses of existing governance arrangements that explicitly or implicitly impact on the market-nature nexus? What are the risks associated with the deepening of monetization of biodiversity services and assets? How can these markets be governed to avoid or mitigate these risks? Can existing governing arrangements be nudged and repurposed, or/and should not governing arrangements be established around major nature market developments, and if so what and how?
   - **Aligning financial governance:** How can environmental and financial governance, including policies, regulation, standards and voluntary standards, reinforce one another, both supporting the integration of biodiversity into finance but also ensuring biodiversity gains? Drawing from both empirical evidence, theory and simulation, in which contexts (policies, types of biodiversity, jurisdictions etc.) is this effective and in which is it not? In Europe, what role could the EU play in this regard, factoring in already ongoing development under, for instance, the EU Taxonomy Regulation?
   - **Nature's trade-offs and priorities:** How can a market-based approach to halting the loss of biodiversity be effectively combined with other priorities, such as the need to mitigate and adapt to climate change or to eradicate poverty? How to ensure that these political agendas are mutually supportive?

Glossary

Biodiversity: The variability among living organisms from all sources 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 of ecosystems.[97]

Biodiversity-Economy nexus: The way in which biodiversity and the economy interact. This includes the benefits that biodiversity provides the economy (through for instance ecosystem services) as well as the impact that the economy has on biodiversity.

Biodiversity markets: The definition of biodiversity markets used throughout the paper includes all exchanges in which biodiversity is implicitly or explicitly priced and known to at least one of the transacting parties. For example, if one of the parties of an agricultural land transaction is knowingly pricing in all or part of the upside expected from that land's conversion to regenerative practices, then a biodiversity market exchange has just occurred. In this sense, it is broader than specific natural capital assets. It includes the suite of all products and services which in some form support or harm biodiversity and hence, indirectly affect the provision of biodiversity-derived ecosystem services.

Biodiversity products and assets: Biodiversity products and assets refer to the goods that are sold in biodiversity markets. As defined above, these may directly provide biodiversity-related ecosystem services (such as a mangrove forest), or indirectly affect the provision of biodiversity-related ecosystem services through their impacts on biodiversity (such as more sustainably sourced consumer goods).

Biodiversity-related liability risk: Risks related to litigation and broader liability claims pertaining to biodiversity loss and breach of the underlying legal frameworks (e.g. case law or reporting breach of biodiversity loss).

Biodiversity-related physical risk: Risks related to the physical impacts of biodiversity loss causing direct economic and financial losses for businesses and investors. The materialisation of biodiversity risks can damage assets and infrastructure or cause a deterioration in supply chains or business operations (resource dependency, scarcity and quality). Risks can be either acute, because they are event driven such as a natural disaster, or chronic, because they materialise over time such as the depletion of natural resources.

Biodiversity-related systemic risk: Systemic risks can refer to (i) the risk that a critical natural system breaks down and no longer functions properly, or (ii) a risk to system-wide financial stability; or (iii) risks that arise at portfolio-level (rather than at organization or transaction-level) of a financial institution. In many cases, (i) can lead to (ii) as systemic risks are typically economy-wide (often global) and lead to significant impacts across all industries simultaneously.

Biodiversity-related transition risk: Risks related to the transition to an economy which conserves and restores biodiversity to a greater extent than today. These types of risks may entail extensive regulatory, legal or liability, technological and market changes and may lead to reputation risks. For affected businesses, this can lead to higher costs, lower revenue and increased litigation risk if their operations are not aligned with the biodiversity-positive transition.

Ecosystem: A dynamic complex of plant, animal and microorganism communities and the non-living environment, interacting as a functional unit (CBD, 2020).[98]

Ecosystem service: The benefits people obtain from ecosystems (Millennium Ecosystem Assessment).[99]

Fiduciary duty: A fiduciary duty is a commitment to act in the best interests of another person or entity. In the context of finance, a fiduciary duty refers to the duty of a financial institution to act in the best interests of its client, typically by protecting and maximising their financial returns.

Financial decision-making: The process of making financing decisions including whether to invest, lend or provide finance in any other form to a given entity, project or other recipient.

Financial institutions: A broad term which encompasses banks, asset managers, insurers and other financial services.

Financial materiality: "Misstatements, including omissions, are considered to be material if there is a substantial likelihood that, individually or in the aggregate, they would influence the judgment made by a reasonable user based on the financial statements"[100].

Fractional ownership: Fractional markets or fractional ownership allow individuals to hold claim to a portion of a given asset or product. In this way, one asset or product can be jointly owned by many different individuals.

Life-cycle assessment (LCA): Life cycle assessment (LCA) is the analysis of the environmental impact of a product over its entire life cycle. This includes the input materials and services that were used in its production, the process of retail and distribution, as well as its consumption and end of life. These specific elements will vary depending on the good or service in question.

Multilateral development finance institutions (DFI): A multilateral development finance institution (DFI) is an international financial institution chartered by two or more countries, typically for the purpose of encouraging economic development in poorer nations. DFIs provide loans, grants and a wide range of credit products to member nations to fund projects that support social, economic, environmental and other purposes.

Natural capital: Natural capital is all renewable and non-renewable environmental resources and processes that provide goods or services that support the past, current or future prosperity of an organization. It includes air, water, land, minerals and forests, biodiversity and ecosystem health (IIRC, 2013).[101]

Proxy market: A market for an item that is closely linked to, but is not exactly the same as, an underlying asset.

Quantitative easing: Quantitative easing is a tool that central banks can use to inject money directly into the economy. Money is either physical, like banknotes, or digital, like the money in bank accounts. Quantitative easing involves creating digital money. Central banks then use this to buy things such as government debt in the form of bonds (Bank of England, 2020).[102]

Recommender systems: Recommender system is the type of information management systems (i.e., filtering, classification, matching), which allows to match information items with users, based on their past or current behavioural preferences (such as selection, rating, screen time, etc.).

Remote sensing data: Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft). Special cameras collect remotely sensed images, which help researchers "sense" things about the Earth (USGS, ND).[103]

Tipping points: "Tipping points mark the shift between contrasting system states that occur when external conditions reach thresholds that trigger an accelerating transition to a contrasting new state… For example, clear lakes become turbid and dominated by algal blooms, coral reefs are overgrown by macroalgae, fisheries collapse owing to overexploitation, and tropical forests shift to savannah-type ecosystems under high fire intensity." (Dakos et al, 2019)[104]

Annex 1: Definitions related to Nature

	Definition	Organization
Biodiversity	'Biological diversity' means the variability among living organisms from all sources 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 of ecosystems.	*Convention on Biological Diversity (CBD)*
Biodiversity	Biodiversity refers to the variety of living species on Earth, including plants, animals, bacteria, and fungi. While Earth's biodiversity is so rich that many species have yet to be discovered, many species are being threatened with extinction due to human activities, putting the Earth's magnificent biodiversity at risk.	*National Geographic*
Biodiversity	Biodiversity means all life on earth.	*WWF Switzerland/ PWC Switzerland*
Nature	Within the context of western science, it includes categories such as biodiversity, ecosystems (both structure and functioning), evolution, the biosphere, humankind's shared evolutionary heritage, and biocultural diversity.	*IPBES*
Nature	Has a broad definition and encompasses, next to biological aspects such as biodiversity, also non-biological aspects such as soil and the weather.	*DNB*
Nature	The global natural ecosystem in its entirety. This encompasses both the stock of natural capital assets as well as the way in which they interact with each other. In this sense, biodiversity is a characteristic of nature, insofar as it refers to the presence of diversity across the natural ecosystem.	*Global Canopy and Vivid Economics*
Natural Capital	Natural capital can be defined as the world's stocks of natural assets which include geology, soil, air, water and all living things. It is from this Natural Capital that humans derive a wide range of services, often called ecosystem services, which make human life possible.	*World Forum on Natural Capital*
Natural Capital	Natural capital is another term for the stock of renewable and non-renewable resources (e.g. plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people.	*Natural Capital Coalition*
Natural Capital	Natural capital is all renewable and non-renewable environmental resources and processes that provide goods or services that support the past, current or future prosperity of an organization. It includes air, water, land, minerals and forests, biodiversity and ecosystem health.	*IIRC* and *CDSB*
Natural Capital	Natural capital is a way of thinking about nature as a stock that provides a flow of benefits to people and the economy. It consists of natural capital assets – such as water, forests and clean air.	*Natural Capital Finance Alliance*

	Definition	Organization
Natural Capital	Natural capital are the elements of nature that directly and indirectly produce value or benefits to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions. The paper lists ten categories of natural assets: species, ecological communities, soils, freshwaters, land, coasts, oceans, atmosphere, minerals and subsoil assets.	*UK Natural Capital Committee*
Natural Capital	Natural capital are natural assets in their role of providing natural resource inputs and environmental services for economic production.	*OECD*
Natural Capital	Natural capital is a way of defining the wide range of benefits we derive from nature.	*Natural Capital Protocol Application Program*
Natural Capital	Natural capital refers to those aspects of the natural environment that deliver socio-economic value through ecosystem services.	*GLOBE*
Natural Capital	Natural capital is the land, air, water, living organisms and all formations of the Earth's biosphere that provide us with ecosystem goods and services imperative for survival and well-being. Furthermore, it is the basis for all human economic activity.	*IISD*

End-Notes

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