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Biodiversity finance: A call for research into financing nature

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Abstract

Biodiversity conservation will supersede climate change risk mitigation and adaptation as the next grand challenge for sustainable finance. Closing the financing gap between what is currently spent and what is needed to be spent over the next 10 years to mobilize private investment to maintain ecosystem integrity and biodiversity, and the services they provide, is estimated to exceed hundreds of billions per year. Yet there are no studies in the top tier journals in finance that have framed the risks related to biodiversity loss, how those risks might be priced, or how the private financing flows need to be intermediated. We lay out one framework and outline important open research questions for financial economists to pursue.

KEYWORDS
biodiversity finance, climate change, corporate financial management, investments

JEL CLASSIFICATION
E50, G11, G40

1 | THE BIODIVERSITY FINANCE RESEARCH IMPERATIVE

Nature and its services are crucial to the global economy. According to a 2022 joint report of the United Nations Environment Programme (UNEP) and the World Economic Forum, more than half of the world's GDP (about $40 trillion) is moderately or highly dependent on nature and its services.[1] Further, our planet is experiencing accelerating

[1] See UNEP (2022). This report draws actively from the 2019 report of Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019) and the UK's HM Treasury 2021 Report led by Partha Dasgupta (Dasgupta, 2021).

biodiversity loss.[2] Extinctions of wild mammals, plants, marine environments, and millions of species at risk of extinction constitute a significant economic risk. Biodiversity loss and climate change represent the twin environmental crises of our era, and the collective choices we make in addressing them could result in profoundly dissimilar outcomes for our economy and our planet. There is, however, one crucial difference between climate change and biodiversity loss: while carbon dioxide can be removed from the atmosphere with currently available, albeit expensive, technology, extinction is forever.

Scientists estimate the world is now losing species at up to 1000 times the background extinction rate of one to five species per year, and the abundance of mammals, birds, fish, reptiles, and amphibians has declined on average by 60% over the last four decades. In addition, even species that are not currently endangered are rapidly losing much of their genetic diversity because of habitat fragmentation and degradation and of local extinction events. The UN's Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has warned that humans are damaging nature far more rapidly than it can renew itself. A new global framework is needed to slow and halt the decades-long decline in biodiversity.

To meet this objective, a transformational shift will be needed in the way markets value nature, nature-based assets, and natural capital. Innovative financing and policy mechanisms must be identified and implemented to mobilize the large amount of funding needed to conserve nature and to reform the harmful agricultural and forest management policies that result in the loss of biodiversity. A 2020 joint report of the Paulson Institute, The Nature Conservancy, and the Cornell Atkinson Center for Sustainability estimates that financial flows into global biodiversity conservation in 2019 ranged between $124 billion and $143 billion, a fraction of the $722 billion to $967 billion per year that their analysis suggests would be required to halt the decline in biodiversity by 2030—a global *biodiversity financing gap* of roughly $700 billion per year.[3]

If we are to steer clear of the most severe biodiversity loss scenarios, a variety of actions will have to be taken by financial institutions, asset managers, asset owners, and corporate financial officers. The keys are to understand and learn to manage the risks to biodiversity arising from their financial and real investments. These risk management methods will have to include screening tools that enable investors to assess the risks and to make informed decisions about the negative impacts on biodiversity of their investments. Conversely, those approaches will help identify the positive biodiversity impacts of investing prospectively in nature-positive financial products and biodiversity offset mechanisms. In addition, a greater focus on investing in natural infrastructure assets like reefs, forests, wetlands, and other natural systems that provide habitat for wildlife while delivering valuable ecosystem services, including watershed and coastal protection, may represent both cost-effective infrastructure solutions and smart investments. Investing in nature-based solutions may also be effective carbon mitigation strategies and can help governments and corporations manage climate risks while meeting their carbon emissions targets.

The notion that private, return-seeking capital will be a crucial part of the solution to biodiversity loss has become more mainstream—at least, within environmental activist circles. But critics have pointed to an apparent paradox: if biodiversity loss is primarily a cost imposed on society, and a loss to private economic agents only secondarily, perhaps it is best viewed as a public good and any solution to biodiversity loss is best handled by the public sector. This focus on private capital results directly from the scale of the problem. Public finance is simply not enough. The work of Deutz et al. (2020) and others—more details below—has highlighted the difference between what is currently spent on nature conservation and what will need to be spent if most biodiversity is to be conserved and sustainably managed for the long term. This so-called "biodiversity financing gap" is estimated to be nearly an order of magnitude larger than current funding for biodiversity, and there is virtually no expectation that governments will be able to fill that void. While charitable expenditures on nature conservation are significant, charitable funding is unlikely to

[2] According to the UNEP, "biodiversity" is the contraction of the terms biological diversity, and it describes the diversity of life on Earth. It includes all organisms, species, and populations; the genetic variation among these; and their complex assemblages of communities and ecosystems. In this paper, we use the term "nature" to refer to biodiversity and the ecosystem services that both natural and sustainably managed habitats provide.

[3] See Deutz et al. (2020).

grow dramatically. This has led observers to turn to private capital as the only possible source of scalable funding for conservation.

Naturally, the fact that only the private investment markets have the scale to close the biodiversity financing gap does not ensure that private capital will in fact be deployed for that purpose. Private capital will be deployed at scale for biodiversity if risk-adjusted returns on investment are competitive. However, other incentive mechanisms may also result in significant capital flows into biodiversity conservation, of which regulation may be the most important. While a corporation may have an incentive to exploit and deplete a public good before its competitors do—even if that comes at a high social cost—governments regularly step into such systems to impose rules on private actors that are better aligned with social good. The regulation of renewable common-property natural resources, such as fisheries, in which private actors are allowed to purchase rights to exploit the fishery within limits that ensure its long-term sustainability, represents but one example.

1.1 | Where is the financial science of biodiversity?

We propose a working definition of biodiversity finance as the practice of raising and managing capital and using financial tools and economic incentives to support sustainable biodiversity management. It is about leveraging and effectively managing economic incentives and policies to help mobilize private capital to achieve the long-term well-being of nature. Financial science as it might relate to biodiversity loss can trace its roots to other sciences. The science of ecology—the study of relationships between living organisms, including humans, and their biological and physical surroundings—has not until recently captured the attention of financial professionals, let alone financial economists, despite its long and distinguished history.

The science of ecological *economics* is similarly well established. As Geoffrey Heal states, "sound economics and sound ecology are not mutually exclusive."[4] Some scholars make the link through active reference to the early work of Thomas Malthus and John Stuart Mill on population economics, but most scholars point to the work of Robert Costanza, the founder of the International Society for Ecological Economics in the 1980s, for attempting the first valuation of the global ecosystem in a 1997 *Nature* article.[5] Important early work in the top economics journals was spearheaded by Martin Weitzman, who focused on the preservation of diversity, how it is to be optimized, and how to design a measure of the "value of diversity" (Weitzman, 1992, 1993).

What we need now is research on how biodiversity management programs can most effectively raise and manage public and private capital. A search of the *Web of Science* for articles published in the top 10 finance journals (including *Financial Management*) that reference "biodiversity," "ecology," or "conservation" yielded no meaningful results. An equivalent search for references to the same search words among the top five economics journals by impact factor yielded 62 results going back as far as Weitzman's work in the early 1990s in the *Quarterly Journal of Economics*. This is a big difference. To render additional power to this informal test, a search in the same 10 finance journals to articles that reference "climate change" yielded 24 results, with the earliest dating to November 2019.

1.2 | A call for research on biodiversity finance

The financing need is great. Public and philanthropic resources are limited. Therefore, a massive mobilization of private capital will be required to mitigate the loss of biodiversity. Finance professionals need guidance from scholars. A 2021

[4] See the preface of Geoffrey Heal's *Nature and the marketplace: Capturing the value of ecosystem services* (Heal, 2000). Heal notes that, *eco*, is derived from *oikos*, the Greek word for "housekeeping." The Greek origin of *economics* denotes "human housekeeping." In the preface, Heal further points out that, given human activity is driving many changes in nature, humans have inadvertently become one of the main drivers of planetary change and that we need to think about "earth keeping" in the sense of considering our impact on the planet as a whole and not just on our own households.

[5] See Costanza et al. (1997). Costanza (1989) answers the question: "What is Ecological Economics?" in the inaugural issue of *Ecological Economics*.

survey of chief investment officers and chief financial officers by Accounting for Sustainability (A4S), a not-for-profit organization that guides finance leaders to adapt their decision-making to enable an integrated approach reflective of the opportunities and risks posed by environmental, natural, and social issues, found that only 9% believed they have the needed tools and techniques to incorporate sustainability into their decision-making. They need the foundational science that financial economists can deliver.

The next sections summarize the fast-moving regulatory framework for biodiversity risks and financial markets. We then present a primer on the economic science on the valuation of biodiversity, important work from which the new financial science can build. We provide background on the biodiversity financing gap and describe a sample of recent case studies on biodiversity-linked financial transactions. Following that, we discuss the defining features and current state of biodiversity metrics, and acknowledge the fact that data availability, their quality, and ease of use will be critical success factors for empirical work by financial economists seeking to measure nature-related risks and opportunities. The article then closes with a brief sampling of open questions in biodiversity finance that will require the attention of financial economists.

2 | REGULATORY CHANGE IS COMING AND FAST

Shifting investor and consumer expectations are resulting in an increasingly complex regulatory landscape for investment, with rapidly developing (and often mutually inconsistent) disclosure requirements on biodiversity impacts. Some of this pressure has been building since the UN Framework Convention on Climate Change (UNFCCC) 26th Conference of the Parties (COP 26) in Glasgow in November 2021. The momentum continues to the 2022 UN Convention on Biological Diversity (CBD) COP 15 in Montreal.

While the more visible examples of regulatory changes are taking place at the national level and in the European Union, some of the most noteworthy developments are taking place at the subnational and even municipal levels.

An important recent example is the Conservation Finance Act (HB0653) passed by the General Assembly of the State of Maryland and signed into law in April 2022. The Act is designed to leverage public funds by expanding private financing to achieve the goal of conserving 30% of lands and waters in Chesapeake Bay by 2030. This act emphasizes water ("blue") infrastructure for improving fish passage or for installation of small hydroelectric capacity, as well as the maintenance and restoration of certain source watersheds. The Act provides for digital platforms to contribute to the preservation of the commercially and ecologically important Chesapeake Bay and the development of climate solutions.

The most ambitious national biodiversity initiative may be the UK's 2021 Environmental Bill, which set new, legally binding targets for nature, water, air quality, and waste management, all to be met by 2030. The Bill includes biodiversity net-gain requirements for major infrastructure projects and creates a new Office of Environmental Protection. The law goes further than other national legislation in restricting illegal deforestation and protecting rainforests through a package of measures to build greater resilience, traceability, and sustainability into national supply chains. Of note are substantial penalties on water companies that discharge sewage into rivers, waterways, and coastlines.

While media attention during COPs 26 and 27 in Glasgow and Sharm-El-Sheikh, respectively, focused on greenhouse gas emissions targets and funding commitments, there were some notable commitments to protecting and restoring ecosystems and managing land sustainably. Through the Glasgow Leaders' Declaration on Forests and Land Use, 137 signatories committed to halting and reversing forest loss and land degradation by 2030, with 12 developed countries pledging $12 billion of public climate funding from 2021 to 2025 to the new Global Forest Finance Pledge. A group of governments and philanthropic organizations pledged over $10 billion to protect the forests of the Congo Basin and to secure forest tenure rights for indigenous peoples and local communities.

Finally, during much of 2022, preparations led to the fourth meeting of the Working Group on the Post-2020 Global Biodiversity Framework of the UN Convention of the Parties on Biological Diversity (CBD) concluded in Montreal in

December 2022, as mentioned above.[6] The overarching goals of the new draft framework are to protect the elements of biodiversity at all levels (genetic, species, ecosystem), sustainability and human well-being in the use of biodiversity, and the fair and equitable sharing of benefits from the use of biodiversity. The targets are bold in scale, focusing on performance targets in wildlife management, marine and coastal biodiversity, reductions in invasive alien species, pesticide usage, plastic waste discharge, and nutrient loss, with a proposed annual $200 billion resource mobilization plan.

Less a legislative or regulatory development and more a voluntary initiative, the Taskforce on Nature-related Financial Disclosures (TNFD) is a notable recent development. TNFD, launched in 2020, was modeled on the highly influential Taskforce on Climate-related Financial Disclosures (TCFD), which was set up by the Financial Stability Board in 2015 to develop recommendations on the information that companies should disclose to help investors, lenders, and insurance companies assess and price climate-related risks. TNFD's first report, entitled *Nature in Scope* (2021), proposes seven TNFD principles and a scope of action. Actions for nature-positive transitions, the report claims, will generate up to $10 trillion in annual business value and create 395 million jobs by 2030, but a framework is needed to identify nature-related risks to support a shift in private investment flows away from nature-negative toward nature-positive outcomes. Metrics, targets, and risk management are the key pillars for such a framework.

3 | THE ECONOMIC SCIENCE OF BIODIVERSITY

The development of the economic science of biodiversity parallels closely that of the economic science of climate change. Both of these literature streams interweave yet differ in important ways. They both trace their origins to the foundational sciences of biodiversity and climate change, respectively. As stated in the introduction, the financial science of climate change began as recently as 2019. The financial science of biodiversity is yet to launch. The goal of this survey is to assist its launch, and the goal of this section of our survey is to anchor that launch in a valuable literature that precedes it.

3.1 | What is biodiversity?

Although the science of flora and fauna is as old as the science of biology, many ascribe the earliest use of the term *biodiversity* to Harvard's Edward O. Wilson in a conference proceedings volume that he edited and was published in 1988, entitled *Biodiversity*.[7] In *Naturalist*, his 1994 autobiography, Wilson credits Walter Rosen, a member of the staff of the National Academy of Sciences, with coining the term. By the time the 1992 UN Conference on Environment and Development (the "Earth Summit") took place in Rio de Janeiro, Brazil, the term was already used widely. It was at the Earth Summit that the UN Convention on Biological Diversity (CBD) was launched. The CBD's working definition of *biodiversity* emphasizes the variety of living organisms, the genetic differences among them, and the ecosystems in which they occur. This definition underscores the fact that the notion of biodiversity applies to various levels of organization, from genes to species to ecosystems.

[6] Opened for signature in 1992 at the Earth Summit in Rio de Janeiro, the CBD entered into an international treaty in 1993 for "the conservation of biodiversity, the sustainable use of the components of biodiversity and the equitable sharing of the benefits derived from the use of genetic resources." With 196 Parties, the CBD seeks to address all threats to biodiversity and ecosystem services, including threats from climate change, through scientific assessments, the development of tools, incentives and processes, the transfer of technologies and good practices, and the full and active involvement of relevant stakeholders including indigenous peoples and local communities, youth, women, NGOs, subnational actors, and the business community. The Cartagena Protocol on Biosafety (2003, 173 Parties) and the Nagoya Protocol on Access and Benefit-Sharing (2014, 136 Parties) are supplementary agreements to the CBD. On December 19, 2022, the CBD's COP 15 summit in Montreal reached an agreement to protect almost a third of the planet's lands and oceans by 2030.

[7] See Wilson (1985, 1988).

The field of biodiversity science today is broad and deep. Much focus is on scenarios of changes in biodiversity—resulting from changes in atmospheric carbon dioxide concentrations, climate, vegetation, and land use, and the known sensitivity of biodiversity to these changes. A study by Sala et al. (2000) in *Science* is regarded as one of the most comprehensive surveys of the drivers of ecosystem change—strongly linked to ecosystem processes and society's use of natural resources—and the major sources of uncertainties.[8] Land-use change, the study argues, has the largest effect followed by climate change, nitrogen deposits, biotic change (how one species invades the biome of another), and elevated carbon dioxide concentration. These are differentially important for freshwater ecosystems, Mediterranean climate and grassland ecosystems, and Northern temperate ecosystems.

3.2 | The economic theory of biodiversity

The economic theory on biodiversity was inspired by Harvard's Martin Weitzman in the early 1990s.[9] The first published study, entitled "On diversity," was the first to define the diversity function to be optimized and to further define how a reasonable measure of "the value of diversity" of a collection of objects can be recursively generated from more fundamental information about the dissimilarity distance between any pair of objects in the set.[10] What Weitzman concludes is that there exists a diversity function that satisfies a well-defined dynamic programming equation, which he calls the "Min-Loss Extinction" equation.

Weitzman's (1993) next paper, "What to preserve? An application of diversity theory to crane conservation," demonstrates how the diversity equation in the 1992 article can be applied to a real-world conservation problem.[11] The equation in Weitzman (1992) to define diversity is ideally represented, he argues, for the declining population of whooping cranes. It shows how the direct benefits (existence value) of the cranes are not captured by value in the diversity function. Section III in Weitzman's 1993 paper describes the wildlife conservation problem of cranes. There are 15 species of cranes with different extinction probabilities among them, but most importantly the extinction of any one species implies a loss of diversity because the *family of wild cranes* has been diminished. The magnitude of the diversity loss is related to how different the extinct crane is from the surviving species of cranes. There is greater loss of diversity when the extinct crane has no close relations among the survivors than when its nearest relation is comparatively close to it. The biodiversity equation represents this intuitive understanding.

To validate the theoretical notions in this earlier work, Metrick and Weitzman (1998) analyze statistically the determinants of government decisions about the preservation of endangered species. The authors obtain data on the top 10 species by total spending at U.S. federal and state agencies from 1989 to 1991. (The bald eagle, Northern spotted owl, and Florida scrub jay are the top three.) The explained variable is the listing of a species for protection, such as by the U.S. Fish and Wildlife Service through the Endangered Species Act of 1973, whether it was so listed by March 1993 among all species or subspecies of all U.S. vertebrates defined by a database of The Nature Conservancy. The other explained variable is the spending amounts across agencies. Among the explanatory variables are fixed effects for taxonomic class (mammals, birds, reptiles), but the focus is on a powerful covariate, *Charisma*, which the authors define as the physical size and degree to which the species are higher forms of life. This finding is interpreted in the context of the dissimilarity distance paradigm of Weitzman (1992).[12]

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[8] See Sala et al. (2000).

[9] We are grateful to Yale's Andrew Metrick, a colleague and coauthor of some of Professor Weitzman's early work on biodiversity, for sharing his retrospectives on the motivation for and impactfulness of Weitzman's research.

[10] See Weitzman (1992).

[11] See Weitzman (1993). In Weitzman's (1998) later *Econometrica* article, "The Noah's ark problem," he gives equal credit for the original diversity equation to a contemporaneous working paper by Solow et al. (1993), published as "On the measurement of biological diversity." Weitzman (1998) links the intuition underlying the Biblical parable of "Noah's ark problem" as the canonical form of the representation on how best to preserve biodiversity under a limited budget constraint.

[12] See a useful survey article by Metrick and Weitzman (1998), "Conflicts and choices in biodiversity preservation."

3.3 | Valuing nature and the marketplace

In his 2000 book, *Nature and the Marketplace*, Geoffrey Heal states that there are no explicit mechanisms for managing and mitigating the impact of human economic activity on "nature's capital," what he calls the natural foundations or biosphere of the planet. This treatise is the first to argue how markets can be valuable tools in mitigating our impact on natural systems that provide infrastructure for societies.

In Chapter 2, Heal describes the "basic economics" of Robert Coase and AC Pigou to distinguish private costs from social costs via taxes and/or subsidies and to link to markets and ecosystems for watershed management, forests for carbon sequestration. He has a discussion of securitization, or tradeable contracts that entitle owners to a portion of the benefits from a venture, with reference to a "watershed saving account," which confers a fraction of the cost savings from a watershed restoration project.[13] Additional examples follow in subsequent chapters. Of special note is Chapter 7 ("Valuation"), in which Heal traces techniques for valuing goods and services for which there is no active market, such as hedonic price indexes, replacement costs, contingent valuation, and nonmarginal values, and he argues that valuation is not necessary for conservation of biodiversity, but that conservation depends on incentives. Markets can provide incentives and a value.

Two useful papers follow from this foundational work of Heal (2000).[14] The first by Nehring and Puppe (2002) proposes a multi-attribute approach to valuing biodiversity—Weitzman's "Noah's ark problem"—under which the diversity of a set of species is the sum of the values of all attributes possessed by some species in the set. The goal is a flexible yet tractable model of diversity that focuses on the aggregate of pairwise dissimilarities between the elements of a set (of species).

Brock and Xepapadeas (2003) argue for a *dynamic* economic welfare measure of biodiversity using what they call a *unified* model of optimal economic management of an ecosystem under ecological and genetic constraints. The work formalizes the intuition that the value of biodiversity stems from the characteristics or services it provides, through ecosystem productivity, insurance, and knowledge, following Heal (2000).

3.4 | Biodiversity indexes

As the Metrick and Weitzman (1998) study makes clear, the measurement of biodiversity or biodiversity loss is a non-trivial exercise. Having good metrics is a critical step toward understanding conservation risk, risk management, and valuation of biodiversity loss. An important fact about biodiversity loss risk is that there are not so clear ecological indicators as there are environmental quality indicators, such as global mean temperature rise and atmospheric carbon dioxide concentrations, which are widely accepted measures of human effects on global climate. Simplicity is not a defining feature of biodiversity.

The characteristics of useful data include its relevance, resolution, and scalability (e.g., less than a square kilometer resolution geospatial data), time-series availability, frequency of update, comprehensive geographic coverage, accessibility, comparability, breadth of coverage by theme (types of species, ecosystems), and, of course, reliability.

The biodiversity literature has defined many measures of biodiversity and biodiversity loss.[15] Species richness (the number of species in each area at a point in time) represents a single but important metric that is a valuable numeraire

[13] The book draws from a commentary by Chichilnisky and Heal (1998), "Economic returns from the biosphere." This work is critical response to what many ecological economists regard as the seminal study of the valuation of biodiversity by Costanza et al. (1997), entitled "The value of the world's ecosystem services and natural capital."

[14] See Nehring and Puppe (2002) and Brock and Xepapadeas (2003). Gordon Rausser and Arthur Small published a study on bioprospecting, or the search for valuable compounds from wild organisms, as a potential source of finance for biodiversity conservation. It is about the value of market incentives for conservation. See Rausser and Small (2000) and Simpson et al. (1996).

[15] This section relies much on "Biodiversity indexes: Value and evaluation purposes" (Supriatna, 2018). There are many examples about the challenges of measuring biodiversity. Supriatna states "Biodiversity is not a numbers game: the quality is more important than quantity. It is not so much in the number of

for the diversity of the biosphere. But it is often argued as inadequate if not integrated with other metrics to fully capture biodiversity. Surrogate or proxy measures often used include species taxa (or a group of any rank, species, family, or class, such as plant functional types of grasses, bushes, or trees) or diversity of distinct gene sequences in a sample of microbial DNA taken from the soil.

There are two popular ecological indices used to account for categorical diversity between subjects or entities:

- The *Shannon Index* was originally proposed by Claude Shannon to quantify the entropy (information content or uncertainty) in strings of text. Also known as the Shannon–Weiner index, the Shannon–Weaver index, or the Shannon entropy measure, the idea is that the more different letters there are, and the more equal their proportional abundance in the string of interest, the more difficult it is to correctly predict which letter will be the next one in the string. It is computed as

$$H = -\sum_{i=1}^{J} p_i \times \ln(p_i) \text{ or } H' = -\sum_{i=1}^{J} (n_i/N) \times \ln(n_i/N),$$

where p_i is the proportion of characters belonging to the ith letter in the string of interest where there are J distinct kinds of letters. In ecology, p_i is usually the proportion of individuals belonging to the ith species (count of n_i out of N total count) in the data set of interest with J distinct species. The minimum value of the index is zero—such a number would tell us that there is no diversity, or there is only one species in that habitat. Higher values mean greater diversity. There is no upper limit to the index. The Shannon entropy measure quantifies the uncertainty in predicting the species identity of an individual that is taken at random from the data set.

- The *Simpson Index*, which is computed as

$$D = \sum_{i=1}^{J} n_i \times (n_i - 1) / [N \times (N - 1)],$$

where the index D ranges between 0 and 1—the higher the value, the lower the diversity. Often, the index of diversity is calculated as 1 – D, so that the higher the value of the index, the higher the diversity of species.

These two index constructions have been used in practice. One biodiversity index related to cities is "The City Biodiversity Index," developed by the Government of Singapore.[16] It was launched in 2008 at the 8th Conference of the Parties to the CBD and has been used for planning and monitoring by dozens of cities, development organizations, and academic networks of researchers. It features 28 different indicators, such as the proportion of natural areas in a city, connectivity measures or ecological networks, native biodiversity in built-up areas (bird species), changes in numbers of native vascular plant species, changes in number of native bird species, habitat restoration, proportion of protected natural areas, proportion of invasive alien species, and many more.

There is scope for even more creative indexes of biodiversity toward valuation and investment research that can be adopted by financial economists. Appendix A lists a series of databases and proprietary inventories from a recent (2022) TNFD discussion paper, entitled "A landscape assessment of nature-related data and analytics availability."

species, but in its identity. For example, fragmenting old growth forest with clear cut would increase species richness at a local scale but not contribute to species richness on a broader scale if sensitive species were lost from the landscape" (p. 2).

[16] The 2021 *Handbook on the Singapore Index on Cities' Biodiversity* (CBD Technical Working Paper No. 98) (Chan et al., 2021) details the construction of the indicators, how they are calculated, the bases for their scoring, and where to download the data.

4 | THE BIODIVERSITY FINANCING GAP AND SOME RECENT FINANCING DEALS

It is a nontrivial challenge to estimate how much investment capital currently flows into nature-based solutions that contribute toward a nature-positive economy. Equally challenging, and related directly to computing cash flows, is estimating the magnitude of investment flows "required" to halt and reverse the biodiversity crisis. Studies addressing these questions have mostly resulted in white papers not subject to the usual rigors of peer review in top scholarly journals. To their credit, however, these white papers acknowledge their efforts are preliminary.

One such study, which grew out of a collaboration between the World Economic Forum (WEF) and the consultancy PwC, resulted in a report entitled *Nature risk rising: Why the crisis engulfing nature matters for business and the economy*. It affirms the WEF's comprehensive risk perception survey in ranking biodiversity loss and ecosystem collapse as one of the top five risks in terms of likelihood and impact in the coming decade. It cites from the IPBES's 2019 *Global assessment report on biodiversity and ecosystem services* to link human activity to eroding the world's terrestrial, oceanic, and species ecological foundations (see Exhibit 1).

The report identifies the three sectors most exposed to nature risks as construction ($4 trillion), agriculture ($2.5 trillion), and food and beverage ($1.4 trillion). Further, nature risks are deemed material for corporations: (a) when businesses depend directly on nature for operations, supply chain performance, real estate asset values, physical security, and business continuity; (b) when the direct and indirect impact of business activities on nature loss can trigger negative consequences, such as losing customers, legal action, and regulatory change that impacts financial performance; and (c) when nature loss causes disruption to society and markets within which businesses operate. Indonesia, Africa, and India were designated the regions with the highest nature dependency, followed by China and South and Central America (see Exhibit 2).

Two important studies in 2020 and 2022 built on earlier work by the WEF by focusing on the investment gap in biodiversity loss mitigation with two distinctly different methodologies and different findings on the size of the gap.

4.1 | A $163 billion biodiversity financing gap

The first such study grew out of a collaboration between the UNEP, the WEF, and the Economics of Land Degradation, and was entitled *The State of Finance for Nature in the G20: Leading by example to close the investment gap* (UNEP, 2022). This UNEP report finds that approximately $133 billion currently flows into land-related nature-based solutions annually with public funds making up 86% of the funds and private funds making up the rest. Over one third of the public funds ($115 billion) is invested by national governments in the protection of biodiversity and landscapes, and the remaining two thirds is in forest restoration, peatland restoration, regenerative agriculture, water conservation, and natural pollution control systems (see Exhibit 3). The $18 billion spent by the private sector spans biodiversity offsets, sustainable supply chains, and private equity impact investing. The report emphasizes how much less finance is flowing into nature than now flows toward climate finance.

The second part of the report estimates that, in order to achieve all future biodiversity, land degradation, and climate targets, G20 countries would need to scale up their annual nature-based solutions investments by an additional $165 billion by 2050. It acknowledges that the estimate considers four principal nature-based solutions linked to forestry, forestry-linked pastures, mangrove restoration, and peatland restoration and further that 60% of that deployed capital is needed in developing economies where fiscal space for investment is more limited. Four clear policy options are laid out such as incentivizing corporations and financial institutions to disclose nature-related risks, aligning investment portfolios to become nature positive, strengthening the case for nature-based solutions using carbon markets, and increasing more concessional capital like subordinate loans, guarantees, and grants. Exhibit 4

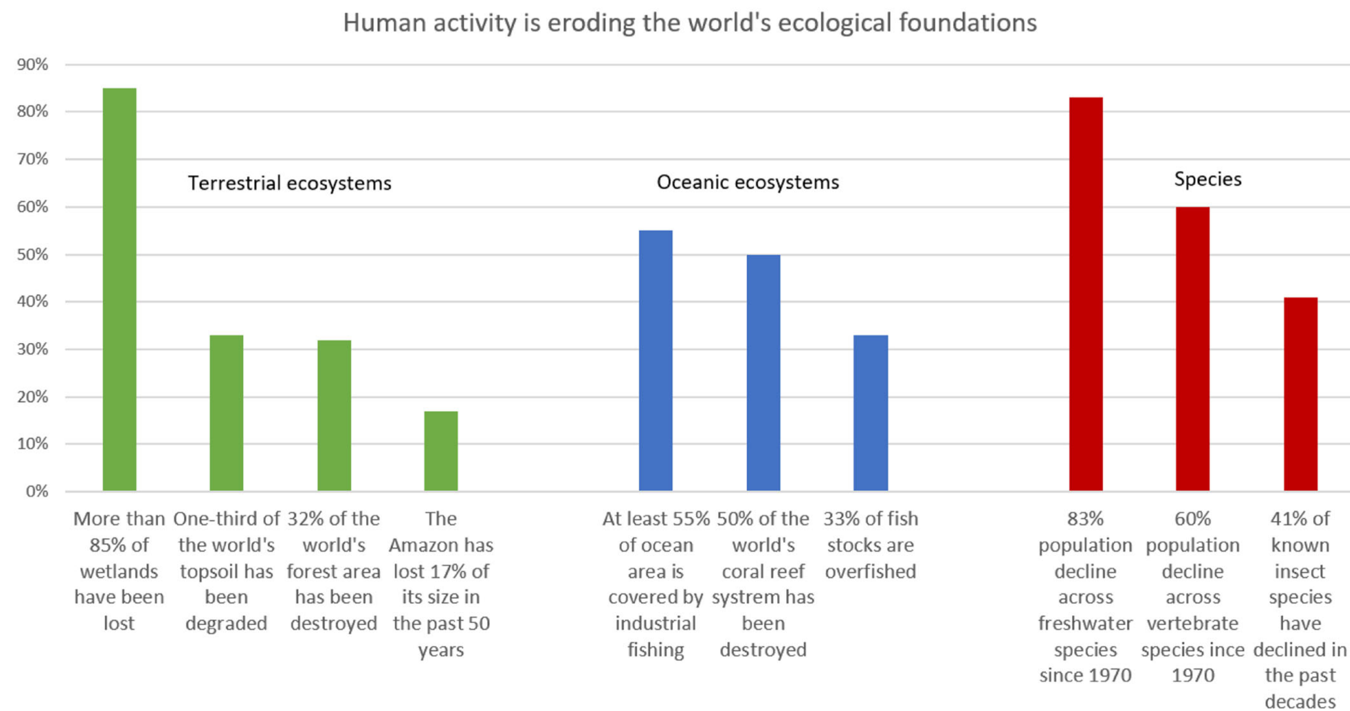

EXHIBIT 1 UN Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) 2019 *Global assessment report on biodiversity and ecosystem services*.
[Color figure can be viewed at wileyonlinelibrary.com]
Source: World Economic Forum, *Nature risk rising: Why the crisis engulfing nature matters for business and the economy* (New Nature Economy Series, WEF, January 2020).

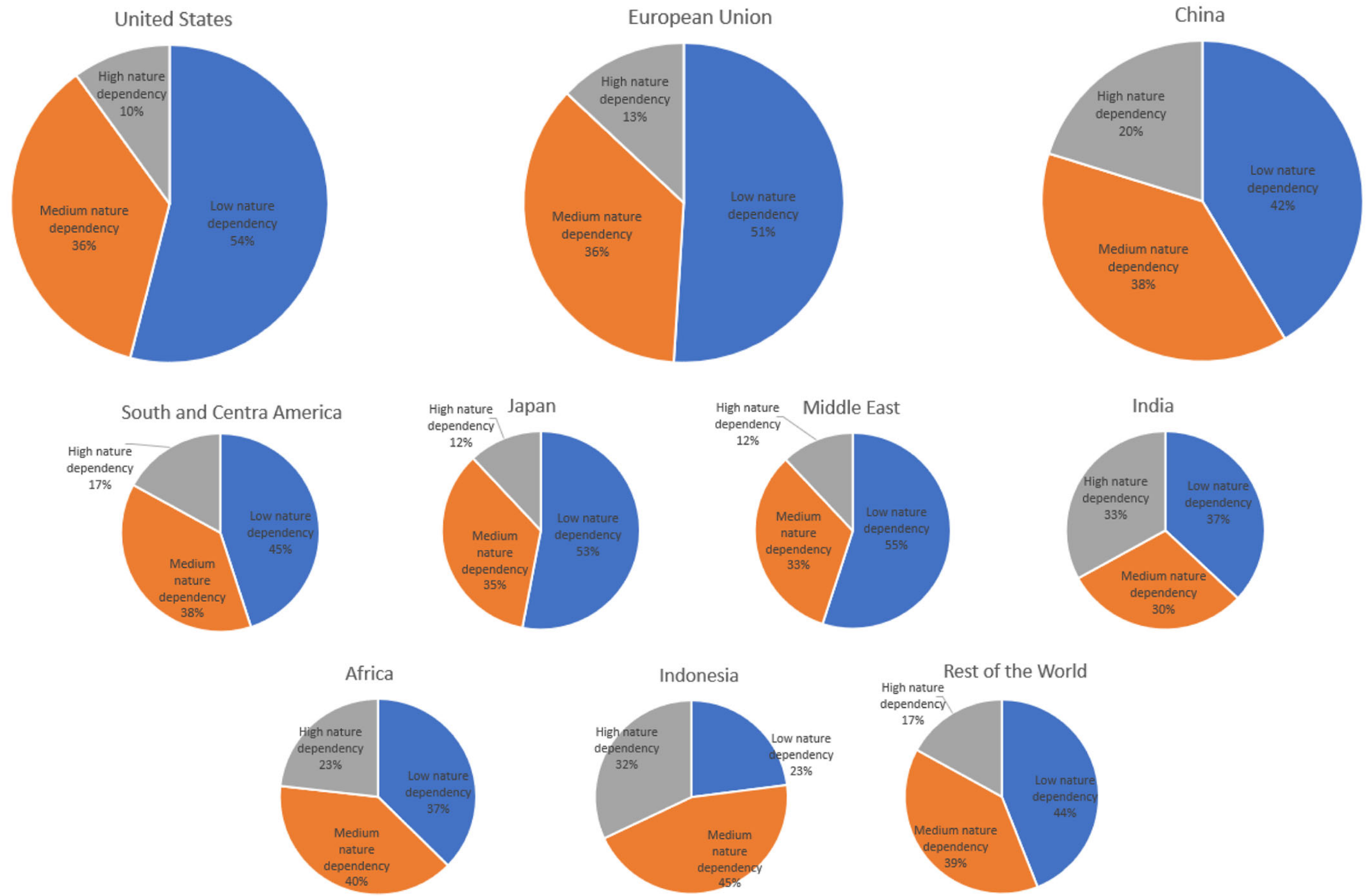

EXHIBIT 2 Variation in the distribution of nature dependency classification by region.
[Color figure can be viewed at wileyonlinelibrary.com]
Source: Adapted from graphs in World Economic Forum, *Nature risk rising: Why the crisis engulfing nature matters for business and the economy* (New Nature Economy Series, WEF, January 2020). Dependency ratings consider a sector's and therefore a region's reliance on ecosystem services at the production process level, for a range of factors, including inputs to production, inputs to research and development, business operations, assimilation of waste, and protection of asset.

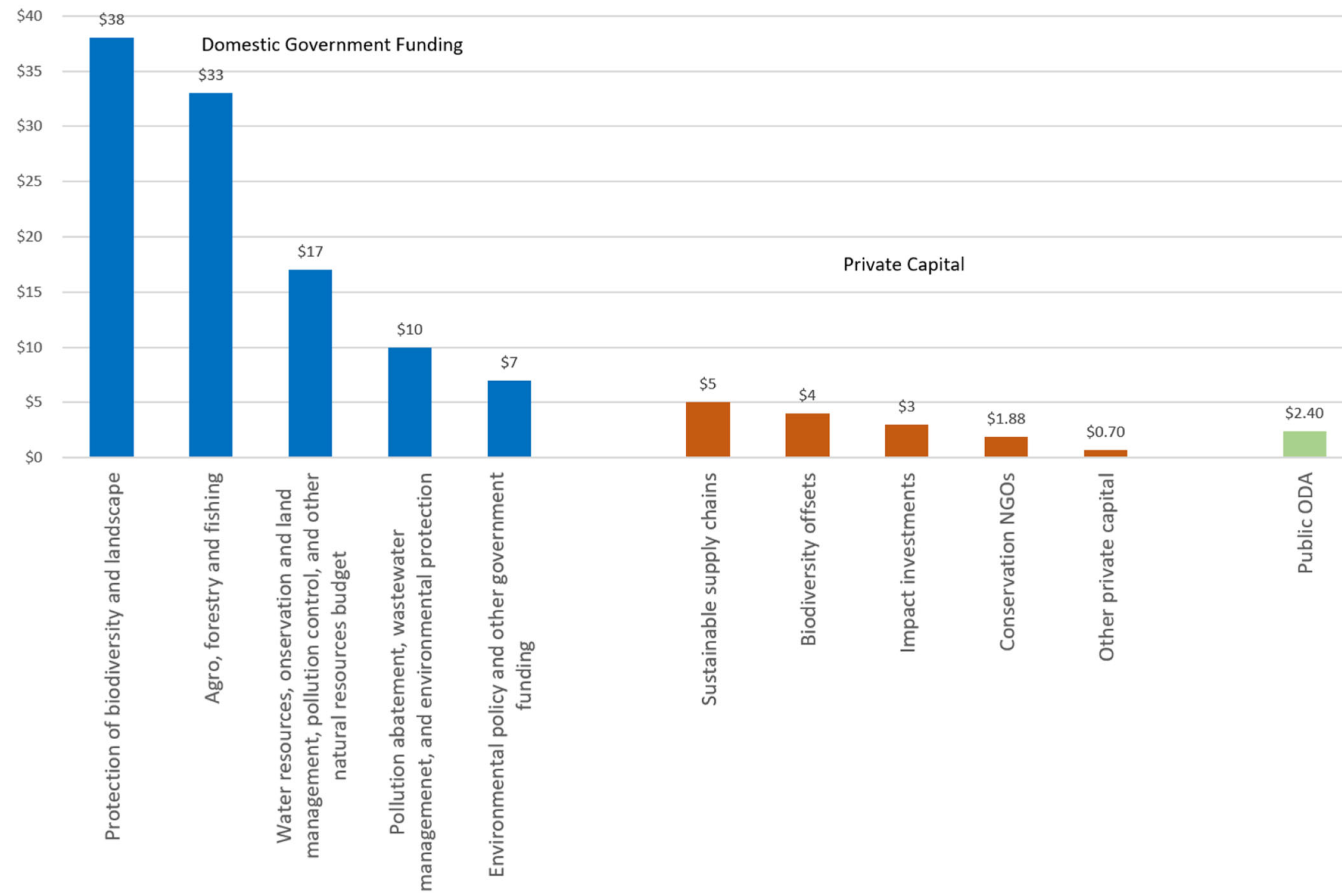

EXHIBIT 3 Current nature-based public and private sector funding.
[Color figure can be viewed at wileyonlinelibrary.com]
Source: Adapted from graphs in UNEP (2022). ODA denotes Official Development Assistance.

EXHIBIT 4 Types of funding shortfalls for G20 countries to meet biodiversity loss mitigation targets

Type	G20 additional annual investment need (2021–2050) in US$	Global future investment need, excluding G20, in US$
Forestry management	$14 billion	$21 billion
Land restoration—forestry	$88 billion	$80 billion
Silvopasture—capital expenses	$3 billion	$6 billion
Silvopasture—operational expenses	$60 billion	$120 billion
Peatland restoration	–	$7 billion
Mangrove restoration	–	$0.5 billion
Total	$165 billion	$235 billion

Note: This table summarizes the additional annual spending needed by the G20 assuming that the current annual G20 spending of $120 billion remains constant. It also shows the additional spending needed, assuming current annual world spending of $130 billion. Insufficient data to calculate peatland restoration and mangrove nature-based solutions for G20 countries are acknowledged.
Source: Adapted from UNEP (2022). Silvopasture denotes forestry land integrated with grazing of domesticated animals.

4.2 | An even bolder biodiversity financing gap estimate

A 2020 study by the Paulson Institute, The Nature Conservancy, and the Cornell's Atkinson Center for Sustainability (Deutz et al., 2020) laid out the broad economic case for protecting nature, examining many known economic/social values of biodiversity, recognizing complexities and interdependencies of nature that can affect valuations, and the biodiversity financing gap between current capital flows and those needed to sustainably manage biodiversity and maintain ecosystem integrity. It also proposed a series of financial and policy mechanisms that can help close the biodiversity financing gap. As of 2019, spending on biodiversity conservation was estimated at between $124 billion and $143 billion per year, very close to the UNEP estimate above (Exhibit 5).

Where the two diverge, however, is in the estimated investment in biodiversity protection needed. Deutz et al. estimate the biodiversity financing gap at between $722 billion and $967 billion per year (Exhibit 6). The largest commitment, they estimate, will be needed to help transition the agricultural sector to sustainable practices by 2030 ($315 billion to $420 billion per year), followed by the transition of global rangelands to sustainable management practices ($81 billion per year), and that for global fisheries ($23 billion to $47 billion per year).

4.3 | Blue bonds, rhino bonds, carbon offsets, and other biodiversity financing deals

Of the seven mechanisms that Deutz et al. (2020) propose to increase capital flows into biodiversity conservation, the most promising in the short term may be the use of domestic budgets and tax policy. Biodiversity offsets, or measurable conservation outcomes designed to compensate for adverse or unavoidable projects, are estimated to come to the forefront by 2030, but these require resolution of challenging measurement issues.

The report forecasts that the development of green, blue, and other innovative nature-related financial products has the greatest potential for the intermediate horizon. Several useful placements serve as examples.

Credit Suisse served as sole structurer and arranger of the successful $364 million placement of Belize's "Blue Bonds" in 2021. Blue Bonds for Conservation was the name of a program launched by The Nature Conservancy in 2019 to help raise investment capital for island and coastal nations to restructure a portion of their national debt and

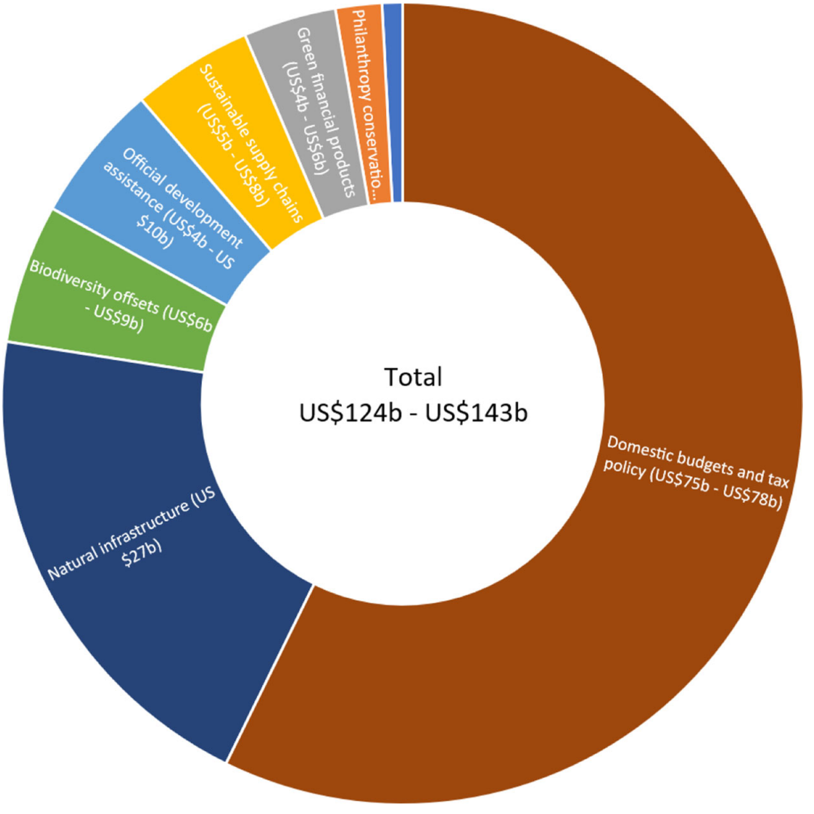

EXHIBIT 5 Paulson Institute, The Nature Conservancy, and Cornell Atkinson Center for Sustainability Estimates of Global Biodiversity Conservation Financing in 2019 (in 2019$billions per year).
[Color figure can be viewed at wileyonlinelibrary.com]
Source: Adapted from graphs in Deutz et al. (2020).

to create long-term sustainable finance for marine protection and sustainable economic development and address climate change. This placement was the largest sovereign bond with marine conservation targets to date.

The successful placement was timely for the Belize government following on the heels of several difficult bond restructuring efforts for Belize during the COVID-19 period. With debt-to-GDP exceeding 130% and current national government bonds trading at 60% discounts, the effort could not have come at a more critical point. The key from Belize's perspective was to reduce the country's existing debt service costs while also securing funding for conservation activities. Of special note, the proceeds of the Blue Bonds are being used by Belize to repurchase a portion of the U.S. dollar-denominated bonds due 2034 and a portion of the financing—US$23.5 million—will be placed in an endowment that will set aside funding for marine conservation accessible from 2041, ultimately aiding in the long-term planning and protection of Belize's marine ecosystems. Finally, about $4 million annually will be paid over the next 20 years to flow into a new, independent conservation fund for Belize with numerous conservation commitments and milestones. Moody's AA rating was critical for Credit Suisse as lead, and it was made possible by the U.S. International Development Finance Corporation (DFC) Office of Structured Finance & Insurance's assurances on political risk, as well as TNC's affirmation of the conservation goals.

The world's first Wildlife Conservation Bond was successfully issued by the World Bank in early 2022 with the help of Credit Suisse as sponsor and the Global Environmental Facility (GEF). The $150 million "Rhino Bond" includes performance payments from investors through the GEF toward contributing to protect and increase the black rhino populations in two protected areas in South Africa, the Addo Elephant National Park and the Great Fish River Nature

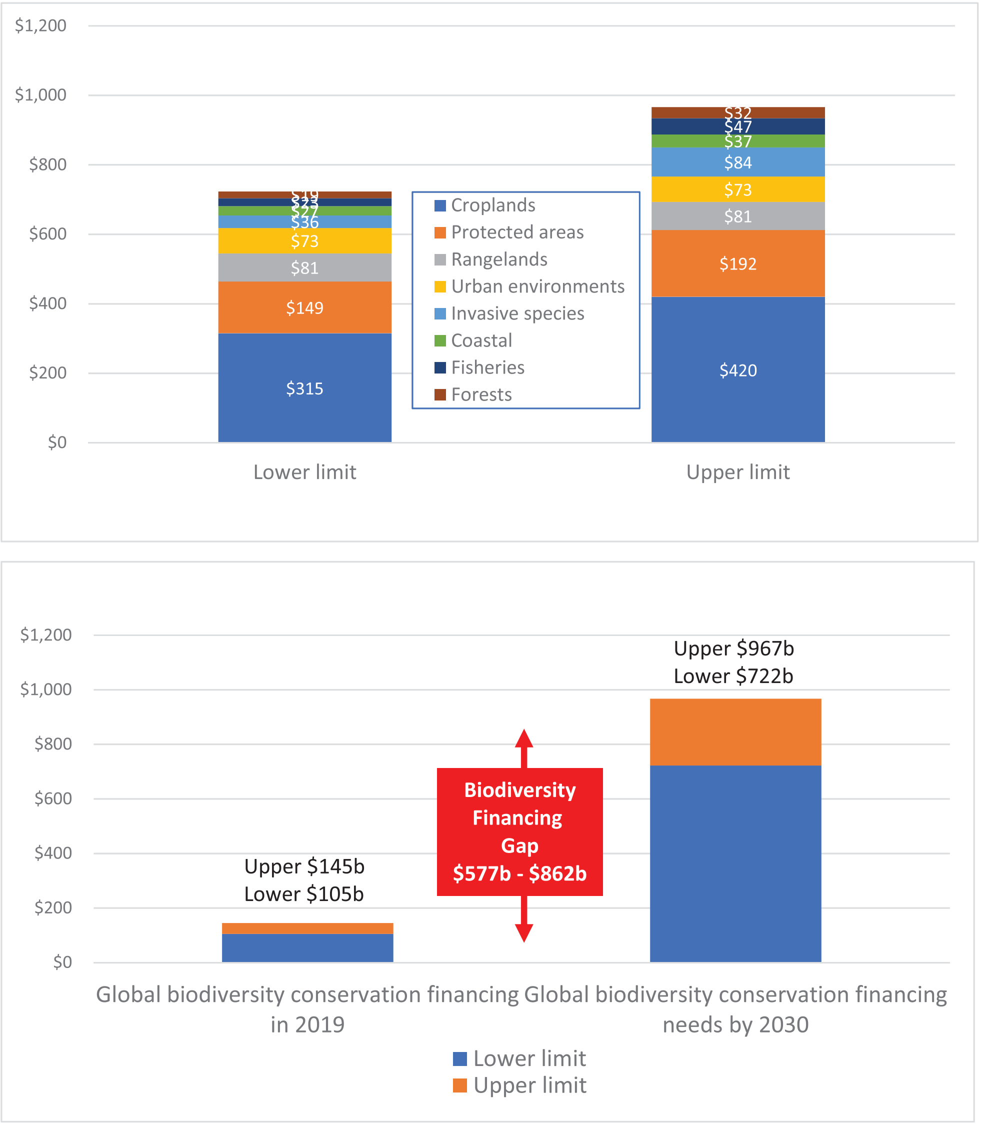

EXHIBIT 6 Paulson Institute, The Nature Conservancy, and Cornell Atkinson Center for Sustainability Estimates of Global Biodiversity Conservation Funding Needs (in 2019$billions per year).
[Color figure can be viewed at wileyonlinelibrary.com]
Source: Adapted from graphs in Deutz et al. (2020).

Reserve. But buyers of the Rhino Bond will receive a payment from the GEF based on preset targets for successful rhinoceros population growth. To receive the maximum payment, the rhino population will need to increase by more than 4% per annum. The key to this newest innovation is that its pay-for-success structure protects an endangered species by leveraging the World Bank's infrastructure and track record in capital markets and in a way that can be replicated and scaled to help channel more private capital for other conservation and climate actions.

Companies are setting ambitious decarbonization goals, not all of which can be easily mitigated given technological and business limitations. To reach net-zero goals, many are seeking to purchase carbon offsets that allow them to balance their hard-to-abate emissions with investments that preserve or restore forests, wetlands, or other natural resources that either remove carbon dioxide from the atmosphere ("sequestration") or prevent new emissions. Carbon offset markets are still early in their development They have been criticized for being difficult to navigate and hard to validate, and are open to greenwashing accusations by market observers. There are some examples of successful carbon offset programs. Consider Forestry and Land Scotland (FLS), a government agency started in 2019 that is responsible for managing Scotland's national forests and land, and vital to the Scottish economy. They link the consequences of climate change and biodiversity loss ("two of the greatest global challenges of this century") and have designed land-based carbon projects, with tree planting and the restoration of degraded peatlands as a cost-effective way for carbon capture and reducing overall greenhouse gas emissions. FLS has a mechanism by which corporations or investors directly can purchase agreed-upon carbon units with an upfront cost to set up a project, an ongoing management fee for FLS to look after the land and the carbon it is sequestering, all agreed upon as a commitment in perpetuity with a system to verify the carbon units on an ongoing basis.[17]

Building on the growing interest in carbon markets transactions that may also deliver collateral benefits to biodiversity, there is now an increasing focus on biodiversity credits as a means to achieve nature-positive outcomes through the use of market mechanisms. There are, however, important barriers to the development of biodiversity credit markets, particularly in the areas of metrics and policy objectives, as we discuss below. Until such obstacles are resolved, it will be very difficult to develop and scale up tradable biodiversity credits.

Sustainable agriculture and forestry currently attract more sustainable financing at scale than almost any other area of green economic activity. While we generally view sustainable agriculture and forestry financing deals as falling under the umbrella of conservation finance, agriculture and forestry are normally premised on the degradation of natural habitats. At least at the time such activities become established in a particular area, agriculture and forestry involve the replacement of a larger number of native species with a much smaller number of cultivated (and often introduced) species. So, sustainable agriculture and forestry practices, including agroforestry, crop rotation, reduced soil tillage, and preservation of hedges and marginal areas for native species, despite their undeniable value to biodiversity conservation, may simply be greener ways of conducting biodiversity-negative economic activities.

Finally, green infrastructure represents one such activity that is in most cases more closely aligned with nature-positive goals than are sustainable agriculture and forestry. The conservation of natural forests for water resource management and the restoration or establishment of coral reefs for coastline and coastal real estate protection, for example, have attracted considerable attention. Another interesting recent development has been the attempt to establish new asset classes based on ecosystem services and the proposal that "natural asset companies" capture the economic value of these ecosystem services. The Intrinsic Exchange Group (IEG) is in the process of developing the criteria for valuing such services, capturing their value, and establishing natural asset companies and, in partnership with the New York Stock Exchange, listing them on a trading platform that will allow investors to buy and sell their equity in a manner that creates financial value for investors while incentivizing the conservation of ecosystem services.

5 | SOME OPEN RESEARCH QUESTIONS IN BIODIVERSITY FINANCE

5.1 | How can financial economists move the needle on biodiversity finance?

The climate finance initiative launched by the *Review of Financial Studies* in 2017 prompted a competition among scholars to develop research proposals on the topic of climate finance with the twin objectives of publishing a special issue

[17] FLS outlines a pricing schedule of £64–£75 per tonne for recreation, £9.80 per ton for air quality regulation dependent on location, £22–£97 per tonne in woodlands for biodiversity, and £7.37 of gross-value-added per tonne through jobs in planting and managing the woodlands. See "Carbon partnerships: How Forestry and Land Scotland can help deliver land-based carbon projects" (March 2022, Forestry and Land Scotland). A recent announcement by Chevron, a major energy producer, introduced a carbon-offset project for Caltex gas station customers who can direct loyalty points via their CaltexGO mobile app to projects that offset a portion of GHG emissions from the fuel they produce. The two carbon sequestration projects for the CaltexGO app are the Rimba Raya Biodiversity Reserve Project in Indonesia's tropical peat swamp forests critical for the Bornean orangutan population and the Reduced Emissions from Deforestation and Degradation in Seima Protection Forest in Cambodia's lower Mekong dry forests crucial for Asian elephants, primates, wild cattle, several carnivores, and birds. Verified Carbon Standard (VCS) Program is the independent third party that authenticates the carbon offsets for Chevron customers.

and, more broadly, of hastening the broader study of an important topic on which there was little to no academic research.[18] Hong et al. (2020) outline the registered-report editorial process, the competition, proposal workshop and final conference, and the resulting eight papers in the special volume. Most importantly, they propose a research agenda for climate finance. Of course, the dozens of papers that define the field of climate finance have developed well beyond the four major research agendas that the authors outlined.

In this last section, we propose a series of research themes framed as open questions on the topic of biodiversity finance. We do so with full understanding that there will be many other themes that financial economists may and will pursue.

5.2 | Some basic knowledge needs

At a fundamental level, there are a series of basic knowledge needs that must be addressed for the field of biodiversity finance to progress. Transaction data and metrics are two such basic knowledge needs.

There has been until now no concerted effort to compile a database of financial transactions in biodiversity finance that will make it possible to do research on performance and impact. While inventories of climate finance transactions exist or can be derived from existing sources, such as the Bloomberg New Energy Finance and the Climate Bonds Initiative, comparable efforts in biodiversity finance have proved more difficult, in part because it is more difficult to draw boundaries and define the scope of biodiversity finance than it is in the area of climate finance.

Reliable and widely accepted metrics constitute another threshold condition for substantial progress in biodiversity finance. The area of climate finance has a simple and well-tracked metric in $MTCO_2e$ (metric tonnes of carbon dioxide equivalent), which is used universally, as well as several other complementary metrics, including mean sea level rise and global average temperature, which are readily available. But just as biological systems are more complex than physical systems, metrics that allow reliable quantification of biodiversity and, more to the point, the impacts of economic and financial activity on biodiversity are more difficult to develop than in climate finance.

The positive climate impacts of an investment in a wind power generation project, an energy efficiency upgrade at an industrial facility, or a green public transit system can all be reduced to $MTCO_2e$ not emitted because of the investment. But in the biodiversity space, one investable project may aim to prevent the extinction of a species of charismatic mega-vertebrate, another to slow the deforestation of a unique area of tropical forest, while yet another aims to restore a degraded habitat, and there are no widely agreed metrics that allow investors to compare these three projects and, assuming similar risk-adjusted rates of return for the three projects, to decide which investment generates the greatest nonfinancial returns. In addition, there are internationally agreed climate policy goals (1.5–2.0°C of warming from a preindustrial baseline), even if these goals do not always translate into government action to achieve the goals. Biodiversity, however, does not yet have comparable, science-based policy goals. This lack of agreed targets for biodiversity conservation and a sharp vision makes any collective action much more difficult.

Much is to be improved upon from existing commercial vendors of ESG (Environmental, Social, and Governance) ratings, according to Boerg et al. (2022), which examines the divergence in scores among KLD, Morningstar Sustainalytics, Moody's ESG (Vigeo-Eiris), S&P Global (RobecoSAM), Refinitiv (Asset4), and Morgan Stanley Capital International's ESG Intangible Value Added (IVA).[19] Consider, for example, the Biodiversity Land Use Score contained within the Environmental Pillar of MSCI's IVA, which states that "this key issue is relevant to companies whose operations risk having a high negative impact on fragile ecosystems. Companies that have policies and programs designed to protect biodiversity and address community concerns on land use, score well on this benchmark. Companies with operations that disturb large and/or fragile, biodiverse areas and lack strategies to minimize and mitigate biodiversity

[18] For more details of the innovative editorial process behind this initiative, see Hong et al. (2020).

[19] See Boerg et al. (2022).

losses, score poorly."[20] Details on how this sub-pillar score (on a ten-point scale) is determined from third-party sources are worthy of further study and potential improvement.

5.3 | Valuation models are key

Beyond transactional data and biodiversity metrics, there is a pressing need for valuation models for natural capital. If indeed more than half of global GDP is moderately or highly dependent on natural capital and its services, the ability to value this capital becomes critically important, and companies need to be able to rigorously assess the value to them of these natural systems, species, populations, and genetic diversity. Investors, in turn, need the tools to be able to model and measure the financial risks of biodiversity-linked investments. Useful guidance on how to operationalize valuation analysis in terms of returns and factor-based models can be had in important recent work on climate change-related risks and possible "greeniums."[21]

In addition to understanding the value of natural capital, we need to better understand the costs associated with protecting biodiversity. While there are estimates of global costs associated with biodiversity conservation (e.g., Deutz et al., 2020), we have little idea how those costs would be spread across the economy or how those actions, if undertaken, would impact economic activity. It is unclear how the financial services industry would be impacted by such changes. While investments in climate mitigation and adaptation are likely to generate substantial revenue for banks from advisory services and project debt financing, it is less clear to what extent a substantial effort to slow and reverse biodiversity loss would result in comparable opportunities for financial institutions.

Compared to the world of climate finance, financial products and services around biodiversity finance are likely to require more creative thinking and innovative structuring. Generating revenue to service debt payments is comparatively simple in the climate area: a proposed green energy project should produce power that, assuming it meets customer demands, generates cash flows to pay back investors. The paradox of biodiversity finance is that it seeks to generate revenue from conserving a natural resource rather than transforming it, which is generally how natural resources are monetized.

Beyond a handful of industries in which it is, in fact, the conservation (rather than the transformation) of natural resources that generates cash flows, with travel and hospitality (and particularly the ecotourism segment of the industry) being the clearest example, generating cash flows from habitat conservation rather than habitat transformation will require the development of unconventional approaches to financing. Taxes and public subsidies can help. But natural infrastructure solutions may be an even more promising area for this. Outside of travel and hospitality, natural infrastructure, and other such economic activities that rely on conserving natural habitats, biodiversity finance may require a greater focus on the development of investment products, such as environmental impact bonds, the business case for which is predicated on future (and difficult to measure) avoided costs. The optimal design and valuation of such investment products will require considerable effort.[22]

The effects of designating a financial product as green or sustainable on customer demand, liquidity, and pricing require increased attention. While preliminary evidence suggests a modest positive pricing effect of issuing a green bond compared to a conventional bond (Flammer, 2021), it is unclear whether this finding will hold up under increased scrutiny or in financial products other than green bonds.[23] Related to this, it is not clear to what extent the lack of an agreed set of metrics in biodiversity finance prevents further investment in the area.

5.4 | Other research themes

A number of potential research questions in biodiversity finance touch on the area of behavioral economics. For example, it is unclear to what extent investment advisors may apply suboptimal investment strategies that are selected,

[20] See the key features and benefits of the MSCI ESG Intangibles Value Assessment.

[21] See Pastor et al. (2022).

[22] See, for example, Brand et al. (2021).

[23] See Flammer (2021).

at least in part, to avoid the appearance of chasing after fads or not focusing on maximizing returns. In their zealous pursuit of risk-adjusted economic returns for their clients, or at least the appearance thereof, are financial advisors deploying their clients' capital in a manner that not only condemns those clients to life on a hot and depauperate planet in the long term but that delivers weak returns, just to avoid appearing like they are investing in "green" or "blue"? Conversely, to what extent might investment decisions be influenced by exposure to adverse environmental impacts?[24]

Another theme is related to nature-linked divestment and its consequences for systemic risk. The effectiveness of negative-screening investment approaches by asset managers, and of tighter disclosure requirements by regulators, in raising corporate environmental risk management standards are unclear. And, if higher risk management standards are found, whether such higher standards translate into measurable positive impacts on biodiversity will have to be assessed. Energy companies have become the new "sin stocks" facing divestment campaigns and lawsuits from shareholders alleging misleading disclosures regarding the costs of climate change. Recent work by Bolton and Kacperczyk (2021) documents that institutions might indeed already be screening out companies of high carbon exposure based on similar considerations.[25] Could we imagine the launch of similar divestment campaigns and lawsuits from shareholders that stem from irresponsible actions by corporations toward their contributions to biodiversity loss by the geographic footprint of their operations? Studies by Akey and Appel (2019) and Naaraayanan et al. (2020) hint that these campaigns are imminent.[26]

Finally, given the very substantial effects that harmful subsidies and similar governmental policies are believed to have on biodiversity, they need to be better understood, as is the extent to which they are distortionary. Reforms and design refinements that improve biodiversity outcomes, while achieving the social and political goals of implementing governments, merit further exploration.

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CONFLICT OF INTEREST STATEMENT

Karolyi serves as a consultant for Avantis Investors, is a member of the working board for Responsible Research in Business and Management (RRBM) and a member of the global advisory council for Accounting for Sustainability (A4S). Tobin is vice-chair and acting chair of the board of directors of the International Union for Conservation of Nature-US and is co-founder and member of the executive committee of the Coalition for Private Investment in Conservation (CPIC).

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[24] See, for example, Choi et al. (2020). A recent working paper by Rizzi (2023), entitled "Nature as a defense from disasters: Natural capital and municipal bond yields" shows promising results on how wetland loss is positively related to municipal bond yields. Natural loss risk is priced into the municipal bond market after extreme weather events.

[25] See Bolton and Kacperczyk (2021).

[26] See Akey and Appel (2019) and Naaraayanan et al. (2020).

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APPENDIX A

Databases and proprietary inventories from Taskforce on Nature-related Financial Disclosures discussion paper "A landscape assessment of nature-related data and analytics availability"

- Biodiversity analysis in the digital era .
- Geospatial ESG .
- Paving the way toward a harmonized biodiversity accounting approach for the financial sector.
- Disclosing nature's potential.
- Biodiversity—The ecosystem at the heart of business biodiversity—CitiGPS (www.citivelocity.com)
- Essential biodiversity variables for mapping and monitoring species populations. Nature Ecology & Evolution
- UN System of Environmental-Economic Accounting. Ecosystem Accounting
- Is biodiversity a material risk for companies?
- UNEP-UNDP reporting on nature-related risks, impacts and dependencies. Report.
- A list of spatial available data Available spatial data— Google Sheets.
- Biodiversity platforms for implementing a sustainable world (www.gbif.org/).
- Workshop report—A synthesis of available scientific input to inform the development of the post-2020 Global Biodiversity Framework.
- Natural capital protocol. A decision-making framework that enables organizations to identify, measure, and value their direct and indirect impacts and dependencies on natural capital. Report.
- "What does 'nature' mean?" by Frederic Ducarm and Denis Couvet, Nature Humanities and Social Sciences Communications, January 31, 2020. The authors examine the origins, etymology, and historical semantics of this word and its different meanings in contemporary European languages. Report.
- "Open-source Biodiversity Data Platform Initiative" by UNEP WCMC and Finance for Biodiversity. Nature Finance. An inventory of biodiversity data for conservation monitoring. Report.
- Taskforce on Nature-related Financial Disclosures proposed technical scope (June 2021). This framework will serve as a mechanism to help organizations understand, disclose, and manage the financial risks and opportunities associated with the deteriorating state of nature and a transition to an economy consistent with meeting future nature-related international agreements such as the UN Convention on Biological Diversity (CBD) and the post-2020 Global Biodiversity Framework. Report.
- "Data integration enables global biodiversity synthesis" by Mason Heberling, Joseph Miller, Daniel Noesgaard, and Dimitry Schigel, February 1, 2021, PNAS. In an analysis of the research uses of the world's largest biodiversity data network, the authors report the emerging roles of open-access data aggregation in the development of increasingly diverse, biodiversity science landscape centered on big data integration, informing ongoing initiatives, and the strategic prioritization of biodiversity data aggregation across diverse knowledge domains, including environmental sciences and policy, evolutionary biology, conservation, and human health. Report