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From impacts to dependencies: A first global assessment of corporate biodiversity risk exposure and responses

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Abstract

There is growing awareness that biodiversity loss poses a significant risk to the global economy, but a lack of clarity on what this means for corporations, and how they are responding. This study provides a first quantitative assessment of biodiversity risk exposure across the world's largest listed companies, compared with their adoption of biodiversity policies, through analysis of disclosures from a sample of 11,812 companies from 2004 to 2018. We find that companies have started responding strategically to biodiversity risk, with 29% having adopted a biodiversity policy by 2018. However, around $7.2 trillion of total enterprise value remains exposed to unmanaged biodiversity risk. Companies in sectors with material impacts on biodiversity tend to have high levels of response, but there is poorer responsiveness to material biodiversity dependency risks. A natural-capital-based view (NCBV) of the firm is proposed to theorise how corporations are constrained by both their impacts and dependencies on natural capital.

KEYWORDS
biodiversity, dependencies, impacts, materiality, natural capital, risk

1 | INTRODUCTION

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) recently presented the most up-to-date global assessment of the status of biodiversity—'the variability among living organisms from all sources including … diversity within species, between species and of ecosystems'[1]—concluding that there is widespread and accelerating decline, with significant consequences for the services provided to people from nature (IPBES, 2019). The global rate of species extinction is already tens to hundreds of times higher than the average rate over the past ten million years and around a million species face extinction within decades unless preventive action is taken (IPBES, 2019). This loss of biodiversity translates into mounting losses of a wide variety of ecosystem services that biodiversity provides to the economy and society (Dasgupta, 2021; IPBES, 2019). In addition to threatening these valuable ecosystem services, the processes that drive biodiversity loss can have further catastrophic effects, for example, with habitat conversion being one of the major systemic drivers of pandemics, including COVID-19 (Wu, 2021).

Awareness of the economic implications of biodiversity loss has come sharply into focus in the last decade (Dempsey, 2013). Indeed, in 2020, the World Economic Forum rated biodiversity loss as one of the top five risks to the global economy, estimating that more than half of global GDP is moderately or highly dependent on natural capital and therefore vulnerable to its loss (World Economic Forum, 2020; World Economic Forum & PwC, 2020). In 2021, the Central Banks and Supervisors Network for Greening the Financial System (NGFS) concluded that the potential impacts of biodiversity risk pose threats to macrofinancial stability (NGFS, 2021). However, it has been much less clear how this global systemic risk translates into specific material operational risk for corporations in different sectors and hence into indirect risk for lenders and investors as providers of capital to the

global economy (Dempsey, 2013; EIRIS, 2010; F&C Asset Management, 2004; Mulder, 2007; Mulder & Koellner, 2011; VfU, 2011). While certain businesses, for example, in the extractives sector (UNEP-WCMC, 2017), have long appreciated the potential business risks arising from their negative *impacts* on biodiversity, the extent to which businesses across the economy may also be exposed to risks arising from their *dependencies* on biodiversity remains an open and understudied question. This has led to growing calls in recent years for investors to 'wake up to biodiversity risk' (Gonçalves, 2021; Nauman, 2020).

In this paper, we develop a unique methodology to identify the sectors materially exposed to biodiversity impact and dependency risks, in a more comprehensive way than in previous studies (EIRIS, 2010; F&C Asset Management, 2004). We then use this sectoral analysis to provide a first quantitative assessment of the extent to which the largest global listed companies are materially exposed to biodiversity risk, and whether or not they are beginning to respond strategically, taking the adoption and disclosure of a biodiversity policy as evidence of at least a first step towards a strategic risk management response (EIRIS, 2010; F&C Asset Management, 2004; Mulder & Koellner, 2011; UNEP Finance Initiative, 2008; VfU, 2011). We find that, as of 2018, around $5.2 trillion of total enterprise value is exposed to material biodiversity impact risk and $20 trillion is exposed to material biodiversity impact risk (all $ figures in US dollars). More than half of these materially exposed companies, representing $1.9 ($7.2) trillion of total enterprise value for impact (dependency) risk, are not yet signalling even a minimal strategic response via the adoption of a biodiversity policy. This demonstrates that biodiversity risk to corporations is significant at a global scale, and not yet comprehensively managed, resulting in underestimated risk exposure for global investors and other stakeholders. Furthermore, our assessment is conservative insofar as adoption of a biodiversity policy is only a first step towards a strategic response and does not guarantee that a company's biodiversity risk management is adequately effective.

To theorise the rationale for companies to respond strategically to biodiversity risk, we start with the lens of the natural-resource-based view (NRBV) of the firm (Hart, 1995). This in turn is based on the resource-based theory that long-term competitive advantage results from a firm's control and effective management over valuable, nonsubstitutable and costly to replicate resources and capabilities (Barney, 1991; Hart, 1995). The NRBV added to the resource-based theory an acknowledgement of the constraints imposed by the natural environment, arguing that unmanaged environmental impacts are ultimately unsustainable in a bounded world; therefore, some degree of future competitive advantage must be based on those capabilities that enable sustainable management of environmental impacts (Hart, 1995). We argue that this is also consistent with a 'natural capital' framing of *dependencies* on the natural environment, complementing the conceptualization based primarily on impacts. Taking this one step further, we propose that natural capital risk—covering both impact and dependency risk—should be explicitly considered as a determinant of the long-term value of a company's strategic resources and capabilities. This leads us to propose what we term a 'natural-capital-based view' (NCBV) of the firm, as a modest update to the NRBV, consistent with its original framing yet bringing it into line with recent approaches to corporate natural capital management (Natural Capital Coalition, 2016; NCFA & PwC, 2018; NCFA & UNEP-WCMC, 2018; UNEP-WCMC, 2017).

Our study contributes to the literature on corporate biodiversity risk management in the following ways. First, by operationalising the first combined use of a sectoral biodiversity impact risk materiality assessment (SASB) and a sectoral natural capital dependency risk materiality assessment tool (ENCORE), we provide a global picture of different types of biodiversity risk across subsectors, enabling a global assessment of biodiversity risk to investment portfolios. Secondly, by considering the disclosure of corporate biodiversity policy adoption across a worldwide sample of 11,812 listed companies and 48,748 company-year observations between 2004 and 2018, we provide one of the most comprehensive cross-country and cross-sectoral studies to date on the extent to which each sector is beginning to respond strategically to biodiversity risk. Thirdly, we demonstrate that there remains a gap in the adoption of biodiversity policies by companies in key sectors exposed to biodiversity risks and that indirect risk exposure for investors (as measured by the total enterprise value of these companies with unmanaged biodiversity risk) is significant. Finally, we contribute to a further evolution of the natural-resource-based view of the firm to include the management of natural capital dependency risk and also provide a number of practical findings of relevance to business, as well as activists and policy-makers.

The paper is structured as follows. In Section 2 we discuss our theoretical considerations and research questions. Section 3 outlines the dataset we collect and the methodology we employ, followed by a synthesis of our results in Section 4. We then discuss our findings and conclude in Section 5.

2 | BACKGROUND

2.1 | Natural capital and biodiversity risk

The concept of 'natural capital'—thinking of the environment as stocks of natural capital assets that yield flows of environmental goods and ecosystem services which have value for the economy and society—has been a central concept in environmental and ecological economics for over three decades (Costanza & Daly, 1992; Pearce, 1988). However, it is only in the most recent decade that the concept has been widely adopted by the corporate sector, swiftly moving from the periphery to the mainstream. A key driver was the 'TEEB for Business' report (TEEB, 2010), which was launched at the 'First Global Business of Biodiversity' symposium in the UK in mid-2010. This led to the launch of the TEEB for Business Coalition in 2012, which was later rebranded as the Natural Capital Coalition (and again more recently, as the Capitals Coalition). The Coalition has developed the Natural Capital Protocol, a standardised framework for businesses to measure, value and report their impacts and dependencies on natural capital (Natural Capital Coalition, 2016), which has

become the most recognised guide for businesses wishing to take a more strategic approach to their environmental management.

A key feature of natural capital thinking, which distinguishes it from earlier conceptual framings of business-environment interactions, is that it places equal emphasis on economic and social *dependencies* on natural capital, in addition to more commonly considered *impacts*. A dependency is defined as 'A business reliance on or use of natural capital', while an impact is 'The negative or positive effect of business activity on natural capital' (Natural Capital Coalition, 2016, p. 34). Natural capital *risks* can arise for businesses through impact and/or dependency pathways. For example, economic activities that have negative impacts on biodiversity may result in regulatory penalties, consumer boycotts or loss of a sustainability certification, which will tend to increase costs and/or reduce revenues and thus affect profitability and credit-worthiness. On the other hand, significant non-substitutable dependencies on the ecosystem services provided by biodiversity may constitute a risk for businesses if that biodiversity is lost or degraded, as is increasingly the case worldwide. The potential scale of natural capital risks has been increasingly highlighted by environmental NGOs, UN bodies and industry associations (Ahlström, 2019; Ascui & Cojoianu, 2019b; Bonner et al., 2012; F&C Asset Management, 2004; Guerry et al., 2015; Leach et al., 2019; Mulder, 2007; Natural Capital Coalition, 2016). Conversely, managing natural capital risks may confer competitive advantages.

A first assessment of biodiversity risks for UK listed companies in 2004 concluded that biodiversity risk was already material for companies in nine sectors, yet a significant majority (about two thirds) of companies in those sectors were not yet taking substantive action to manage their biodiversity risk (F&C Asset Management, 2004). A key recommendation was that 'Companies with material or potentially material biodiversity risks should develop and publish specific policies or statements that recognise the significance of the relationship between biodiversity and their business' (F&C Asset Management, 2004, p. 4). A broader global study of 1800 listed companies within the FTSE All-World Development Index in 2010 found little evidence of such action, with only 26% of companies in medium and high-risk sectors having a 'moderate' or 'good' policy in place (EIRIS, 2010). Larger businesses and those in high-impact sectors were more likely to have biodiversity policies in place. Similarly, a global survey of 1576 company executives in 2010 found that only a quarter of responding businesses had a biodiversity policy in place (McKinsey & Company, 2010). A review of biodiversity reporting by 147 of the top 150 companies in the Fortune Global 500 in 2014 found that 28 (19%) reported having a biodiversity policy (Adler et al., 2018), while a similar study of the top 100 companies from the Fortune Global 500 in 2016 found that 31 had clearly stated biodiversity commitments (Addison et al., 2019). A variety of studies at national level have reported broadly similar findings about low levels of biodiversity disclosure (Houdet & Cherrington, 2019; Rimmel & Jonäll, 2013; van Liempd et al., 2013). To the best of our knowledge, our analysis is the first to significantly improve on the F&C Asset Management (2004) and EIRIS (2010) identification of sectors exposed to biodiversity risk and to assess corporate responses at a more comprehensive global scale.

Academic research on companies' relationship with biodiversity has approached the issue from a variety of perspectives, including legitimacy (Bhattacharyya & Yang, 2019; Suchman, 1995), corporate awareness (Atkins et al., 2018; Atkins & Maroun, 2018), accounting and reporting (Addison et al., 2018; Addison et al., 2019, 2020; Adler et al., 2018; Atkins & Maroun, 2018; Cuckston, 2017; Jones, 1996, 2003; Jones et al., 2013) and reacting or engaging with stakeholder values and preferences (Boiral et al., 2018, 2019). However, there is relatively little academic literature engaging with the issue of biodiversity specifically as a source of strategic risk and opportunity for businesses (Boiral et al., 2018, 2019; Houdet et al., 2012; Winn & Pogutz, 2013), despite the existence of a substantial practice-oriented literature (Bonner et al., 2012; Hanson et al., 2012; IUCN French Committee, 2016; Lammerant et al., 2019; NGFS, 2021; OECD, 2019; Schaltegger & Beständig, 2010; TEEB, 2011; UNEP Finance Initiative, 2008; VfU, 2011; WBCSD, ERM, IUCN, & PwC, 2011). Dempsey (2013, p. 46) argues that this practice-oriented literature is actively engaged in making biodiversity 'legible and meaningful to firms' through the use of risk language and metrics, in advance of widespread corporate acknowledgement of these risks. While it may seem intuitively obvious that companies should take action to manage material risks, Dempsey (p. 44) points out the flip side of risk is 'the competitive advantages and opportunities that could be gained from *managing this risk*' (italics in original). In this paper, we turn to the NRBV as a starting point for understanding why responding to biodiversity risk might help create or maintain a firm's long-term competitive advantage.

2.2 | The natural-resource-based view of the firm

In the 25 years since Hart (1995) first developed the NRBV, business practice with respect to management of the natural environment has evolved significantly (Winn & Pogutz, 2013). In this section, we review the evolution of the NRBV and place it in the context of the recent developments in business management of natural capital outlined in the previous section.

The natural-resource-based view of the firm elaborated on the resource-based theory (RBT) that long-term competitive advantage results from a firm's control and effective management over valuable, nonsubstitutable and costly to replicate resources and capabilities (Barney, 1991). Hart (1995) added to this the constraints imposed by the physical environment, pointing out that few, if any, organisational strategies relying on resource-based competitive advantages can continue very far into the future if they are not environmentally sustainable. An important insight here was that environmental constraints are fundamentally, in the longer term, physical rather than merely regulatory or legal in nature, even though they may well manifest much earlier through the latter. At the same time, Hart recognised that competitive advantage on its own may be a necessary but not sufficient explanation for strategic success, as firms also require social legitimacy in order to thrive (Atkins et al., 2015; Suchman, 1995).

Hart (1995) developed the examples of pollution prevention, product stewardship and sustainable development in order to show how firms can mobilise particular resources and capabilities (e.g., stakeholder integration and new capability in production and operations, in the case of product stewardship) to obtain competitive advantage (e.g., by pre-empting competitors and establishing new standards that are favourable to the firm). All of the strategies identified by Hart (1995) and Hart and Dowell (2011) in a follow-up review of the NRBV 15 years later have to do with reducing environmental impacts, for example, through minimising emissions, waste and other environmental burdens. While this reflects one important aspect of the constraints imposed by the physical environment—the reality that such impacts cannot continue to grow indefinitely and are increasingly likely to be regulated or otherwise controlled by society—it does not adequately acknowledge the constraints on future availability of critical natural resources that are brought about not by the company's own impacts but by broader environmental or social changes, such as climate change or population growth. By contrast, these latter constraints are highlighted by the business approach to natural capital which has recently risen to prominence, exemplified by the Natural Capital Protocol (Natural Capital Coalition, 2016).

Although the NRBV was originally framed almost exclusively in terms of limitations imposed on firms due to environmental *impacts*, it seems unobjectionable that it should also accommodate the idea of business *dependencies* on natural capital. Furthermore, 'capital' has always been considered a key resource under the RBT and expanding the concept of capital to include natural capital is fundamentally aligned with the NRBV's core observation that nature imposes some irresolvable constraints on firm activity over the longer term. Nevertheless, the term 'natural capital' is not mentioned in Hart's (1995) original formulation of the NRBV nor even in Hart and Dowell (2011), and we therefore suggest that the theoretical framework would benefit from more deliberate attention to both impacts and dependencies on natural capital as equally important strategic constraints. We propose that this could be called a 'natural-capital-based view' (NCBV) of the firm.

Both the RBT and the NRBV have evolved from originally rather static views of the firm and its environment to more explicitly considering the dynamic nature of competition and thus the advantages offered by dynamic capabilities, defined as 'the capabilities that allow firms to reconfigure resources to gain advantages as markets shift in discontinuous ways' (Hart & Dowell, 2011, p. 1473). We suggest that the analogous approach in the NCBV would consider the *risks* associated with resources that are critical to the operation of the firm; and their corollary, the *opportunities* for competitive advantage that can arise for companies that are better able to manage these risks and exploit new opportunities. Such opportunities might include improved resource efficiency, enhanced customer loyalty from responsible business conduct, diversification into new environmental markets such as biodiversity offsets (Houdet et al., 2020; Milner-Gulland et al., 2020; Moilanen & Kotiaho, 2021) and sustainable investment (Gortsos, 2021), or improved supply chain resilience to biodiversity-related shocks (Gomez et al., 2021; Shroff & Cortés, 2020). By developing dynamic capabilities and reducing their reliance on high-risk resources—that is, economic activities with material natural capital impacts and dependencies—firms should become more resilient to both expected and unexpected changes and thus improve their dynamic competitive advantage. Over time, as biodiversity loss has accelerated, we would therefore expect firms with highly material impacts and dependencies on biodiversity to take a proactive approach to managing and reducing those risks, which we consider likely to be signalled by adoption (and, for listed companies, public disclosure) of a biodiversity policy. This leads us to frame our first two research questions: *To what extent are global listed companies exposed to material biodiversity risks?* and *To what extent are companies with material biodiversity risks responding strategically by adopting a biodiversity policy?* Finally, we seek to understand *What are the characteristics of companies that adopt biodiversity policies?*

3 | DATA AND METHODOLOGY

3.1 | Listed company sample

We collected our global listed company sample by downloading the index constituents of the Bloomberg World Index (BWI) every year from 2000 to 2018 from the Bloomberg terminal. The BWI is a capitalization-weighted index of all equities included in the BWI Series. Equities in the series were in the top 85% market capitalization of their respective Bloomberg Classification Sector at the time of the rebalancing of the capitalization-weighting within the index. The index constituents were downloaded as of the first week of March of every year. This results in a dataset of 11,812 listed companies which have been part of the index in any given year between 2000 and 2018. Given that delisted companies (for whatever reason) are no longer tracked by Bloomberg, we remove the missing observations post delisting. As we will outline below, Bloomberg collects a robust set of independent and control variables that we use from 2004 onwards; hence, our final dataset is an unbalanced panel of 48,748 company-year observations between 2004 and 2018.

3.2 | Dependent variable

3.2.1 | Biodiversity policy

For each company, we match the biodiversity policy datapoint from Bloomberg, which indicates whether the company has disclosed, in its annual or sustainability reports, any initiatives to ensure the protection of biodiversity. The variable is coded as a binary variable (1—which quantifies the disclosure of at least one biodiversity-related policy; or 0—for the absence of any disclosed biodiversity policies in a given year).

3.3 | Independent variables

3.3.1 | Biodiversity dependency risk

A biodiversity dependency risk variable was constructed by extracting information on the materiality of biodiversity-related dependency risks from the ENCORE platform.[2] The ENCORE platform provides a structured, evidence-based materiality assessment of natural capital dependency risks for 138 industry subsectors, largely based on the 158 subsectors of the Global Industry Classification Standard (GICS).[3] The companies in our dataset are categorised in 419 subsectors according to the Bloomberg Industry Classification System (BICS). We mapped these subsectors onto the 138 ENCORE subsectors manually, according to the closest overall sector and subsector description, so that each company in the sample could be assigned a biodiversity dependency risk materiality score according to its BICS subsector.

The ENCORE natural capital dependency risk assessment methodology (NCFA & UNEP-WCMC, 2018) first considers the significance of a set of 21 ecosystem services to the production processes commonly used in each sector, then evaluates the importance of eight natural capital asset classes to the provision of those ecosystem services and finally assesses the influence of 27 major drivers of environmental change on the condition of those assets. The result is a ranking of dependency risk materiality (very low, low, medium, high or very high) associated with the ecosystem service that is relied on by each subsector. Evidence to support each stage of the ENCORE assessment was derived from review of both peer-reviewed and grey literature, complemented with interviews with sector specialists (NCFA & UNEP-WCMC, 2018).

The 21 ecosystem services considered within ENCORE are based on a substantial simplification of the Common International Classification of Ecosystem Services (Haines-Young & Potschin, 2018), excluding cultural ecosystem services. They are further grouped into four functional categories or types of benefit provided: (i) *direct physical input* (e.g., wood fibre is an input to paper production), (ii) *enables production process* (e.g., pollination enables fruit production), (iii) *mitigates direct impacts* associated with production (e.g., certain habitats can provide bioremediation of waste products such as sewage) and (iv) *protection from disruption* (e.g., natural enemies of pests can provide pest control, thus protecting agriculture or forestry from disruption). ENCORE's eight natural capital asset classes are derived from the natural capital framework proposed by Leach et al. (2019), excluding the asset class of nonrenewable energy (fossil fuels). Two of these eight natural capital asset classes are relevant to biodiversity: species (including genetic resources) and habitats. For example, the economic process of 'natural fibre production' (associated with the apparel sector) depends on the ecosystem service 'fibres and other materials' for direct physical inputs and also depends on the ecosystem service 'bioremediation' to mitigate its direct impacts—and both ecosystem services are linked to the 'species' and 'habitats' natural capital assets.

We extracted the dependency materiality assessment from ENCORE for all subsectors and all functional categories on all ecosystem services associated with biodiversity. According to the ENCORE classification, very low and low materiality imply that a production process can continue as is or with minor modifications even when there is full disruption of the ecosystem service provided by biodiversity, or such disruption does not materially affect the company's profits (NCFA & UNEP-WCMC, 2018). Therefore, we considered an industry subsector's biodiversity dependency risk to be material only if it was assessed at medium or higher materiality, since at these levels production processes can be significantly affected by disruptions, materially affecting company profits. Furthermore, we considered dependency materiality for each industry subsector in two ways: (i) across any of the four functional categories and (ii) within each of the four functional categories separately.

3.3.2 | Biodiversity impact risk

The biodiversity impact risk variable was constructed by examining the Sustainability Accounting Standards Board (SASB) Materiality Map® and SASB standards for each industry subsector.[4] Within these standards, materiality assessment is based on evidence of wide interest from a variety of user groups and evidence of financial impact, in line with the approach used by the Securities and Exchange Commission in the US (Khan et al., 2016). While it is important to acknowledge this geographical bias in the SASB framework, it nevertheless provides a structured and well accepted insight into biodiversity impact risks across different industry sectors. Each industry subsector that had a disclosure topic and accounting metrics under the general issue of 'ecological impacts' was coded as 1 for potential biodiversity impact risk. All other subsectors were coded as 0. SASB subsectors were mapped onto the 419 BICS subsectors with a similar approach to that deployed for the ENCORE data.

3.3.3 | Further control variables

In addition to year, country and subsectoral controls, we also control for market capitalisation, long- and short-term debt outstanding, number of employees in any given year and whether the company reports its GHG emissions, which is often the first step a company takes towards environmental sustainability.

3.4 | Model specification

After exploring the extent to which companies are exposed to material biodiversity risk, and whether they are beginning to respond strategically to these risks by adopting a biodiversity policy, we investigated which sectoral, subsectoral and country level characteristics are associated with the likelihood that a company adopts a biodiversity policy. Our data are organised as an unbalanced panel of 48,748 company-year observations between 2004 and 2018. We employ a binary logistic regression model with robust standard errors.

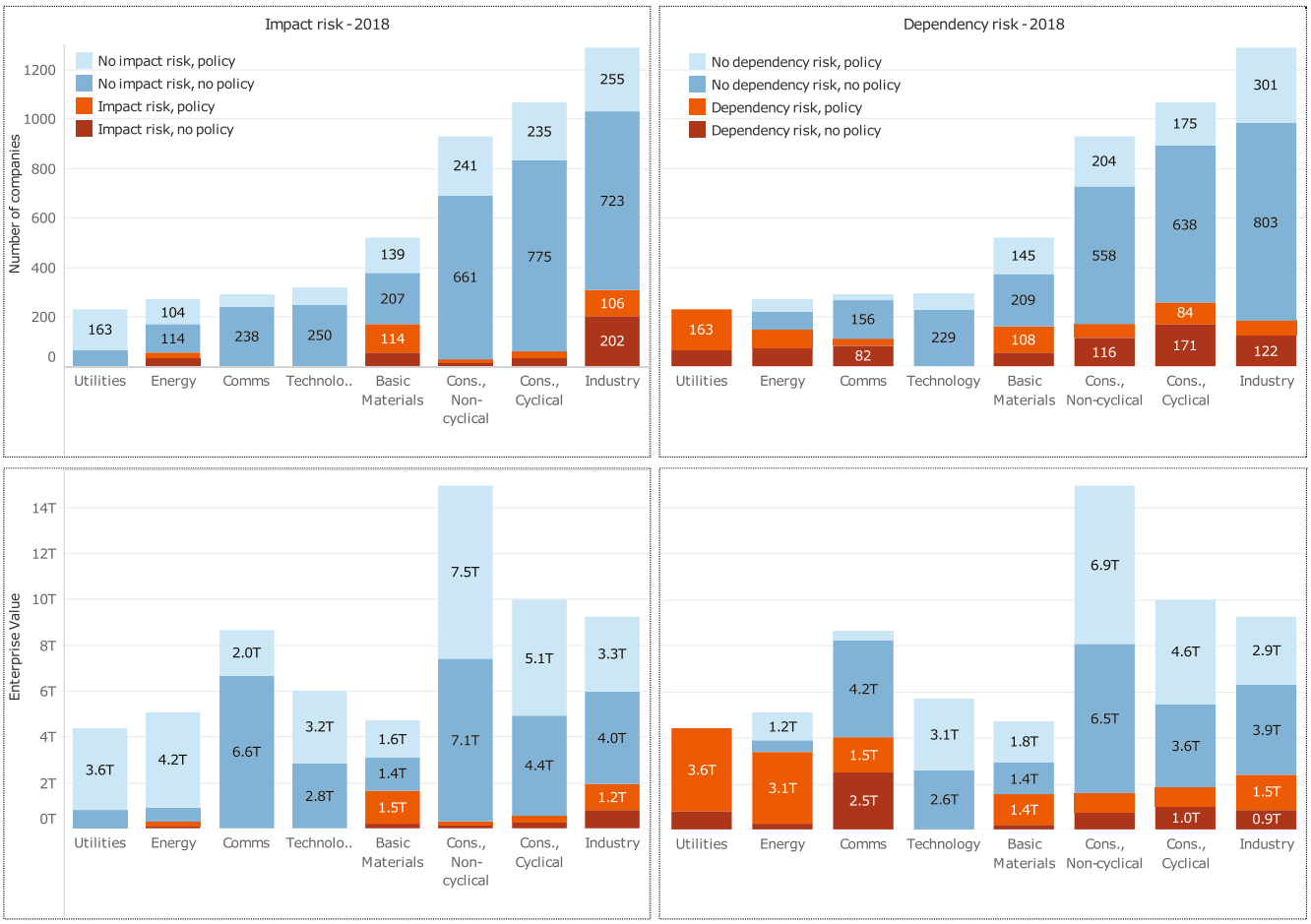

FIGURE 1 Listed companies by number (top) and enterprise value (bottom) exposed/not exposed to material biodiversity impact/dependency risk (left/right), by sector. Data from Bloomberg

The full model specification is the following, where ε_i is the stochastic error and μ_t is a time dummy variable.

$$\begin{aligned}\text{Biodiversity Policy} = {} & \beta_0 + \beta_1 * \text{Direct Physical Input} + \beta_2 \\ & * \text{Enables Production Process} + \beta_3 \\ & * \text{Mitigates Direct Impact} + \beta_4 \\ & * \text{Protection from Disruption} + \beta_5 \\ & * \text{Biodiversity Impact Risk} + \beta_6 * \textit{GHG Reporting} \\ & + \beta_7 * \ln(\textit{Market Capitalisation}) + \beta_8 \\ & * \ln(\textit{Short and long term debt}) + \beta_9 * \ln(\textit{Employees}) \\ & + \beta_{10} * \textit{Country Effect} + \beta_{11} * \textit{Sub} - \textit{Sectoral Effects} \\ & + \mu_t + \varepsilon_{i,t}\end{aligned}$$

A number of robustness checks were conducted (see supporting information).

4 | SYNTHESIS OF RESULTS

4.1 | Exposure and response of global listed companies to biodiversity risk

Our analysis shows that, in 2018, 637 (~10%) of the largest global listed companies were directly exposed to material biodiversity impact risk, and 1254 (~21%) were exposed to material biodiversity dependency risk. Both types of risk are therefore relatively concentrated, although biodiversity dependency risk is twice as prevalent as biodiversity impact risk. Overall, 1299 (~21%) of the largest global listed companies are exposed to one type of biodiversity risk or the other (or both together).

However, companies differ in their relative enterprise value (combined market capitalisation and debt outstanding). In 2018, $5.2 trillion (5% of our sample) in total enterprise value was exposed to material biodiversity impact risk and $20 trillion (17%) to material biodiversity dependency risk. Overall, US$22 trillion (~20%) of total enterprise value was exposed to either type of biodiversity risk (or both together).

In terms of sectoral distribution, the basic materials and industrial sectors represented the majority (by number) of companies exposed to biodiversity impact risk, while biodiversity dependency risks are found across a wider range of sectors, including utilities, communications, energy, cyclical and noncyclical consumer goods, alongside basic materials and industrials. The distribution of enterprise value exposed to biodiversity risk is broadly similar, although with some relative differences (orange bars in lower pane of Figure 1).

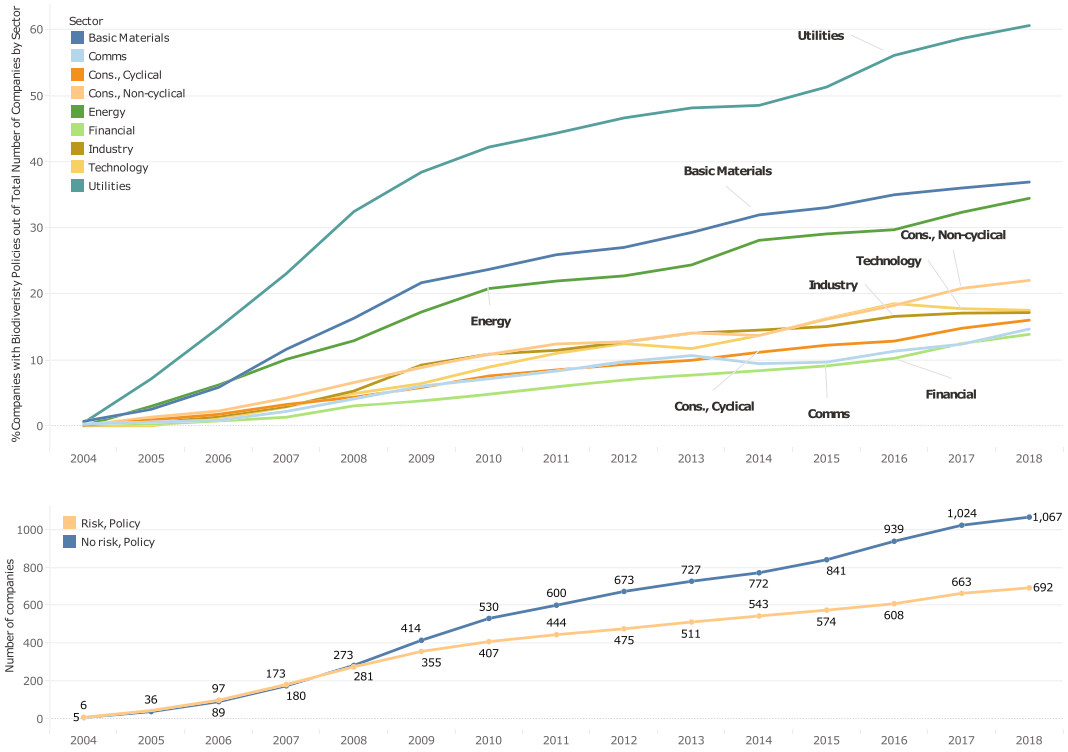

FIGURE 2 Percentage of listed companies with biodiversity policies by sector (top), number of companies exposed/not exposed to risk that have a biodiversity policy (bottom). Data from Bloomberg

Adoption of biodiversity policies in listed companies worldwide has grown strongly from only 11 companies in 2004 to 1759 companies in 2018 (29% of the top 85% listed companies in 2018). Companies with a biodiversity policy represented $51.1 trillion (46% of our sample) in total enterprise value, compared with $58.5 trillion (54%) in companies without a biodiversity policy.

At the sectoral level (Figure 2), the utilities sector is leading, with over 60% of listed companies in the sector adopting a biodiversity policy by the end of 2018. This is followed by the basic materials sector and the energy sector with ~37% and 34% of companies, respectively. At the other end of the spectrum, the financial and communications sectors are lagging in biodiversity policy adoption with only 14% and 13% of companies in these sectors reporting any biodiversity-related initiatives. At the subsector (industry) level there is much greater heterogeneity, with 100% of cosmetics and toiletries companies having adopted a biodiversity policy by 2018, followed by integrated oil and gas companies (96%), electric utilities (85%), fossil energy pipelines (76.5%), gold mining (74%), forestry (71%), oil refining (70%) and water (70%). Consistent with the sectoral picture, within the financial sector, there is an overall low adoption of biodiversity policies, particularly in the US commercial banking industry (0%) and the global consumer loan industry (0%). In private equity houses, the adoption is at ~16%, for non-US commercial banks, we see an adoption of over 27%, while for global diversified banking institutions this figure reaches 66% (see online appendix OA.1).

Figure 1 also shows what proportion of at-risk companies in each sector have responded strategically by adopting a biodiversity policy. It shows that *unmanaged* biodiversity impact risk—companies with material biodiversity impact that are *not* responding strategically by implementing a biodiversity policy—is concentrated in the industrial and basic materials sectors (by number of companies). Unmanaged biodiversity dependency risk is spread more widely across the cyclical and noncyclical consumer goods, industrial, communications, basic materials, energy and utilities sectors. Overall, 353 (684) companies with unmanaged biodiversity impact (dependency) risk represent 55% (54%) of at-risk companies in our 2018 sample (by number of companies). These companies with unmanaged biodiversity risk represented $1.9 trillion (1% of our sample) in total enterprise value for impact risk and $7.2 trillion (6%) for dependency risk. Finally, Figure 2 shows that 1067 (~17% in total) companies with biodiversity policies are *not* actually materially exposed to biodiversity risk, at least as estimated by SASB and ENCORE materiality ratings, with these numbers steadily growing since 2004 and outpacing companies actually exposed to biodiversity risk since 2008.

Figure 3 illustrates the relative enterprise value of listed companies exposed to biodiversity impact/dependency risk, with/without biodiversity policies, by subsector (industry). The largest enterprise value exposure to biodiversity impact risks is concentrated in mining, engineering and construction, lodging, food and building materials (Figure 3a). However, some of these industries, such as mining and engineering and construction, have relatively high rates of strategic response to these risks. The industries with the greatest enterprise value exposure to unmanaged biodiversity impact risk are engineering

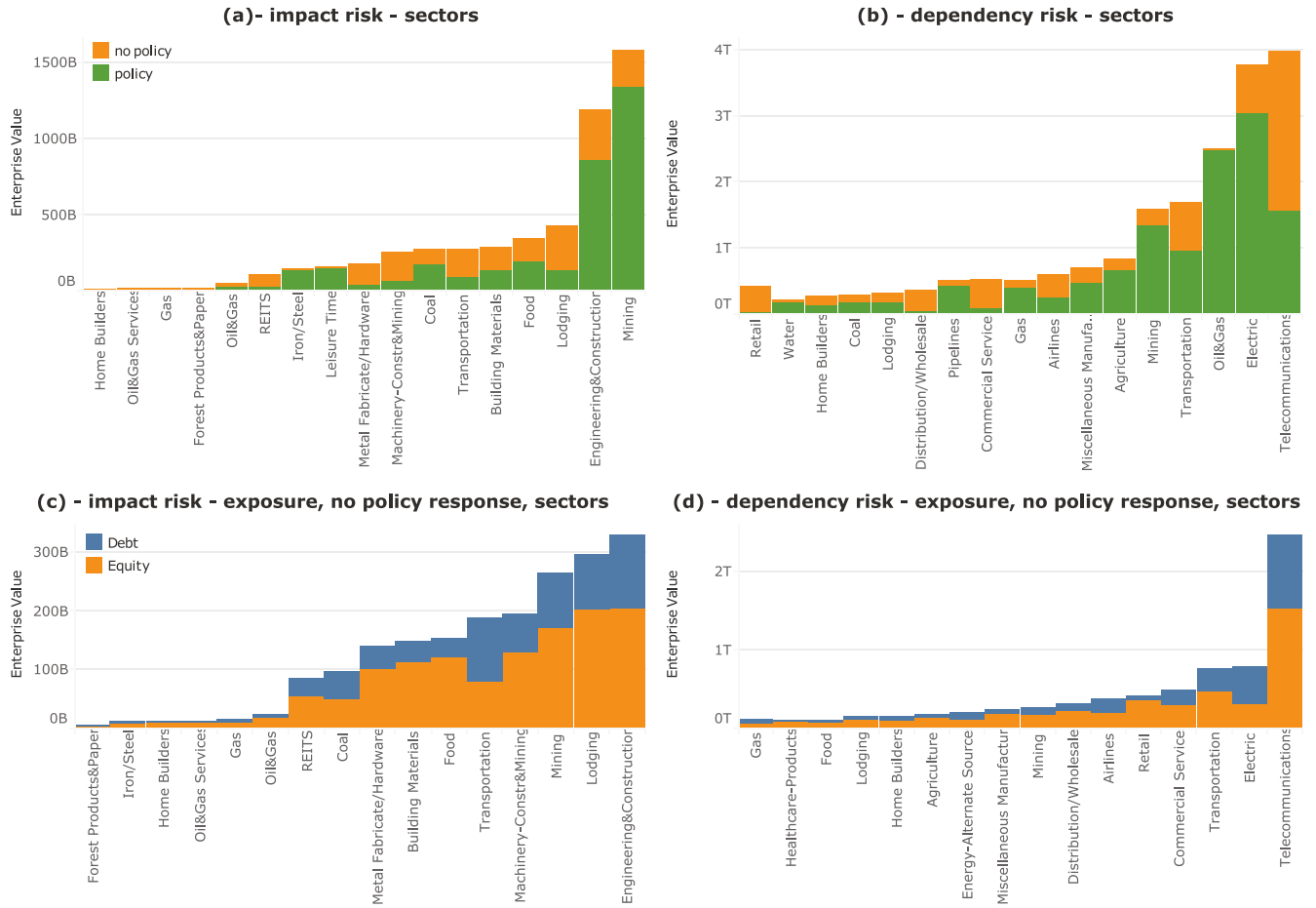

FIGURE 3 Enterprise value globally of listed companies exposed/not exposed to material biodiversity risk, with/without biodiversity policies, by industry in 2018 (a—Impact risk; b—Dependency risk) and enterprise value (share of debt and equity highlighted) exposed to unmanaged biodiversity risk, by industry (c—Impact risk; d—Dependency risk). Data from Bloomberg

and construction (~$330 billion), lodging (~$294 billion), and mining (~$263 billion) (Figure 3c). The most exposed asset class in secondary financial markets is equities; however, in the transportation and coal industries, the total amount of outstanding debt is equivalent to equities.

The industries with the largest enterprise value exposed to biodiversity dependency risk are telecommunications, electric utilities, oil and gas, transportation, mining and agriculture (Figure 3b). The bulk of exposure to unmanaged biodiversity dependency risk is concentrated in the telecommunications (~$2.4 trillion), electric utilities ($782 billion) and transportation (~$750 billion) industries, with the remainder (~$2.4 trillion) spread across many other smaller exposures (Figure 3d). However, as unmanaged biodiversity dependency risk is so much larger than unmanaged biodiversity impact risk, a number of these smaller industry exposures are nevertheless significant, such as airlines, with $340 billion in capital exposed to unmanaged dependency risk (roughly 58% of the industry in 2018). Finally, much like unmanaged impact risk, most of the enterprise value is associated with equity, with only the electric utilities industry having a higher proportion of debt than equity.

4.2 | Characteristics of companies that adopt biodiversity policies

Moving to our statistical models (Models 1 and 2, Table 1, Appendix A1), we observe that between 2004 and 2018, larger companies in terms of market capitalisation, debt outstanding and employee numbers are more likely to adopt biodiversity policies. Our results also suggest that those companies that have already taken initial steps in measuring and reporting their climate impact are more likely to continue their journey in responding to the biodiversity crisis ($\beta_{\text{GHG Reporting}} = 1.168$, $p < 0.01$, Model 2, odds ratio 3.21).

Exploring the impact of sectoral biodiversity dependency risks on likelihood of company adoption of biodiversity policies, we find that there are three types of biodiversity dependencies that are positively related to the corporate biodiversity policy adoption rate. These are the following: (i) biodiversity as a direct physical input to the production process (e.g., animal based energy) ($\beta = 0.434$, $p < 0.01$, Model 3, odds ratio:1.54), (ii) biodiversity as an enabler to the production process (e.g., pollination) ($\beta = 0.902$, $p < 0.01$, Model 4, odds ratio: 2.46) and (iii) biodiversity providing protection from disruption

TABLE 1 Statistical models with biodiversity dependency and impact risk

Independent variable: Biodiversity policy (1 if company has at least one biodiversity policy, 0 otherwise)									
Model variables	Model 1 controls	Model 2 controls + GHG	Model 3 dependency: Direct physical input	Model 4 dependency: Enables production process	Model 5 dependency: Mitigates direct impact	Model 6 dependency: Protection from disruption	Model 7 SASB sectors	Model 8 impact and granular dependencies	Model 9 impact and aggregate dependency
Market capitalisation	0.443***	0.351***	0.356***	0.360***	0.356***	0.352***	0.363***	0.363***	0.362***
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Short- and long-term debt	0.166***	0.147***	0.147***	0.151***	0.148***	0.138***	0.141***	0.140***	0.135***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Employees	0.029**	−0.022*	−0.023*	−0.032**	−0.029**	−0.015	−0.020	−0.018	−0.014
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
GHG reporting		1.168***	1.161***	1.158***	1.166***	1.163***	1.173***	1.164***	1.169***
		(0.033)	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)	(0.033)
Biodiversity dependency risk									
Direct physical input			0.434***					0.035	
			(0.093)					(0.107)	
Enables production process				0.902***				0.521***	
				(0.058)				(0.077)	
Mitigates direct impacts					0.524***			−0.478***	
					(0.135)			(0.148)	
Protection from disruption						0.394***		0.145***	
						(0.036)		(0.042)	

TABLE 1 (Continued)

Independent variable: Biodiversity policy (1 if company has at least one biodiversity policy, 0 otherwise)									
Model variables	Model 1 controls	Model 2 controls + GHG	Model 3 dependency: Direct physical input	Model 4 dependency: Enables production process	Model 5 dependency: Mitigates direct impact	Model 6 dependency: Protection from disruption	Model 7 SASB sectors	Model 8 impact and granular dependencies	Model 9 impact and aggregate dependency
Biodiversity impact risk									
SASB biodiversity risk							0.778***	0.650***	0.704***
							(0.043)	(0.049)	(0.044)
Aggregate dependency risk									
Aggregate dependency exposure									0.296***
									(0.037)
Constant	−8.140***	−6.650***	−6.677***	−6.885***	−6.630***	−6.749***	−6.920***	−7.076***	−6.969***
	(1.151)	(1.179)	(1.178)	(1.176)	(1.177)	(1.177)	(1.180)	(1.179)	(1.179)
Country controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Industry controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	46,306	46,306	46,169	46,169	46,169	46,169	46,306	46,169	46,169
Pseudo *R*-squared	0.266	0.291	0.291	0.295	0.291	0.293	0.297	0.299	0.298
Log-likelihood	−19,348	−18,700	−18,660	−18,552	−18,665	−18,611	−18,541	−18,454	−18,481

Note: Robust standard errors in parentheses. Logistic regression model. Dependent variable spanning 2005 to 2018. Data from Bloomberg, ENCORE and SASB.
***$p < 0.01$. **$p < 0.05$. *$p < 0.1$.

(e.g., biological pest control) ($\beta = 0.394$, $p < 0.01$, Model 6, odds ratio: 1.48). Interestingly, material dependency on biodiversity services that provide mitigation of direct impacts associated with a production process (e.g., bioremediation in aquaculture) is negatively related to the rate of adoption of biodiversity policies when we control for all other types of dependencies ($\beta = -0.478$, $p < 0.01$, Model 8, odds ratio: 0.62).

In Model 8, we introduce the effect of sectoral biodiversity impact risks as classified by SASB. We find this effect also to be positive, including when we use an aggregate measure of dependency risk alongside it in Model 9 ($\beta = 0.704$, $p < 0.01$, odds ratio: 2.02).

We conducted several robustness tests, none of which significantly change our main results (see supporting information for details).

5 | DISCUSSION AND CONCLUSIONS

In this paper, we set out to answer three underexplored questions in the literature:

1. *To what extent are global listed companies exposed to material biodiversity risks?*
2. *To what extent are companies with material biodiversity risks responding strategically to these risks by adopting a biodiversity policy?*
3. *What are the characteristics of companies which adopt biodiversity policies?*

We provide answers based on large-scale evidence by combining subsectoral biodiversity risk materiality ratings from ENCORE and SASB with analysis of the worldwide disclosure of corporate biodiversity policy adoption across a sample of 11,812 listed companies and 48,748 company-year observations between 2004 and 2018.

Our analysis shows, first of all, that a significant proportion of the largest global listed companies (~21% by number and 20% by total enterprise value) are materially exposed to biodiversity impact and/or dependency risk. These numbers are lower than the EIRIS (2010) estimate (that 42% of FTSE All-World Development index companies were moderately or highly exposed to biodiversity risk). We believe that our assessment is more accurate due to our significantly more granular and robust assessment of impact and dependency risks at subsector level. Nevertheless, this is still a significant proportion of global listed companies.

Given this risk exposure, it is encouraging that companies have started responding strategically, with companies adopting and reporting a biodiversity policy growing from a mere 11 companies in 2004 to 1759 companies in 2018 (29% of the largest listed companies worldwide, representing 46% of the total enterprise value of our sample). Companies with a larger market capitalization, debt outstanding and employee numbers regardless of the sector, are more likely to adopt biodiversity policies, as are companies that have already adopted a strategic response to climate change. Furthermore, exposure to both impact risk and dependency risk positively affects the likelihood of a company to adopt a biodiversity policy (suggesting that there is some awareness of the materiality of these risks). However, only three of the four types of biodiversity dependencies are positively related with biodiversity policy adoption, with the fourth type (dependency on biodiversity services that provide mitigation of direct impacts) being negatively related. This suggests that awareness of this particular type of biodiversity dependency may still be limited (or its materiality may be overestimated by the ENCORE methodology).

Our results show that companies in the utilities, basic materials and energy sectors are most likely to have implemented a biodiversity policy by the year 2018. Perhaps unsurprisingly, these tend to be sectors associated with large companies operating major industrial facilities (such mines, power stations and oil and gas exploration) that can have significant impacts on biodiversity. Likewise at the subsectoral (industry) level, we see that a strategic approach to biodiversity is, again, dominated by industries associated with major impacts through deforestation (e.g., gold mining and forestry and cosmetics and toiletries indirectly via their use of inputs such as palm oil and wood fibre) or large-scale pollution events such as oil leaks (integrated oil and gas companies, fossil energy pipelines and oil refining). We therefore conclude that, until 2018 at least, companies have mainly responded strategically to biodiversity impact risk and less so to biodiversity dependency risk. This is significant, as material biodiversity dependency risk affects nearly four times the total enterprise value ($20 trillion) that is exposed to material biodiversity impact risk ($5.2 trillion).

Of greater concern, our analysis shows that of the 637 (1254) companies exposed to material biodiversity impact (dependency) risk in 2018, 353 (684) had not yet adopted a biodiversity policy, representing ~55% (54%) of these at-risk companies by number and ~36% (36%) by total enterprise value. This finding demonstrates that there is still significant unmanaged biodiversity risk in corporations worldwide, to which companies are not yet responding strategically.

Cojoianu et al. (2015) showed that biodiversity and natural capital related risks are some of the least considered indicators in the investment processes of financial institutions, although in principle, their incorporation in financial decision-making is possible and can yield significant benefits, including reputational, for financial institutions (Ascui & Cojoianu, 2019a; Cojoianu & Ascui, 2018; Hoepner et al., 2016). While the financial sector is not currently considered to be directly exposed to biodiversity risks (according to either SASB or ENCORE methodologies), it can be considered to be indirectly exposed to the enterprise value at risk elsewhere in the economy, through its loans, investments and financial risk management products. Leading financial institutions and regulators are beginning to highlight the potential individual and systemic risks that this indirect exposure may raise (Finance for Biodiversity Pledge, 2020; NGFS, 2021; OECD, 2019). Furthermore, the growth of the responsible investment movement in the financial sector and entry into force in March 2021 of the EU Sustainable Finance Disclosure Regulation might provide a further driver of financial sector strategic response to biodiversity risk, as ESG and sustainability considerations in financial

products will be covered by stricter disclosure regulations and expectations (Cornillie et al., 2021).

Our study highlights the need to raise awareness of biodiversity dependencies in general (i.e., moving beyond consideration of impacts). We therefore propose reframing the NRBV in terms of a natural-capital-based view (NCBV) of the firm, which would place more equal emphasis on understanding how corporations are constrained not only by limits on their environmental impacts but also by exogenous threats to the natural capital and ecosystem services that they depend upon. Such a framing is also consistent with the emerging concept of 'double materiality'—that is, that companies should consider both their own impacts on the natural environment and how they are affected by environmental issues (Garst et al., 2021; NGFS, 2021). More broadly, our findings show that a significant amount of capital—over $7 trillion—is exposed to material unmanaged biodiversity risk, mainly to do with dependencies, and this calls for much greater awareness, across business, of biodiversity risk in general and of biodiversity dependency risk in particular.

The proposed NCBV can provide a novel and easily communicable framework for researching and managing corporate engagement with natural capital. This is important given that global biodiversity targets established to date (CBD Secretariat, 2013) are not easily translated to a business audience (Addison et al., 2019), and awareness of biodiversity risks is much lower than awareness of climate change risks, which have been covered extensively in the past decade (Hahn et al., 2017; TCFD, 2017; Winn & Pogutz, 2013). Incorporating biodiversity risk into corporate strategy can enable companies to build competitive advantages in the new and fast-changing context of novel regulations on sustainable investment (Bai et al., 2021; Eckert & Kovalevska, 2021; Siri & Zhu, 2019), while also helping to address the global biodiversity crisis. For example, understanding biodiversity dependencies as well as impacts will be of importance for companies and financial market players claiming sustainability credentials under the EU Taxonomy and the EU Sustainable Finance Disclosure Regulation (Cornillie et al., 2021; Gortsos, 2021).

The paper has a number of implications for different stakeholder groups. For business, it shows that there is still a long way to go, with 55% of global listed at-risk companies not having a biodiversity policy as of 2018, representing over $7 trillion in enterprise value. Companies interested in taking a more proactive approach to biodiversity strategy can use our analysis to better understand their biodiversity risk exposure and see how they compare with their peers on biodiversity policy adoption. Activists and policy-makers can also use this analysis to identify which sectors and industries are leaders or laggards, thus where to target pressure or support in taking a more strategic approach to material biodiversity risks (e.g., telecommunications and airlines).

Our analysis has various limitations. The analysis depends on the robustness of Bloomberg coding of biodiversity policy adoption, and the SASB and ENCORE methodologies. Further research could triangulate against other data sources. Furthermore, disclosure of a biodiversity policy can only be considered evidence of a company having taken a first step towards a strategic response and is no guarantee of the adequacy of that response—hence, at-risk companies with a policy may still be significantly exposed to biodiversity risk. At the time of undertaking this analysis, ENCORE only provided materiality assessments for natural capital dependencies and not impacts, and the coverage of dependencies excluded possible dependencies on cultural services, which may be significant for certain types of biodiversity or habitats. Perhaps most importantly, the ENCORE methodology excludes what can be termed 'ecosystem disservices' (Shapiro & Báldi, 2014; von von Döhren & Haase, 2015, 2019) or 'negative dependencies'—for example, businesses may be exposed to additional substantial biodiversity-related risks that are not captured here, such as those associated with pests, diseases, weeds and health impacts from pollen. These negative dependencies have been shown to be highly material for various agricultural industries (Ascui & Cojoianu, 2019a; Cojoianu & Ascui, 2018). Overall, these exclusions suggest that our risk assessments are likely to be conservative, and the real biodiversity risks to businesses may be higher than we have indicated. These are all areas calling for further research.

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ENDNOTES

[1] Article 2 of the Convention on Biological Diversity—https://www.cbd.int/convention/articles/?a=cbd-02 (accessed 27 July 2020).

[2] https://encore.naturalcapital.finance/en/explore (accessed 27 July 2020).

[3] https://www.msci.com/gics (accessed 27 July 2020). A total of 24 GICS subsectors are not included in ENCORE, while two (biotechnology and pharmaceuticals) are included in ENCORE but further subdivided into manufacturing and services, and two (iron and life sciences manufacturing) are included in ENCORE but not GICS.

[4] https://www.sasb.org (accessed 15 January 2021).

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SUPPORTING INFORMATION

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APPENDIX A

A.1 | Appendix A.1. Correlation matrix and descriptive statistics

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) Biodiversity policy	1.000								
(2) SASB biodiversity risk	0.108*	1.000							
(3) Direct physical input	0.035*	−0.029*	1.000						
(4) Enables production process	0.229*	0.257*	0.510*	1.000					
(5) Mitigates direct impacts	0.026*	0.235*	−0.014*	0.270*	1.000				
(6) Protection from disruption	0.167*	0.223*	0.319*	0.607*	0.170*	1.000			
(7) Market capitalisation	0.218*	−0.070*	−0.062*	0.041*	−0.005	0.049*	1.000		
(8) Short-and long-term debt	0.205*	−0.040*	−0.052*	0.051*	−0.007*	0.080*	0.616*	1.000	
(9) employees	0.220*	−0.002	−0.048*	0.008*	0.015*	0.041*	0.613*	0.513*	1.000

* Shows significance at the 0.05 level.

Variables	Obs	Mean	St. dev	Min	Max
(1) Biodiversity policy	59,443	0.24	0.43	0	1
(2) SASB biodiversity risk	58,443	0.10	0.30	0	1
(3) Direct physical input	59,269	0.02	0.30	0	1
(4) Enables production process	59,269	0.10	0.30	0	1
(5) Mitigates direct impacts	59,269	0.008	0.09	0	1
(6) Protection from disruption	59,269	0.21	0.41	0	1
(7) Market capitalisation	57,204	10,307	29,657	0	3,008,000
(8) Short- and long-term debt	56,011	8960	63,139	0	3,391,920
(9) Employees	50,414	24,286	62,018	1	2,300,000