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A resilience approach to corporate biodiversity impact measurement

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Abstract

Measuring biodiversity impact is attracting corporate attention as firms face increasing scrutiny over the ongoing sixth mass extinction of animals. Extant approaches to measurement are relatively nascent and do not directly address the dynamic complexity that can cause abrupt ecosystem change. Measurement approaches largely overlook when transformational change may occur and how changes to biodiversity may influence its likelihood. We posit that corporate biodiversity impact measurement can be advanced by incorporating resilience thinking from the natural sciences. Resilience thinking can refocus measurement on how biodiversity contributes to an ecosystem's capacity to adapt to disturbances and avoid sudden, transformative change. We propose a set of seven key mechanisms that can inform measurement development across three biodiversity attributes: abundance, composition and distribution. To conclude, we discuss opportunities for accounting researchers to advance corporate biodiversity measurement approaches connected to ecosystem resilience.

KEYWORDS

biodiversity, corporate biodiversity management, impact measurement, natural science, resilience

1 | INTRODUCTION

Organisms on Earth are facing biological annihilation (Ceballos et al., 2017). Biodiversity is being lost across the planet as species face declining populations, extirpation and extinction at rates unparalleled during human existence (Ceballos et al., 2017). Biodiversity is defined as 'the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems' (UN, 1992: p. 3). It is a key determinant of how ecosystems function and whether change is gradual, or sudden and nonlinear (Cardinale et al., 2012; Hooper et al., 2005).

Human activity is the primary driver of the sixth great wave of species extinction and biodiversity loss (Ceballos et al., 2017; Díaz et al., 2019). In particular, businesses are inextricably linked to the main drivers of species depletion, including land-use changes (e.g., agricultural expansion), direct exploitation of resources (e.g., fishing), pollution, climate change and the introduction of invasive alien species (Díaz et al., 2019). In turn, humanity and businesses are significantly impacted by biodiversity loss as ecosystems begin to function differently, thereby affecting how organisms provide

Abbreviations: BIM, Biodiversity Impact Metric; Extract, Biodiversity Indicators for Extractive Companies; FSC, Forest Stewardship Council; GLOBIO, Global Biodiversity Model for Policy Support; IPIECA, International Petroleum Industry Environmental Conservation Association; IUCN, International Union for Conservation of Nature; MSA, Mean Species Abundance; UNEP-WCMC, United Nations Environment Programme-World Conservation Monitoring Centre; WWF, World Wildlife Fund.

ecosystem services (Cardinale et al., 2012; Winn & Pogutz, 2013). The urgent need to protect biodiversity has led to a prevailing consensus that firms need to measure their impacts on biodiversity to inform conservation efforts (Jones, 2014a).

Accounting studies are beginning to build knowledge on corporate biodiversity impact measurement, although the field is nascent and relatively peripheral to mainstream academic discourse (Roberts et al., 2021). Studies have begun to offer insights on aspects such as the extent of current measurement and reporting (Adler et al., 2018; Rimmel & Jonäll, 2013), antecedents (Haque & Jones, 2020) and the impacts of measurement on conservation efforts (Atkins & Atkins, 2019). Notably, accounting scholars have developed guidance in the form of methodologies and frameworks (Jones, 2014b; Schaltegger & Beständig, 2010) and advanced the two main approaches of corporate biodiversity impact measurement: ecosystem services and natural inventory (Jones, 2014b).

These approaches work well in stable environments when ecosystems change gradually and maintain states close to equilibrium (Folke, 2006). By assessing the changes in flows of ecosystem services or stocks of natural capital over time, managers build proximate and linear cause-and-effect linkages to firm actions. This informs managers' expectations of impending changes to the state of biodiversity and highlights which components require active management. For instance, a forestry company may decide to harvest the same number of trees based on historical data if the forest was able to regenerate new trees to replace those felled. Yet, changes to ecosystem functioning can be abrupt due to nonlinear dynamics whereby 'a cause does not produce a proportional effect' (Meadows, 2008, p. 91). Critically, once certain levels of variables that control system behaviour (e.g., nitrogen content of soil, vegetation coverage and key predator populations) are exceeded, important processes and relationships break down, destabilising the ecosystem and causing transformative change (Walker & Salt, 2006).

Transformative change is the process whereby a system fundamentally reorganises itself to behave differently, with entirely new structures and processes (Gunderson, 2000; Peterson et al., 1998; Walker & Salt, 2006). For instance, if nitrogen content in the soil of a forest reaches a critically low level where tree growth is not possible, the system transforms from a forest to a grassland (Walker & Salt, 2006). Whereas inadvertent transformations can occur through gradual changes in controlling variables beyond unforeseen thresholds, they are frequently the result of abrupt, sudden changes to internal processes or external pressures, such as extreme weather events and disease (Walker & Salt, 2006). Such shocks and disturbances test an ecosystem's ability to maintain its functioning when specific habitats are temporarily altered (e.g., due to flooding), and/or species are depleted or extirpated (e.g., due to disease).

Transformations can be irreversible or take generations to recover from, with no guarantee of success (Yorque et al., 2002). Consequences of transformations can be disastrous to humans, businesses and other living beings when ecosystem services cease or are fundamentally altered. For instance, a coral reef may transform into an algae system if too much nitrogen is present (Walker & Salt, 2012). This would directly impact tourism companies that rely on its amenity value, marine life that depends on it as a habitat and breeding ground, and fisheries that depend on local fish populations. Consequences can extend further as localised transformations impact the likelihood of transformations on a global scale. For instance, clearing forests transforms them into grasslands or eroded landscapes, thereby decreasing carbon sequestration and moving the global climatic system closer to crossing thresholds of a 'hothouse Earth' scenario (Steffen et al., 2018).

Extant measurement approaches to corporate biodiversity impact can be criticised for offering little information to managers about when transformative change may occur and how changes to biodiversity influence the likelihood of such change (Costanza et al., 2017; Kosoy & Corbera, 2010). This can result in managers underestimating corporate impacts on biodiversity, as ecosystems can appear to be functioning normally while their ability to avoid inadvertent transformation erodes. To address these shortcomings, we posit that extant approaches to corporate biodiversity impact measurement may be strengthened by drawing upon resilience thinking from the natural sciences.

Resilience thinking informs managers how social-ecological systems persist or change over time (Holling, 1973). It highlights how change can be sudden and nonlinear, directing managerial attention to responses to the external and internal perturbations that can stimulate transformative reconfigurations of ecosystem functioning (Walker & Salt, 2006). Organisational scholars have begun to use resilience thinking to advocate for managerial approaches that are sensitive to slow and delayed changes in controlling variables (Williams et al., 2021), connect firm behaviour to system thresholds (Whiteman et al., 2013) and reveal interdependencies between firm and system level adaptation and transformations (Clément & Rivera, 2017). We extend the use of resilience thinking to corporate biodiversity impact measurement to uncover hidden impacts of firms' activities and enable managers to make decisions that are likely to improve the effectiveness of biodiversity conservation and regeneration initiatives. Drawing on the natural sciences, we explain the complex relationship between biodiversity and resilience across three aspects: abundance, composition and distribution. Using this framework, we present seven key mechanisms that can be incorporated into measurement approaches to yield information about how biodiversity impacts dynamics of transformative change.

Our article is organised as follows. We begin by introducing corporate biodiversity impact measurement and explain the shortcomings of prominent mainstream approaches to address nonlinear dynamics of transformative change. Then, we introduce resilience thinking as a lens to address these issues and explain its relevance across three attributes of biodiversity: abundance, composition and distribution. We consider implications for corporate biodiversity impact measurement across the attributes by proposing seven key mechanisms meriting attention. We use two pioneering methodologies of the natural inventory approach to assess the status of addressing these mechanisms in practice. Finally, we discuss the theoretical and managerial implications of our proposal to incorporate resilience thinking to address shortcomings regarding transformational change, focusing on implementation difficulties and how future researchers may further develop the suggested approach.

2 | CORPORATE BIODIVERSITY IMPACT MEASUREMENT

The impact of business on biodiversity is attracting increased societal attention, and firms are increasingly measuring and reporting their interrelations to maintain social license to operate (Boiral et al., 2019). Biodiversity is being incorporated into sustainability reporting standards such as the Global Reporting Initiative's 'GRI 304' (GRI, 2016), and business associations have sought to offer their members guidance, such as the World Business Council for Sustainable Development's 'Guide to Corporate Ecosystem Valuation' (WBCSD, 2011). In a recent study of the top 100 Fortune 500 companies, Addison et al. (2019) found that 49 mentioned biodiversity in their sustainability reports, and 31 had made clear commitments. Yet, biodiversity reporting remains limited as organisations lack knowledge, disclose existing information inadequately (Roberts et al., 2021), or are driven by image maintenance and greenwashing in their reporting (Boiral, 2016). Existing reporting standards have been criticised for not sufficiently accounting for nature's decline (Addison et al., 2020; Roberts et al., 2021) and few companies are explicitly measuring corporate biodiversity impact (Addison et al., 2019; Jones, 2014b).

Measuring corporate biodiversity impact provides a foundation for corporate biodiversity management by revealing potential actions to improve biodiversity and how such actions may be assessed and monitored. 'By accounting for biodiversity (i.e. disclosing, measuring and reporting for biodiversity) we make what was formerly invisible visible' (Jones & Solomon, 2013, p. 675). While relatively peripheral to the mainstream academic discourse, accounting scholars have examined disclosures of the top Fortune Global companies (Addison et al., 2019; Adler et al., 2018), corporations in Sweden (Rimmel & Jonäll, 2013), local governments (Gaia & Jones, 2019) and financial institutions (Mulder & Koellner, 2011), among others. Researchers have identified many difficulties which can be attributed to the broadness and vagueness of biodiversity (Addison et al., 2019), which includes all living things from genes to ecosystems. Biodiversity cannot be captured by any single unit or indicator (Purvis & Hector, 2000) and can remain abstract and difficult for managers to grasp (Quarshie et al., 2019). Consequently, few firms are quantifying their corporate biodiversity impact in sustainability reports (Addison et al., 2019), or pursuing corporate biodiversity initiatives such as ISO 14001 and the Forest Stewardship Council (FSC) certification (Boiral et al., 2018).

Scholars have sought to aid practice by providing insight into a variety of considerations regarding corporate biodiversity impact measurement. Considerations include, but are not limited to, the need for philosophical choices (e.g., anthropogenic or ecocentric approaches; Atkins et al., 2014), how to incorporate undiscovered species, temporal and spatial scales of measurement, and whether and how to monetize biodiversity (Jones & Solomon, 2013). Broadly speaking, scholarly approaches to measuring corporate biodiversity impact focus on two approaches, either ecosystem services or natural inventory (Jones, 2014b), as shown in Table 1. We introduce these two approaches and consider their extant incorporation of how biodiversity impacts ecosystem resilience.

The *ecosystem services* approach involves adopting an anthropocentric perspective concerned with changes in the value that humans can extract from the ecosystem. Scholars have proposed various categories of ecosystem services, including provisioning services (e.g., food, water and fibres), regulating services (e.g., waste treatment, climate regulation and erosion prevention), habitat services (e.g., maintenance of genetic diversity) and cultural and amenity services (e.g., spiritual experience, recreation and aesthetics) (TEEB, 2010). The approach measures the quality and quantity of the current flow of ecosystem services available and assigns a monetary value to them. By explicitly valuing these ecosystem services, the approach aims to help assess corporate dependencies and impacts on ecosystems (Houdet et al., 2012) and develops a business case for biodiversity conservation and regeneration (Jones, 2014b). It is a top-down approach to corporate biodiversity impact measurement resting on the logic that biodiversity contributes to the processes underlying ecosystem services (Mace et al., 2012). Changes in the quality and quantity of ecosystem services indicates to firms, albeit indirectly, that changes to biodiversity are occurring and management attention may be necessary to preserve or enhance them.

TABLE 1 Extant approaches to corporate biodiversity impact measurement

Approach	Ecosystem services	Natural inventory
Description	Measuring the benefits derived from ecosystems to help understand the value of biodiversity and to identify changes in the quality and quantity of ecosystem functioning	Measuring individual biodiversity components of habitats, flora and fauna to identify changes in quantity and protect components that are endangered or at risk
Unit of measurement	Flows	Stocks
Approach	Top-down	Bottom-up
Perspective	Anthropocentric	Ecocentric
Valuation	Monetization	Quantification (though monetization also possible)
Scholarly examples	Boyd and Banzhaf (2007); Costanza et al. (1997); Houdet et al. (2012)	Jones (1996, 2003); Siddiqui (2013)

The *natural inventory* approach involves adopting an ecocentric perspective that records changes to the stocks of habitats, flora and fauna (Cuckston, 2017; Jones, 2003). The aim of this bottom-up approach is to record levels and assess the wellbeing of each biodiversity component within an ecosystem (Jones, 2014b). Natural inventory approaches primarily use quantification methods to record the abundance of biodiversity and to assess the extent to which components are at risk of extirpation or extinction (Cuckston, 2018; Jones, 2014b). Quantified accounts can be monetized using valuation techniques for environmental resources, although there is no consensus on the necessity or desirability of doing so (Atkins & Maroun, 2018; Milne, 1991), especially for biodiversity components thought critical to nature (Jones, 2003).

Natural inventory frameworks differ in the scope of individual species recorded (e.g., some focus only on endangered species) (Atkins & Maroun, 2018), the extent to which habitats are analysed, and impacts of corporate activity (Atkins & Atkins, 2019). Jones's (1996) influential pyramid of hierarchical criticality offers a six-level natural inventory approach whereby the extent to which the scope of biodiversity is recorded progressively increases. This framework considers the ecological worth of habitats and focuses managerial attention on monitoring and conserving habitats, flora and fauna deemed endangered and rare. At a foundational level, habitats are distinguished by type (e.g., woodland, grassland) and assessed for their criticality to wildlife (e.g., the diversity and rarity of species therein). To increase the scope, individual species thought to be endangered or at risk of extirpation or extinction (critical flora and fauna) in all habitats are recorded, followed by all species and populations within critical habitats. To maximise the scope, a general inventory of species and populations across all habitats is recorded. The approach invites firms to find a scope of inventory that is most appropriate for their purposes and encourages them to increase this scope over time (Jones, 2014b).

The ecosystem services and natural inventory approaches have contributed significantly to advancing theory and practice regarding corporate biodiversity impact measurement (Jones & Solomon, 2013). Yet, both are limited in how they address change dynamics in ecosystems. Change is assumed to be linear and can be understood by comparing two static pictures of an ecosystem's health. This ignores that change within an ecosystem can be nonlinear and transformational, as fundamental changes to ecological processes occur once certain thresholds are reached (Holling, 1973). They fail to inform firms whether shocks and disturbances could push ecosystems beyond these points and overlook important information that would help them avoid transgressing them (Costanza et al., 2017; Mace et al., 2012).

Critically, neither approach currently seeks to portray the complexity of ecosystem functioning that determines dynamics of ecosystem change (Kosoy & Corbera, 2010). Understanding the persistence of ecosystems and when transformative change may occur requires insight into the spatial patterns and interaction effects of biodiversity (Holling, 1973). The ecosystem services approach, which focuses on the flow of benefits that humans can extract from these services, disregards which individual species or species configurations fulfil the ecosystem functions necessary to deliver the services (Jones & Solomon, 2013). Consequently, it fails to account for how ecosystem provisioning may change after shocks and disturbances occur (Oliver et al., 2015). Natural inventory approaches directly measure the stock of biodiversity, yet do not consider the interactions of species necessary to deliver and maintain ecological functioning (Atkins & Maroun, 2018). Instead, individual species are treated as equally worthy of corporate action for conservation and preservation based on their intrinsic value (Jones & Solomon, 2013). This fails to provide managers with an understanding of which species may have disproportionate impacts on ecosystem functioning and those which, if lost, would leave ecosystems at greater risk of degrading transformative change. Figure 1 presents a simplified visualisation of transformative change stimulated by a shock or disturbance and the changes to biodiversity and ecosystem services.

Without this information, extant approaches can provide managers with false interpretations of the health of ecosystems and the respective losses in biodiversity that can be endured while maintaining ecological services to firms (Kosoy & Corbera, 2010). Managers are at risk of misinterpreting the value of biodiversity and individual species to ecosystem functioning, and miscalculating the impacts of species loss. Ecosystems may seem healthy as they continue to offer ecosystem services or host a sufficient abundance of species, yet surprise managers by collapsing as critical points are transgressed and the ecosystem loses the capacity to operate in the same manner (Yorque et al., 2002). Furthermore, omitting information on change dynamics misses important opportunities to guide conservation and preservation efforts to avoid ecosystem collapse. We seek to address these issues and advance extant measurement approaches by drawing on resilience thinking from the natural sciences.

3 | BIODIVERSITY AND SOCIAL-ECOLOGICAL RESILIENCE

Resilience thinking was introduced by Holling (1973) to help understand the capacity of social-ecological systems to cope with disturbances and persist in the same regime. Social-ecological resilience is commonly defined as 'the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks' (Walker et al., 2004, p. 4). Stability of social-ecological systems occurs in a basin or domain of attraction (Holling, 1973), commonly referred to as a 'regime'. In contrast to ecological theories of steady-state dynamics (Gunderson, 2000), resilience thinking proposes that social-ecological systems have more than one domain of attraction within which 'there is a stable equilibrium' (Holling, 1973, p. 5) or 'attractor'.

Resilience of a social-ecological system is not a fixed property but expands and contracts within an adaptive cycle of systems change involving continual loops of exploration (release and reorganisation stages) and exploitation (exploitation and conservation stages) (Holling & Gunderson, 2002). When resilience is low, social-ecological

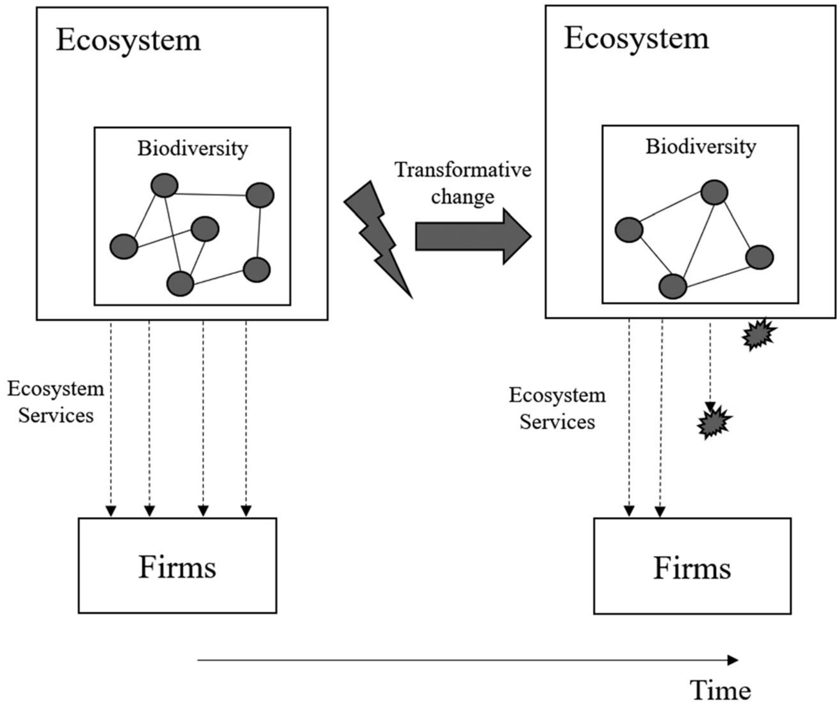

FIGURE 1 Transformative change and extant approaches to measurement

systems are highly susceptible or vulnerable to shocks and disturbances, forcing them to reorganise in a period of nonlinear change. When a system changes too much, it crosses thresholds into a new regime, behaving in new ways with new interactions between its elements in a new structure (Andersen et al., 2009; Walker & Salt, 2006). Such a regime shift leads to a new state that may be desirable or undesirable for firms (Allen et al., 2014; Beisner et al., 2003; Gunderson, 2000). For instance, high rates of deforestation that exceed regeneration rates may cause a tropical forest to become an eroded landscape such as a grassland without trees or birds (Walker & Salt, 2006).

Transformations are abnormal occurrences in ecosystems and are commonly driven by nonlinear dynamics initiated by shocks and disturbances (Allen et al., 2014; Andersen et al., 2009). From a managerial perspective, transformational responses may be inadvertent (e.g., ecosystem collapse) or deliberate (e.g., land-use changes) (Nelson et al., 2007). Regime shifts may lead to significant losses to ecosystem services that yield benefits for firms and may be irreversible, at least within a human lifetime (Yorque et al., 2002). The likelihood of regime shifts occurring depends on the size of the disturbance and the resilience of the social-ecological system (Beisner et al., 2003).

Biodiversity plays a critical role in determining the resilience of social-ecological systems and is pivotal to maintaining an ecosystem's capacity to adapt to avoid collapses in ecosystem functioning (Elmqvist et al., 2003; Folke et al., 2004; Loreau, 2000). Biodiversity is a key variable that controls system behaviour and stabilises ecological processes (Walker & Salt, 2006). It is essential for an ecosystem's self-organising ability and its self-repairing capacity after experiencing disruptive events (Folke, 2006). Resilience thinking highlights the importance of species' roles within ecosystems, their spatial and temporal dynamics and how they interact to reinforce one another in times of disruption (Peterson et al., 1998).

Biodiversity is a complex and multidimensional construct that seeks to capture diversity at levels of genetics, species, communities and ecosystems (Millennium Ecosystem Assessment, 2005). Although ecologists have offered a wide variety of approaches to capture its essence (Pereira et al., 2013), in practice the primary focus is on measuring the presence and abundance of species while overlooking aspects that account for most of an ecosystem's diversity (Lyashevska & Farnsworth, 2012).

We explain the influence of biodiversity on resilience within three core interconnected attributes of biodiversity used by the World Wildlife Fund (WWF) (2018): abundance, composition and distribution. We slightly deviate from the WWF's categories by subsuming extinction risk (the presence of species) into abundance. In Table 2 we offer a description of the three attributes and key considerations.

3.1 | Abundance (amount)

Identifying the presence of organisms and populations of individual species within ecosystems can be seen as the cornerstone of biodiversity studies (Gotelli & Colwell, 2011). Abundance represents the accumulated capital, or elements of an ecosystem determining its potential for productivity. The presence of organisms and their abundance determine whether and how ecological functions are carried out, as well as the quantity and speed at which the functions can be performed. For instance, organisms break down and recycle nutrients, convert sunlight into energy and stabilise the climate. Loss of organisms may thus impair the extent to which these ecological functions

TABLE 2 Biodiversity and social-ecological resilience

Biodiversity attribute	Description
Abundance (*amount*)	The absolute quantity of organisms in a geographic area or ecosystem and changes over time relative to the populations required to maintain ecosystem functionality.
Composition (*variation*)	The structural characteristics of biodiversity within a geographic area or ecosystem, and relative changes over time. Considerations of the functional roles of organisms and how species collectively offer options for responding to disturbances.
Distribution (*spatiality*)	The spread of biodiversity across an ecosystem and its relative changes over time. Considerations of the spatial variation and connectivity of ecosystems, and the communities of species within.

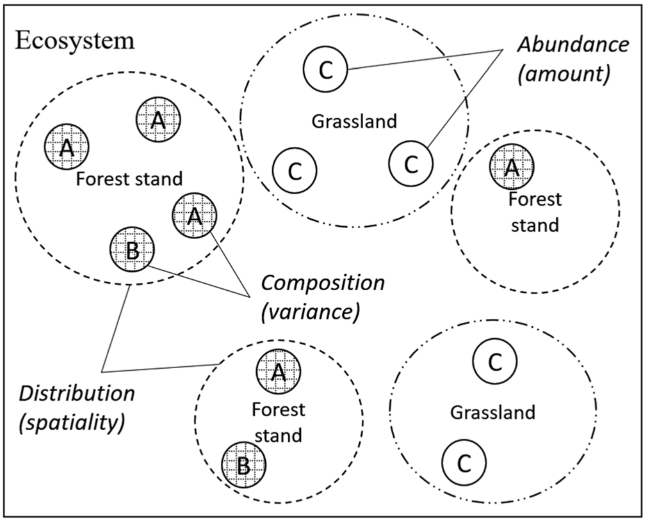

FIGURE 2 Three main attributes of biodiversity

are performed, which then may impact an ecosystem's overall structure and functioning (Cardinale et al., 2012).

3.2 | Composition (variation)

Composition refers to the structural characteristics of biodiversity within a geographic area or ecosystem, and relative changes over time. It concerns the balance of species that are present and how loss to one species may impact overall functioning. Resilient social-ecological systems are able to cope with species loss and maintain the same function and structure, as they have the 'insurance capacity' of substitute species that may perform the same function (Oliver et al., 2015; Walker & Salt, 2006). Conversely, social-ecological systems with low resilience struggle to deal with species loss, potentially causing them to cross critical thresholds and transform.

3.3 | Distribution (spatiality)

Distribution refers to how biodiversity is spread across an area or ecosystem. It concerns the structure and variation of ecosystems (Quinlan et al., 2016) and the distribution of the species therein. Biodiversity is often unevenly distributed within an ecosystem, with patches rich in species having a disproportionately high impact on ecosystem functioning (Holling & Gunderson, 2002). Patches exhibit different responses to shocks due to differences in biodiversity abundance and composition. Resilience may be compromised by an over-reliance on patches rich in biodiversity (Walker, 1992), as connectedness between patches does not enable internal control for responding to shocks and disturbances (Holling & Gunderson, 2002).

Figure 2 presents a simplified visual representation of the three main biodiversity attributes.

By gaining insight into these three aspects that connect biodiversity to the resilience of social-ecological systems, managers can begin to move away from steady-state thinking of managing for average conditions towards managing for the shocks and disturbances that drive nonlinear responses and potentially transformative change (Holling & Gunderson, 2002). Managerial thinking shifts from beliefs that an ecosystem can only function in one way and always seeks to return to the same equilibrium point when disturbed, to recognition of the vulnerabilities to transformative change imposed by new processes and structuring (Holling et al., 2002). Managers can feel better positioned to more accurately place value on biodiversity based on its respective role and contribution to how social-ecological systems can respond to shocks and disturbances.

Measurement of biodiversity's contribution to resilience can help inform managers of the current vulnerability of the social-ecological system and predict how ecosystems may change in the face of natural disruptions or from impacts of corporate activity (Holling & Gunderson, 2002; Yorque et al., 2002). For instance, it can help managers understand how critical a loss of certain species may influence resilience. Accordingly, resilience thinking can shape conservation and regeneration efforts to help prevent undesired regime shifts by maintaining the capacity to absorb and adapt to disruptions (Walker, 1992).

4 | ADVANCING CORPORATE BIODIVERSITY IMPACT MEASUREMENT THROUGH RESILIENCE THINKING

Here, we suggest how biodiversity impact measurement approaches may incorporate resilience thinking to address nonlinear dynamics common to ecosystem regime change (Andersen et al., 2009). We offer seven key mechanisms through which biodiversity influences resilience across the three biodiversity attributes of abundance, composition and distribution. Although these are not the only mechanisms of the complex and dynamic relationship between biodiversity and social-ecological system resilience, we believe that measuring them would improve extant measurement approaches and enable managers to better understand when and why ecosystems may undergo sudden and transformative change. In Table 3, we provide an overview of the key mechanisms and potential implications for corporate biodiversity impact measurement.

We complement our conceptual arguments by offering examples of how the three biodiversity attributes of abundance, composition and distribution are addressed in practice. These illustrations reflect the extent to which the seven key mechanisms of the influence of biodiversity on ecosystem resilience are being measured in practice. We draw upon two pioneering methodologies to measure corporate biodiversity impact that have good measurement transparency and offer different approaches (Berger et al., 2018). The *Biodiversity Impact Metric (BIM)* has a commodity level focus, and the *Biodiversity Indicators for Extractive Companies* (*Extract*) has a project/site level focus. Both are representations of the natural inventory approach, which we believe has the greatest capacity to incorporate the seven key mechanisms connecting biodiversity and ecosystem resilience. In Table A1, we provide an overview of the two methodologies.

TABLE 3 Resilience and corporate biodiversity impact measurement

Biodiversity attribute	Mechanism of biodiversity influence on resilience	Potential measurements	Implication for corporate biodiversity impact measurement
Abundance (amount)	Populations and threshold limits	• Identify ecological threshold limits, current ecosystem state, and potential implications of ecosystem behaviour within new regimes.	Measuring business impact on the abundance of organisms in view of the ecosystems susceptibility to transformative change. Measures reveal how business activity may increase an ecosystems risk of moving into less desirable regimes through population losses. Directs managerial attention to impacts on species with a disproportionately important role in maintaining ecological functioning.
	Keystone species	• Identify and measure change to populations of keystone species.	
Composition (diversity)	Genetic diversity	• Measure total genetic code available within an ecosystem and the natural background rates of change.	Measuring business impact on the options available to ecosystems for responding and adapting to shocks and disturbances. Measures help firms gain an understanding of business impact across ecological functions and draw attention to those that would be most impacted by species losses.
	Functional diversity and redundancy	• Measure changes of population abundance across functional groups (Steffen et al., 2015), identify how many species perform the same ecosystem function and assess functions with few substitutes available.	
	Response diversity	• Assess how species respond to different shocks and disturbances and identify the ecosystems key vulnerabilities.	
Distribution (spatiality)	Spatial variability	• Map relevant areas, assess heterogeneity of biodiversity, identify keystone patches and assess connectivity.	Measuring business impact on the spatial configurations of ecosystems and the spread of biodiversity within them. Measures enable an understanding of how business activities support or hinder spatial heterogeneity and appropriate connectivity across ecosystems. Draws managerial attention to keystone patches and the reliance of species on specific areas.
	Community diversity	• Assess the number, size and distribution of species communities.	

4.1 | Abundance: Measurement of adaptation limits

Measures of abundance are core to natural inventory approaches and offer managers a quantitative impression of an ecosystem's relative health (Gotelli & Colwell, 2011). Measuring abundance typically involves calculating total organismal abundance (sum of all individuals of all species) (Hill et al., 2018), and individual organism abundance through frequency counting or mass calculations (Bar-on et al., 2018). Changes to total organismal abundance serve as general signals to managers of changes to ecosystem health, while individual organism abundance reveals which species have particularly vulnerable population sizes and may be threatened by extirpation or even extinction (Cuckston, 2018).

Resilience thinking draws management attention to understanding populations relative to *threshold limits*, that is, the points at which ecosystems may fundamentally reconfigure (Beisner et al., 2003; Groffman et al., 2006). Ecosystems with small populations of species can be highly vulnerable to shocks and disturbances, as few organisms need to be disturbed for ecosystem functionality to be compromised. On the other hand, high populations of species may exceed carrying capacity and create internal pressure to transform the ecosystem. Measures of organism abundance may be linked to estimates of upper and lower threshold values that can become goals for managers to prevent ecosystem transformation (Andersen et al., 2009; Smith et al., 2009). Yet, predicting threshold values is difficult (see Andersen et al., 2009, for a range of exploratory and inferential techniques). Typically, threshold limits are obscure until they are passed (i.e., when the system is observably behaving in a fundamentally new manner), and they are continually changing (Andersen et al., 2009). Moreover, measures must address the complexity of multiple and interacting threshold limits, as managing for only one may leave managers blind to transgressing another (Anderies et al., 2006).

Pragmatic approaches may focus solely on estimating thresholds for individual organisms that are critical to the behaviour of social-ecological systems (Walker & Salt, 2006). Species with a disproportionately large influence on ecosystem functioning and structure relative to their abundance are considered *keystone species* (Nunez & Dimarco, 2012). Keystone species are significant determinants of biodiversity impact on resilience, as they drive change within ecosystems (Walker, 1992). Although keystone species often are top predators, they can also be prey, plants, mutualists or ecosystem modifiers (Mills et al., 1993).

Reductions in keystone species can fundamentally alter ecosystem behaviour and structure and create significant 'ripple' effects on the abundance of other species within an ecosystem. For instance, a keystone species may perform an important ecosystem function to which there is very low functional redundancy. This was the case in the ground-breaking marine experiments of Professor Robert T. Paine, whereby removal of sea stars resulted in the local ecosystem losing roughly half of its resident biodiversity, as no other species could control mussel populations (Nunez & Dimarco, 2012; Paine, 1966). In contrast, removing 'passenger' species which have a proportionately small influence on an ecosystem has little impact. Yet passengers have the potential to become drivers if ecological conditions change (Gunderson, 2000), so they should not be disregarded as unimportant. Instead, managers may seek to extend measurements to passengers that may become keystone species, given the most likely changes to ecological conditions.

4.1.1 | Illustration of current practice

Both the BIM and Extract methodologies offer ways to measure abundance, yet are disconnected from estimates of threshold limits. Total organismal abundance is measured in comparison to an undisturbed ecosystem. For example, the BIM methodology uses the 'Mean Species Abundance' (MSA) metric of GLOBIO, the Global Biodiversity Model for Policy Support. Total organismal abundance is expressed as a percentage relative to an area's natural state (e.g., an MSA score of 0.5 indicates that 50% of biodiversity remains relative to the area's natural state). While this does indicate increasing fragility to shocks and disturbances, it does not indicate the point at which transformative change may be expected. The methodologies also measure individual organism abundance by categorising habitats. Here the focus is on endangered species rather than keystone species that can drive ecosystem change. To determine the respective ecological importance of different habitats, both methodologies incorporate a measure for the endangered species using the International Union for Conservation of Nature (IUCN) Red List. Business impacts on more valuable habitats (i.e., with more endangered species) are assigned higher impact values.

4.2 | Composition: Measurement of insurance capacity

Measures of composition from a resilience perspective emphasise the need for social-ecological systems to maintain the ability to deliver ecosystem functions in new ways when disruptions occur (Holling & Gunderson, 2002). Mechanisms of biodiversity impact on resilience centre on diversity and redundancy, requiring managers to develop understandings of which species deliver ecological functions and how each may respond to shocks and disturbances. We believe that natural inventory approaches may incorporate these aspects by building on existing data regarding the presence of individual species, whereas ecosystem services approaches would require substantial disaggregation of current measures.

Already common to natural inventory approaches, managers may seek to identify variation among species currently present within an ecosystem. *Genetic diversity* is the total amount of genetically unique biological material in an ecosystem's 'information bank' (Steffen et al., 2015). Genetic diversity builds on abundance measures of the number of different species present (e.g., caterpillars, antelopes and bees) to measure the number of genetic variations within species (e.g., Indian Palm Squirrel and American Red Squirrel). Genetics studies offer several estimation techniques, including measures of allelic-diversity (genotypic differences), by recording representative genotype samples of relevant species (Caballero & García-Dorado, 2013; Pereira et al., 2013). Improving genetic diversity strengthens long-term resilience, as organisms have more ways to persist and adapt in the face of disturbances (Loreau, 2000). Yet history offers numerous examples of why extreme care is necessary in efforts to manage genetic diversity through activities such as reintroducing extirpated species (Viggers et al., 1993). Furthermore, genetic diversity may not always be desirable in situations where it enables pest species to resist expulsion efforts or allows disease to persist and spread (Oliver et al., 2015).

Measurement approaches can build upon this initial measure by categorising species based on their ecological functioning and building understandings of functional diversity and redundancy. *Functional diversity* reflects the abundance of functionally distinct species within an ecosystem (Petchey & Gaston, 2006; Walker, 1992) and is measured by categorising organisms based on the range of tasks they perform, such as pollination, nutrient cycling and climate stabilisation. Functionally diverse ecosystems have an abundance of unique trait combinations (McWilliam et al., 2018) operating at different spatial and temporal scales (Peterson et al., 1998) to provide greater stability in times of disruption (Deutsch et al., 2003). Ecologists have suggested different measures of functional diversity, such as the Functional Attribute Diversity measure that connects the number of unique functional trait combinations to the distance between species in trait space (Walker et al., 1999).

Functional redundancy refers to the number of species that share sets of traits (McWilliam et al., 2018), that is, the ability to perform substitute functions and compensate for each other in times of loss (Biggs et al., 2012). Functional redundancy is based on the observation that some species fulfil nearly identical functional roles. If many species contribute to the same ecosystem function, then species loss may have little consequence, as other species can fill the gap (Nunez & Dimarco, 2012; Rosenfeld, 2002). Using these measures, managerial approaches may consider how to best maintain functional groups within an ecosystem to ensure task diversity. Managers may also seek to prioritise mitigating the avoidance of species loss in functional groups with low redundancy due to potentially large negative impacts (Rosenfeld, 2002).

Finally, measurement approaches can seek to measure how species that fulfil the same ecosystem function respond differently to shocks and disturbances, known as *response diversity* (Elmqvist et al., 2003). For instance, two species carrying out a pollination function may differ in their susceptibility to a disease, meaning that when one is negatively affected, the other can continue to pollinate. Measuring response diversity provides additional insights into the vulnerability of ecosystem functions, and an understanding of which shocks an ecosystem may be most susceptible to and should be avoided. This information can shape corporate action aimed at maintaining high response diversity to prevent species loss (Elmqvist et al., 2003).

4.2.1 | Illustration of current practice

The Extract methodology offers an example approach to considering aspects of composition by using measures of functional diversity and redundancy assessed by the biodiversity indicator 'Ecosystem composition by functional type'. This requires the evaluation of functional types of species in an ecosystem through either remote assessments or in situ morphologies. While the execution of this analysis is still under development, Hooper et al. (2002) proposed to either categorise species 'based on physiognomic attributes' (Hooper et al., 2002, p. 196) or to compare species across interrelated traits such as 'the organisms' life history, resource use, reproduction and responses to external factors' (p. 199) with the ambition of establishing the functional roles of species in an ecosystem. Yet, the approach currently does not seek to measure genetic diversity, focussing instead on 'population counts for groups of species easy to monitor and/or important for ecosystem services' (UNEP-WCMC, 2017, p. 36). It also does not measure response diversity. The BIM methodology does not account for aspects of composition within its measurement.

4.3 | Distribution: Measurement of spatial differences

Biodiversity and individual species are not typically uniformly distributed across ecosystems. To understand the impact of biodiversity on ecosystem resilience from a distribution perspective, it is important to measure and manage these differences by considering an ecosystem's *spatial variability*. Landscapes are commonly used as a spatial unit of analysis to capture the diverse ecological functions performed, how biodiversity may reside and move, and how humans use ecological services (CGIAR, 2014). Patches and habitats within landscapes are referred to as nodes, which are then connected through links, such as species interactions and habitat corridors (Christie & Knowles, 2015). We consider two aspects of spatial variability: spatial heterogeneity of biodiversity and connectivity.

Spatial heterogeneity of biodiversity across landscapes, that is, variations in habitat, as well as types and densities of flora and fauna, can protect against ecosystem collapse, as patches with different responses to shocks can ensure ongoing ecosystem functioning. Accordingly, measures presenting large scale spatial homogeneity such as monocropping may indicate a vulnerable ecosystem to managers, who may be stimulated to consider how economic activities across landscapes can be diversified to enable spatial heterogeneity (Herrick et al., 2019). For example, by planting high density forests for wood products alongside patches of meadow for low-intensity grazing. Managers may direct particular attention to conserving areas deemed 'keystone patches' that have high biodiversity and a disproportionately high impact on ecosystem functioning, and by supporting vulnerable patches through approaches such as establishing adjacent patches with high biodiversity (Biggs et al., 2012). Measuring spatial heterogeneity involves comparing biodiversity on different scales, from patches (Burnett et al., 1998) to landscapes (Nichols et al., 1998).

Connectivity within a landscape concerns the presence and strength of linkages between patches and habitats (Biggs et al., 2012). Measuring connectivity is difficult, as it is multifaceted (e.g., interaction strengths and resource flows) and not a stable property (Biggs et al., 2012). Interpreting a measure of connectivity and knowing how to manage it is also difficult for managers as they confront the tensions between advantages of high and low connectivity. Strong connectivity within landscapes permits species populations to move easily between habitats, supporting the viability of populations. This provides benefits by increasing flows of materials such as nutrients, making it easier for species to find locations for nesting and foraging (Groffman et al., 2006), reducing inbreeding, increasing capacity for recovery from disturbances, and providing migration options during disturbances such as sudden land-use changes or fires. Yet, strong connectivity also increases the potential for shocks such as diseases and invasive species to spread widely and quickly throughout a landscape (Biggs et al., 2012). Hence, studies indicate that resilience appears highest within moderately connected systems (Biggs et al., 2012) and when landscapes with high internal connectivity are loosely connected with one another (Biggs et al., 2012).

In addition to spatial variability, measures of distribution can incorporate how the spatial distribution of individual species communities within landscapes, known as *community diversity*, impacts resilience (Walker, 1992). Measures of community diversity require knowledge of the movements of individual species and the spatial scales which enable them to survive (Saunders et al., 1991). Measures can focus on assessing the dependence of a species on a patch or habitat within a landscape. A species that is heavily dependent on one or a few habitats may be highly vulnerable to shocks and extirpation threats that can reduce ecosystem resilience. This has important implications for managerial approaches overly focused on preserving keystone patches, as these may cause communities of certain species to become overly concentrated in these areas. Likewise, communities of species should not become overly fragmented across landscapes, as this can negatively affect breeding, thereby reducing the genetic diversity of the isolated species population, which in turn may negatively affect their ability to adapt to changing conditions (Saunders et al., 1991).

4.3.1 | Illustration of current practice

Consideration of distribution is limited in our two methodological examples. Some measurements can be found within habitat classification processes which seek to measure the relative importance of an area's biodiversity in relation to the wider ecosystem. The Extract methodology categorisation scheme includes aspects of the density of biodiversity, the extent to which ecosystems are threatened, and uniqueness. This reveals critical habitats that draw managerial attention for conservation, in line with the keystone patches approach. Yet, the methodology neither considers differences between areas in order to measure spatial heterogeneity, nor seeks to measure their connectivity. Similarly, the BIM evaluates an ecosystem's relative importance by measuring the number of distinct species in an area and the uniqueness of these species worldwide. The BIM accounts for the community diversity of individual species by calculating the proportion of an analysed habitat relative to its total global range, thereby indicating relative dependence on certain habitats. The measurement is based on the IUCN Red List and its dataset on the habitat ranges of terrestrial species.

5 | DISCUSSION

Extant approaches to corporate biodiversity impact measurement have largely overlooked important ways in which biodiversity influences nonlinear dynamics that drive ecosystem transformations (Costanza et al., 2017; Kosoy & Corbera, 2010). Both mainstream approaches to measuring ecosystem services and natural inventory yield limited insights regarding the timing of nonlinear changes that may push ecosystem across thresholds, and how changes to biodiversity may influence the likelihood of such changes. Our article contributes to advancing these approaches by drawing upon resilience thinking from the natural sciences to address these limitations. We posit that resilience thinking can enable managers to develop new understandings of the importance of certain organisms and species, and better recognise their roles in enabling ecosystems to retain the same basic functioning. For instance, by recognising functional redundancy and response diversity, managers may develop a greater appreciation for organisms that previously seemed to have little influence on an ecosystem's functionality.

We present a set of seven interconnected key mechanisms through which biodiversity influences resilience across three biodiversity attributes of abundance, composition and distribution. These mechanisms contribute to a key but neglected issue in biodiversity accounting of what firms should be measuring (Jones & Solomon, 2013). Measuring these mechanisms can help firms progress from measuring corporate biodiversity impact too narrowly by considering only species richness or quantity of habitat protected (Addison et al., 2019; Bartkowski et al., 2015). Each mechanism advances multi-attribute approaches to measuring corporate biodiversity impact by providing managers with a more nuanced understanding of an ecosystem's relative health based on its ability to adapt to disturbances and avoid sudden and transformative change. Managers can synthesise these mechanism measurements to predict ecosystem responses to changes in corporate impact (Yorque et al., 2002). Figure 3 offers a simplified example of using abundance, composition and distribution to understand transformative change.

We start with a seemingly healthy ecosystem that is delivering a range of ecosystem services to firms at high levels. We offer an over-simplified ecosystem of four species (A–D) that are active within the same three habitats, two with strong interconnectivity. Species A and B fulfil the same ecosystem function, but no substitutes are available for Species C and D. To ease interpretation, all species have the same spatial and temporal ranges.

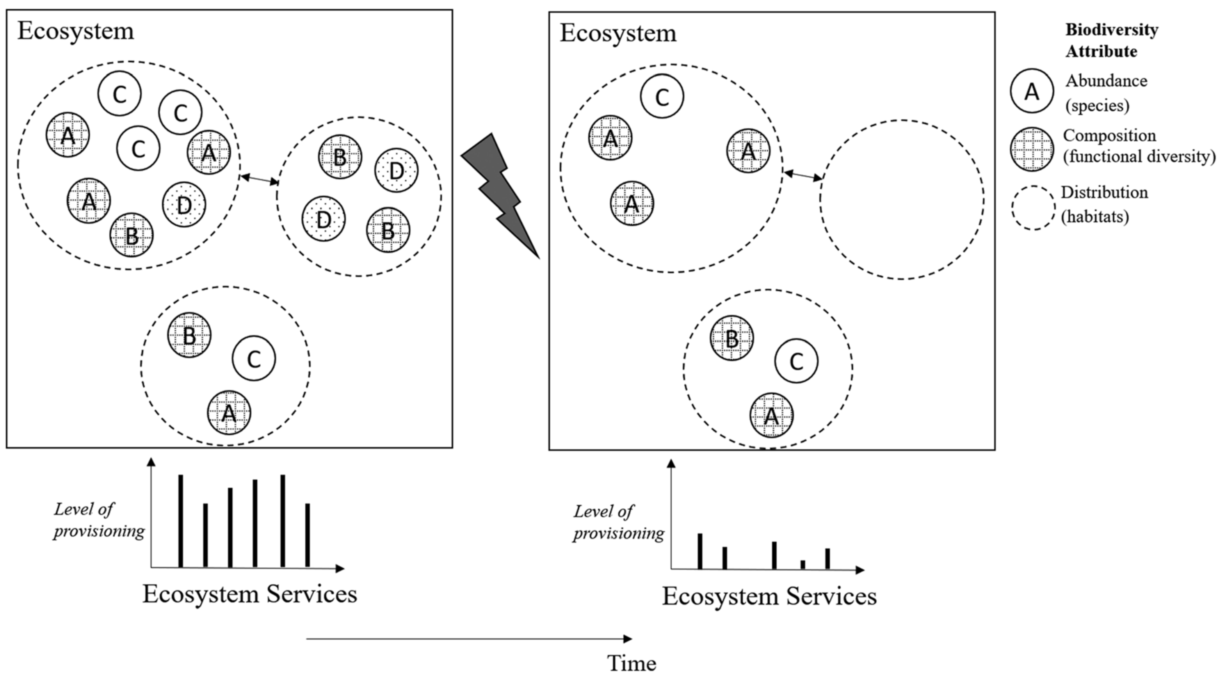

FIGURE 3 Ecosystem undergoing transformative change due to new corporate pressure

The ecosystem is shocked by a firm introducing a new chemical pollutant into the largest patch of habitat. The pollutant quickly spreads to the adjacent habitat (e.g., via a waterway), yet the final patch remains unaffected because it is disconnected (*spatial variability*). Species B is highly vulnerable to the pollutant but maintains a presence in the ecosystem due to its distribution (*community diversity*). Species A has a stronger response to the disease (*response diversity*) and can substitute for the loss of Species B (*functional redundancy*) to maintain the same level of provisioning for the ecosystem. Species D is also highly vulnerable and not abundant; when it becomes extirpated (*populations and threshold limits*), its ecosystem functionality cannot be replaced (*keystone species*). In this illustration, this functioning is critical to the performance of the entire ecosystem and sends ripple effects that initiate the ecosystem's transformation and reconfiguration into a new regime with far fewer benefits to firms.

By considering the mechanisms within this paper, the firm within the illustration could have formed a qualitative judgement on the resilience of the ecosystem to predict whether it was more likely to adapt to corporate pressure and continue its normal functioning, or undergo transformative change. Managers may have recognised the ecosystem's precariousness relative to threshold points and understood that the ecosystem was likely to reconfigure into a regime less favourable to business operations (Walker et al., 2004). This could have informed managers to avoid the release of the chemical pollutant, and conversely seek building the adaptability of the ecosystem to help prevent it from transforming when a shock occurs. Specifically, managers could have identified the importance of Species D as a keystone species and taken actions to support or strengthen its abundance, such as through breeding initiatives or habitat conservation. In addition, managers may have been stimulated to pursue strategies for proactive transformations at the firm-level to help avoid transformations of the ecosystem, or at least operate more successfully if a regime shift would occur (Clément & Rivera, 2017).

We envision application of the key mechanisms to advance natural inventory approaches, answering calls to elaborate how firms may develop more detailed understandings of ecological functioning and interconnections of species (Atkins & Maroun, 2018, 2020; Rimmel & Jonäll, 2013). Natural inventory approaches are most appropriate, as they already seek to directly account for biodiversity components and indirectly consider their composition and distribution (Jones, 1996; 2003). Incorporating measures of the mechanisms presented in this article can help situate inventory results within the wider dynamics of ecosystem change and yield a more nuanced understanding of how changes in biodiversity increase an ecosystem's vulnerability to transformative change. For instance, current measures of species abundance can be updated to offer information about composition by identifying ecological functions, categorising species and reviewing for functional redundancy. Likewise, existing habitat classifications can be improved by providing additional information about distribution, such as measurements of spatial connectivity.

Although the proposed mechanisms can help firms in diverse sectors, we see them as most relevant for sectors that are deeply embedded within ecosystems through high levels of dependency and impact (Winn & Pogutz, 2013), such as agriculture, forestry, fisheries, mining and tourism. For such sectors, ecosystem transformations to alternate regimes can have potentially disastrous effects to the ecosystem services they depend on, and much can be gained from preventing them. For instance, by gaining a better understanding of ecosystem resilience fisheries may expand their impact measurement beyond targeted fish and their food chains, to incorporating a wider array of species and spatial considerations. This may enable them to prevent ecosystem collapse through better understanding the value of actions such as innovating fishing methods to avoid bycatches and agreeing on 'no take zones' within the marine ecosystem (Walker & Salt, 2012). Our measures also would be most valuable for firms that are embedded within ecosystems that have shifted far from a stable equilibrium with moderate to high precariousness relative to threshold points. In these situations, managers must quickly become sensitive to feedback from the ecosystem (Whiteman et al., 2013), identify ways to improve ecosystem resilience and measure outcomes of restoration initiatives. Finally, the measures would be particularly useful for firms that are seeking to improve organisational resilience without jeopardising the resilience of the wider ecosystem (Clément & Rivera, 2017; Williams et al., 2021).

Nevertheless, we recognise that incorporating these mechanisms is likely to impose significant data requirements and is a key reason why extant approaches are relatively simplified (Bartkowski et al., 2015). For instance, implementing measures of composition and distribution likely requires in-depth longitudinal studies of individual species that are costly and difficult to perform in large or hard to access geographical areas. Moreover, because ecosystems are constantly changing, measurements must be continually updated in order to remain relevant and useful for firm decision-making (Carpenter et al., 2001). These reasons make measurement of the mechanisms most practicable for large firms, yet smaller companies may find financially feasible options through establishing cross-sector partnerships (Dentoni et al., 2021) and restricting data collection to areas of high conservation value or perceived high precariousness. In all cases, it is likely that firms will need to collaborate closely with national biodiversity authorities, non-governmental organisations and scientific bodies (Pereira et al., 2013). Additional research is required to assess feasibility and develop potential proxy measures for data sampling to yield robust yet pragmatic ways to represent the seven mechanisms (Oliver et al., 2015). Empirical studies may focus on reducing the set of measures by understanding their interaction effects and seeking to identify which prove most useful for managers to make decisions for action. For instance, studies may reveal that isolating individual firm impacts for certain measures is very difficult and does not provide a better understanding of the effectiveness of efforts to regenerate biodiversity.

Finally, we acknowledge that the scientific understanding of how ecosystems function, the interconnectedness of species, and how biodiversity influences change dynamics is far from complete (Atkins & Atkins, 2019; Bartkowski et al., 2015; Mace et al., 2012). Although the measures outlined here will enable firms to gain a better understanding of ecological functioning, they will not yield the complete picture necessary to accurately predict ecosystem change. There is no definitive list of mechanisms regarding how biodiversity influences ecosystem resilience, and many other factors also contribute to determining an ecosystem's capacity for change, such as the capacity for learning and experimentation, and the adaptability of governance systems (Biggs et al., 2012). We invite accounting scholars to explore this complex relationship to unlock additional ways to enhance how extant approaches to corporate biodiversity measurement provide information on nonlinear change dynamics and transformations.

6 | CONCLUDING REMARKS

The ongoing sixth mass extinction of animals demands corporate attention, as it threatens to collapse global ecosystems and push the Earth into a new regime that is less conducive to life (Steffen et al., 2015). Yet, measurement approaches to corporate biodiversity impact that inform corporate action largely overlook such nonlinear and transformative change dynamics within social-ecological systems. We believe that resilience thinking from the natural sciences offers a conceptual foundation for accounting scholars to address this shortcoming. By measuring the key mechanisms of how biodiversity influences ecosystem resilience, we posit that managers will obtain richer insights into nonlinear change dynamics and directions for corporate action that protect ecosystems from collapse and avoid surprises. We conclude by inviting accounting scholars to build upon the foundations of our conceptual work by empirically studying how pragmatic measures can be developed and how they can influence managerial understandings of biodiversity loss and conservation efforts.

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APPENDIX A.

TABLE A1 Select methodologies of corporate biodiversity impact

	Biodiversity impact metric (BIM)	Biodiversity indicators for extractive companies (extract)
Release year	2018	Pilot phase
Founding organisation(s)	Cambridge Institute for Sustainable Leadership (United Kingdom)	United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), international petroleum industry environmental conservation association (IPIECA), the Proteus partnership, Conservation International, Fauna & Flora International
Scope	Commodities	Projects & sites
Focus	Natural inventory	Natural inventory
Description	• Links the activities of individual companies (on commodity level) to the biodiversity status of impacted land. • Assess (1) land area impacted, (2) biodiversity quantity impacted and (3) biodiversity quality impacted. • The biodiversity status of an area is determined using the 'mean species abundance' (MSA) metric.	• The methodology can be used by extractive (i.e., mining) companies to assess their biodiversity impact at project- or site-level. • A state-pressure-response framework (1) assess the initial biodiversity state, (2) define pressures upon biodiversity via various external indicators to monitor impacts and (3) record company responses and their impacts.
Source link	https://www.wavespartnership.org/sites/waves/files/kc/Measuring%20Business%20Impacts%20on%20Nature.pdf	https://www2.unep-wcmc.org/system/dataset_file_fields/files/000/000/487/original/Biodiversity_Indicators_for_Extractive_Companies_FINAL.pdf?1516357616