PLANETARY BOUNDARIES: ECOLOGICAL FOUNDATIONS FOR CORPORATE SUSTAINABILITY

GAIL WHITEMAN*
Rotterdam School of Management
Erasmus University, The Netherlands
Email: gwhiteman@rsm.nl

BRIAN WALKER
The Commonwealth Scientific and Industrial Research Organisation (CSIRO) Sustainable Ecosystems, Canberra, Australia, &
Stockholm Resilience Centre
Stockholm University, SE-106 91 Stockholm, Sweden.
Email: Brian.Walker@csiro.au

PAOLO PEREGO
Rotterdam School of Management
Erasmus University, The Netherlands
Email: pperego@rsm.nl

*Corresponding Author

March 2012

PLANETARY BOUNDARIES: ECOLOGICAL FOUNDATIONS FOR CORPORATE SUSTAINABILITY

ABSTRACT

Management studies on corporate sustainability practices have grown considerably. The field now has significant knowledge of sustainability issues that are firm and industry focused. However, complex ecological problems are increasing, not decreasing. In this paper, we argue that it is time for corporate sustainability scholars to reconsider the ecological and systemic foundations for sustainability, and to integrate our work more closely with the natural sciences. To address this, our paper introduces a new development in the natural sciences – the delineation of nine 'Planetary Boundaries' which govern life as we know it – including a call for more systemic research that measures the impact of companies on boundary processes that are at, or possibly beyond, three threshold points – climate change, the global nitrogen cycle (N), and rate of biodiversity loss – and closing in on others. We also discuss practical implications of the Planetary Boundaries framework for corporate sustainability, including governance and institutional challenges.

Key Words: foundations, Planetary Boundaries, sustainability, management, ecology,

INTRODUCTION

"Quite simply, how many organizations could exist in the absence of oxygen production, fresh water supply, or fertile soil?" (Gladwin, Kennelly and Krause, 1995, p. 875)

Management research on corporate sustainability faces a paradox: On the one hand, sustainability is no longer a fringe topic and corporations routinely invest in eco-efficiency measures. On the other hand, data from ecological analyses indicates a worsening, and in some cases, alarming state of affairs. Why this disconnect? Part of the problem may be that "[w]e simply do not know to what extent corporate greening actually contributes to ecological sustainability or whether it does at all" (Kallio and Nordberg, 2006: 447). Despite awareness of the declining state of ecosystems, business management scholars have yet to adequately link business processes to macro ecological processes and boundary conditions. This is a gap that we seek to address.

On the positive side, many companies have progressed from reactive responses to environmental threats in the early years to more proactive business strategies that seek to address sustainability in an integrated, strategic manner (see Bansal and Hoffman, 2011; Darnall et al., 2010; Etzion, 2007; Hart and Dowell, 2011; Hoffman, 1997; Jermier, Forbes, Benn and Orsato, 2006). Corporate investment in sustainable initiatives also remains significant despite the financial crisis, illustrating that sustainability is not simply an "add on" when times are good: e.g. a 2010 Ernst and Young report shows that nearly three-quarters of global firms with annual revenue of +$1 billion were planning to increase their climate related investments (Ernst & Young, 2010). On the negative side, the 2005 Millennium Ecosystem Assessment by the World Resources Institute reported that 60% of ecosystems were significantly degraded. In 2007, the Intergovernmental Panel on Climate Change warned of an impending climate crisis. Recent quantitative studies indicate that the pace of climate change and other ecological problems (rate of biodiversity loss, phosphorous and nitrogen loads, etc.) is *faster* than anticipated (Lenton et al., 2008; Richardson, et al., 2009; Rockström et al., 2009a and b).

Currently, research on corporate sustainability remains disconnected from this state of affairs in at least three ways. First, the majority of empirical studies do not quantitatively measure the role of companies within the decline of Earth systems (Kallio and Nordberg, 2006; Levy, 1997a; Levy and Lichtenstein, 2011; Walker et al., 2009), with the exception of the impressive stream of research on toxic release inventories at the firm or industry level in the US (e.g. Berchicci, Dowell and King, forthcoming; King, Prado and Rivera, 2011; King and Lenox, 2002) and to some extent, company voluntary reporting on CO_2 emissions (Busch, 2010; Kolk and Pinkse, 2008a/b; Levy and Lichtenstein, 2011; Reid and Toffel, 2009) and water use (cf. Kurland and Zell, 2010). Instead, the business management literature remains focused on understanding the social, organizational or institutional implications of corporate sustainability, in isolation from quantitative indicators of ecosystem functioning (Bansal and Hoffman, 2011; Etzion, 2007; Goldstein, Hilliard and Parker, 2011; Kallio and Nordberg, 2006; Milne, Ball and Gray, 2008). While clearly valuable, research that focuses on corporate behavior in isolation from ecologically material impacts (Whiteman and Cooper, 2011) risks creating an unbalanced picture of progress, one that decouples social and organizational efforts for sustainability (Banerjee, 2003) from the on-the-ground, in-the-air and through-the-water material impacts of collective corporate and consumer activity.

Secondly, research on corporate sustainability remains resolutely anchored on firm and industry level behavior usually involving single-issues like toxic emissions or climate change, and there has been inadequate integration of systems thinking within our empirical designs (Levy and Lichtenstein, 2011). Given that many of the Earth's environmental problems are interrelated in complex, non-linear ways (Rockstrom et al., 2009a, 2009b), it is unlikely that firm-focused actions in corporate sustainability will be able, on their own, to resolve these systemic challenges (Ehrenfield, 2007; Levy, 1997a; Marcus, Kurucz and Colbert, 2010; Valente, 2010; Walker et al., 2009). Corporate sustainability activities simply do not contain "mechanisms to ensure that human impacts on the environment, in aggregate, are reduced to some acceptable and sustainable level" (Levy, 1997a, p. 134). We therefore need more studies that analyze how the micro role of firms and industries interact with "a macro-view" of the world "informed by system dynamics" in order to better address "environmental externalities and collective action failures [that] are leading to the 'tragedy of the commons'" (Levy and Lichtenstein, 2011, pp. 601-602).

Finally, there has been little ongoing integration of theory and data from the natural sciences within the business and environment literature (cf. Bansal and Hoffman, 2011). Notwithstanding the field's early appreciation of the value of ecological thought (Starik and Rands, 1995; Shrivastava, 1994), there is little cross-over from the pages of *Nature* and that of top business management journals. And yet it is in journals such as *Nature* that the very foundations of sustainability are routinely debated and refined. More common has been a reliance upon sociological, institutional and economic theories as foundations for research on corporate sustainability (Ansari, Gray, and Wijen, 2011; Berchicci and King, 2007; Clemens and Bakstran, 2010; Etzion, 2007). While valuable, these pillars are incomplete without the integration of advancements in ecological knowledge, which together can form a multidisciplinary and ecologically-grounded foundation for sustainability.

Despite the concerted effort towards corporate sustainability, we continue to miss the 'big' picture. Our paper seeks to address this paradox by introducing a recent theoretical development in the science of sustainability – the delineation of 'Planetary Boundaries' (Rockstrom et al., 2009a) (see section 1). Unveiled in *Nature* in December, 2009, scholars (predominantly from the natural sciences) synthesized a vast wealth of ecological theory, models and empirical studies to identify a set of nine 'Planetary Boundaries' that define what has been termed "the safe operating space" for humanity – if we cross these boundaries we will face "a state less conducive to human development" (Rockström et al., 2009a, p. 472). In this paper, we consider implications of the Planetary Boundaries framework for research and practice in corporate sustainability. We review management studies on corporate sustainability and identify the gaps in our knowledge and approach in light of this framework (section 2). The final section (3) outlines how Planetary Boundaries can serve as a rich foundation for future research on corporate sustainability.

1. CORPORATE SUSTAINABILITY

In the 1990s, the issue of corporate sustainability emerged in management studies, energized by two high profile special issues in the *Academy of Management Review* (Starik and Rands, 1995) and the *Academy of Management Journal* (Starik and Marcus, 2000) and the creation of new journals such as *Organization & The Environment* and *Business Strategy and the Environment*. A number of themes are apparent in much of the early work.

First, there was widespread recognition of the critical roles played by multinational companies within global environmental problems. Companies were key drivers of industrial development yet remained (at that time) an unstudied source of environmental problems (e.g., Shrivastava, 1995, pp 936-937). Secondly, concerns were raised about the pervasive ideological disconnect between companies (and organizations more generally) and the natural environment (Shrivastva, 1994). Gladwin et al. (1995, p. 875) pointed out that: "most management theorizing and research continues to proceed as if organizations lack biophysical foundations. Organic and biotic limits in the natural world are excluded from the realm of organizational science." This, they argued, was unsustainable and untenable. Without providing specific details, Gladwin et al. called for greater recognition of the inherently embedded nature of management studies and corporate practice. Scholars also recognized that firms' financial and competitive performance would become increasingly reliant upon the state of the Earth system (Hart, 1995). This created added incentive for more studies in corporate sustainability.

Thirdly, even at this early stage of our field's development, it is clear that management scholars understood the need for research on corporate sustainability to adopt systemic analysis and to integrate insights from ecology (Starik and Rands, 1995). Purser, Park and Montuori (1995), for example, explicitly argued for the integration of early ecologists' ideas on ecosystem health and the capacity for renewal (e.g., Odum, 1959; Leopold, 1949). What is equally apparent is that few articles provided direction on how to actually do this. Management scholars encouraged research on the conditions, factors and characteristics that allowed an organization or company to be ecologically sustainable, but did not provide direction on how this could be operationalized. How could management scholars integrate measures of ecosystem functioning into their studies on corporate sustainability? Which measures? Furthermore, an implicit but non-specified goal was to maintain relative stability of ecosystems with only minor systemic change. This is encapsulated in the basic definition of sustainability offered by Starik and Rands (1995, p. 909): "ecological sustainability is the ability of one or more entities, either individually or collectively, to exist and flourish (either unchanged or in evolved forms) for lengthy timeframes, in such a manner that the existence and flourishing of other collectivities of entities is permitted at related levels and in related systems." While this makes for an appealing narrative on sustainability (Dunford and Jones, 2000), this definition was hard if not impossible to operationalize – What is a lengthy timeframe? How does one define flourishing? What levels of change are permitted? At what focal scale is the system being affected? While clearly useful in kick-starting an environmental focus in business and management studies, these sorts of descriptions were also at odds with the development in ecosystem theory which, by the mid-1980s, had begun to focus more on the resilience of ever changing nested systems as opposed to stability (e.g., Holling, 1986).

Firm and Industry Focus

Despite early calls for a systemic conceptualization of environmental problems, from an empirical perspective, the majority of studies on corporate sustainability do not take a systems perspective as a starting point, and remain more linearly focused on firm and industry effects. Nevertheless, interest in research and practice on corporate sustainability has grown considerably (cf. Bansal and Hoffman, 2011).

Management studies have provided much needed insight into the various financial, institutional and ethical drivers of corporate sustainability and green consumer behavior (cf. Bansal and Hoffman, 2011). Corporate sustainability research has likewise gradually emerged as a distinct stream within the accounting and finance literature (cf. Hoffman, 2011), albeit with a high degree of fragmentation in terms of research methodology and standpoint (cf. Berthelot, Cormier and Maignan, 2003; Gray, 2010; Gray and Bebbington, 2000; Hoffman, 2011; Lee and Hutchinson, 2005).

These studies provide convincing evidence that many companies are engaged in sustainability practices (to varying degrees). However, research also suggests many corporate reports describe "sustainability" as a "journey" with no explicit destination or quantifiable boundaries (Milne, Kearins and Walton, 2006). By framing sustainability this way -- as a non-specified, firm-specific journey – corporations collectively defer the "radical change that …is necessary for its achievement" (Milne et al., 2006: 821). Furthermore, corporate environmental management may effectively manage institutional pressures but (intentionally or unintentionally) continue business-as-usual and ignore global environmental degradation (Banerjee, 2003; Levy, 1997a; Milne et al., 2006). Some accounting researchers are even more critical on this issue, since they argue that organizational 'accounts of sustainability' (mainly in the form of corporate environmental and social reports) have little if anything to do with sustainability (Gray, 2006; Gray and Milne, 2004; Milne, Ball and Gray, 2008; Milne et al., 2009). While businesses strive to construct the dominant discourse around sustainability, they point out that businesses often ignore scientific discourse on Earth systems.

Concern over the non-systemic basis of firm and industry focused research has appeared in a number of recent publications. For example, according to Gray (2010, p. 48), "Sustainability is a system-based concept and, environmentally at least, only begins to make any sense at the level of eco-systems and is probably difficult to really conceptualise at anything below planetary and species levels." Similarly, Levy and Lichtenstein (2011) emphasize that systems theory provides a critical theoretical framework to capture the complex socio-technical system within which business and policy makers are operating. Appeals for more systemic empirical research on corporate sustainability have also re-emerged partly because of the cross-over of research from industrial ecology and economic geography (Ehrenfield, 2007; Guthey and Whiteman, 2009; Korhonen and Seager, 2008; Lifset and Boons, 2011; Loorbach et al., 2010; Porter, 2006; Marcus et al., 2010; Seager, 2008).

Industrial ecologists analyze "individual firms as a focal actor within resource networks; regionally bounded groups of firms...global stocks and flows of a particular substance… and material flows in cities and nation states (Lifset and Boons, 2011, p. 312). One of the goals of industrial ecology is to study how inter-firm linkages can increase sustainability within a system, using tools such as 'Material Flow Analysis' (MFA) which "quantifies the inputs, outputs, and accumulation of materials at various scales" (Lifset and Boons, 2011, p. 320). Economic geography also attempts to understand economic and environmental interactions within bounded areas, using a landscape, eco-region or geographic cluster as the primary level of analysis (Allen, 1997; Baas, 2008; Baas and Boons, 2005; Boons, 2008; Boons and Roome, 2005; Guthey and Whiteman, 2009; Whiteman et al., 2004). While some of these studies suggest that the ecosystem in question becomes more sustainable over time (e.g., Guthey and Whiteman, 2009), other empirical findings suggest that results have been mixed, because systemic projects such as eco-parks may not become implemented beyond a shared vision or policy (cf. Lifset and Boons, 2011).

While these kinds of studies are promising, systems thinking remains in the margins, and the majority of empirical studies on corporate sustainability in core management journals (including the 2000 special issue in *AMJ*) seemed to have forgotten about the ecosystem. Natural science has not.

2. NATURAL SCIENCE AND PLANETARY SYSTEMS

From a geological time frame, environmental stability is a relatively recent turn of events. That is, "the planet's environment has been unusually stable for the past 10,000 years..." (Rockstrom et al., 2009a, p. 472). Much of this steadiness is related to the stabilization of global temperatures, which has allowed humans to progressively engage in agriculture, and social and economic infrastructure throughout the Holocene period. Yet data indicates that our hospitable, stable natural environment is beginning to change. "Now, largely because of a rapidly growing reliance on fossil fuels and industrialized forms of agriculture, human activities have reached a level that could damage the systems that keep Earth in the desirable Holocene state" (Rockström et al., 2009a, p. 472).

Ecologists (and related disciplines such as climatology, oceanography, biology, etc.) publish thousands of studies each year on elements of the biosphere (species, processes) over time and try to integrate these by ecological system (e.g., watershed) and by eco-region (e.g,. the integrated Arctic subsystem). Studies are also summarized in synthesis studies such as the IPCC reports, State of the Arctic Report Cards, and the Millennium Ecosystsem Assessment. What is becoming apparent is that earlier assumptions about the stability, linearity and reversibility of changes in ecosystems and the Earth systems fell short of what actually happens.

A characteristic feature of natural systems is that they exhibit non-linear dynamics with abrupt changes. They are all complex adaptive systems, and the key characteristic about such systems is that they are self-organizing systems – *but* within limits. Their capacity to self-organise in the same kind of way has limits and if those limits are exceeded the system no longer tends to recover towards its current "identity", but instead tends towards some different configuration (Walker and Salt, 2006). Such behaviour reflects the non-linear system nature of the Earth and its subsystems, such as the Arctic. The natural sciences therefore focus less on the somewhat vague term 'sustainability' and more on the idea of 'resilience' at a systemic level, and attempt to measure this via indicators. Resilience is "the capacity of a system to absorb shocks while maintaining function" (Folke et al., 2002). Vulnerability, the flip side (though not the exact opposite) of resilience, arises when actors limit (or exceed) their ability to make sense of, and respond to, feedback from the natural environment (Ostrom et al., 1999). Resilience thinking was initially formulated in the mid-1980s (Holling, 1986) and stood in stark contrast to previous ecological theories which tried to understand steady state dynamics in order to design appropriate but rather static natural resource management regimes. In contrast, resilience thinkers accepted the non-linear nature of systems and sought to influence specific process variables at a focal scale (such as rates of biodiversity in a watershed) to help maintain or increase resilience in an ever changing system (Gunderson and Holling, 2002; Holling, 1986).

Research in the natural sciences also seeks to understand how social processes are relevant to ecosystem function. A social-ecological system "is a system in which people depend on resources provided by ecosystems, and ecosystem dynamics are influenced, to varying degrees, by human activities" (Chapin et al., 2009, p. 2) and vice versa – social dynamics are influenced, to varying degrees, by ecosystem conditions and dynamic ecological processes (Chapin et al., 2009; Folke et al., 2002; Holling, 1986). The elements of resilience thinking applied to social-ecological systems entail coordinated action by a large numbers of actors, raising the problem of collective action (Walker and Salt, 2006).

Planetary Boundaries

The concept of Planetary Boundaries is a provocative extension of social-ecological systems thinking, an approach that acknowledges that one issue alone – whether it is climate change, ocean acidification or biodiversity loss -- cannot be managed in isolation. The reality is that changes in the state of the Earth system are determined by a suite of interlocked processes in a complex pattern of environmental and social dynamics. In an attempt to capture and integrate this multi-scale, multi-system complexity, natural scientists have identified essential planetary processes that govern life as we know it. According to Rockström et al. in the journal *Nature* (2009a, p. 474), "The boundaries we propose represent a new approach to defining biophysical preconditions for human development. For the first time, we are trying to quantify the safe limits outside of which the Earth system cannot continue to function in a stable, Holocene-like state."

INSERT FIGURE 1 ABOUT HERE

The planet's boundaries rest upon nine critical Earth-system processes and their associated thresholds: climate change, rate of biodiversity loss (terrestrial and marine);

interference with the nitrogen (N) and phosphorous (P) cycles (due largely to artificial fertilizers and industrial agricultural practices); stratospheric ozone depletion; ocean acidification; global freshwater use; change in land use; chemical pollution, and atmospheric aerosol loading. These processes together form a set of boundary conditions that signify concrete ecological constraints. Three of these boundaries – rate of biodiversity loss, nitrogen cycles and climate change -- have already been crossed. The others are under intense pressure, directly from the ongoing environmental degradation of land and sea and air masses, and indirectly from the cascading systemic effects from changes to other processes. While not all of the Earth's processes can be adequately assessed in minutiae, there is agreement on the need to make ongoing sense of these dynamic processes and to manage in a way that enhances the resilience of dynamic social-ecological systems (Chapin et al., 2009; Holling, 1986; Folke et al., 2002).

The nine boundaries differ in the ways in which they work, varying from those that have critical threshold levels reflecting discontinuous dynamics to those that probably do not have discontinuities but, rather, steeply curving response functions, or even step changes. The expanded version of the *Nature* paper (Rockström et al., 2009b) presents more detail on how this happens. The strength of interactions among the boundaries makes those with steeply changing effects very significant not only because of their direct effects on human wellbeing, but because changes in them can trigger threshold shifts in others.

Boundary processes operate at different scales in terms of thresholds. Table 1 (from Rockström et al., 2009b) summarizes the boundary characters of the nine processes in terms of scale. Scale is defined as "the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon, and levels as "the units of analysis that are located at different positions on a scale" (Cash et al., 2006. p. 2).

INSERT TABLE 1 ABOUT HERE

Climate change, ocean acidification and stratospheric ozone are all planetary scale boundaries that have, or are very likely to exhibit, global-scale threshold effects. If crossed, it will be very difficult or impossible to recover as the Earth system begins moving to a new configuration. Global phosphorus (P) and nitrogen (N) cycles, atmospheric aerosol loading, land use change and freshwater use all have regional to global scale effects and all could exhibit discontinuous threshold effects, although this is not certain. Their direct effects, however, are such that crossing their safe boundary levels greatly increases the likelihood of significant declines in human wellbeing. The rate of biodiversity loss and chemical pollution are processes that operate primarily at local up to regional scales, but aggregate up to affect planetary resilience. For example, the functional consequences of biodiversity loss are not yet obvious in most ecosystems or agro-ecosystems, but in some local places where it has reached critical levels (like many coral reefs), the ecosystems have changed drastically – both in the way they look and function (Bellwood et al., 2006). If the current rate of biodiversity loss world-wide continues, then more and more ecosystems will begin to fail. In particular, as these local-regional scale processes accumulate, the ability of the systems concerned to recover from other disturbances (climate shocks, diseases) diminishes.

Operational Indicators of Key Threshold Effects

Scientists suggest that planetary boundaries can be monitored by a small subset of the large amount of available ecological information: "Most of these thresholds can be defined by a critical value for one or more control variables, such as carbon dioxide concentration." (Rockström et al., 2009a, p. 472). Figure 1 outlines key controlling variables and suggested levels that they should not exceed, after which threshold effects become likely. Controlling variables have been identified for seven of the nine planetary processes, and Table 1 also provides specific levels of the key controlling variables that determine where the thresholds are. These controlling variables can be measured and assessed on an ongoing basis. The scientists involved stress that their numbers are preliminary estimates that need to be questioned and evaluated, but the idea of global sustainability is no longer a vague or utopian concept. Rather, it can be addressed via explicit measurement of these planetary boundary processes.

Compared to other national or global sustainability indices currently available, the PB controlling variables provide a viable and meaningful alternative that allows for cross-firm, cross-sector and cross-country analysis. Various studies point out that despite the compactness of aggregate indicators of sustainability and their ability to generate uni-dimensional rankings that ensure broad comparability, valuable information may be lost in combining disparate, disaggregated variables within highly context specific settings (cf. Dewulf and Van Langenhove, 2005; Goldstein, Hillard and Parker, 2011; Van Zeijl-Rozema, Ferraguto and Caratti, 2011). For instance, in their analysis on eleven indices that are widely used in policy practice to measure national sustainable development (like the Ecological Footprint, the Environmental Vulnerability Index, or the Index of Sustainable Economic Welfare), Böhringer and Jochem (2007) conclude that these indices fail to fulfill fundamental scientific requirements of validity and reliability (i.e. normalization, weighting, and aggregation), and reveal a high degree of arbitrariness. On the contrary, PB variables guarantee a higher degree of consistency and meaningful aggregation (commensurability) than composite indices. This should allow researchers, policy makers and managers to look for evidence about the impact of organizational choices on sustainability at a specific, micro level, as well as for broader regularities at various levels of aggregation. The PB approach is therefore highly functional in addressing the current divide between the natural scientists and social scientists in the identification of operational indicators that provide manageable units of information on sustainability conditions.

However, key challenges remain. Although ecologists know quite a lot about macro level measures and thresholds for each of the nine processes, they do not know much about the disaggregated sources of these problems. This is an important information gap. To effectively govern within our planetary boundaries, society needs to identify the different sources of N, P, CO_2, aerosols, ozone, (etc.), and the various organizations (including companies) driving emissions, land use and fresh water changes. The disaggregation of planetary control variables is necessary both in terms of greater geographic and organizational analysis of sources of emissions and ecosystem change. A key outstanding question is: How do we attribute different geographies, industries and firms that collectively contribute to the net planetary effect? That requires information that is not readily accessible to ecologists, but is likely related to corporate activities. We will address this in the last sections. Next, we turn our attention to the literature on corporate sustainability and discuss whether and how the debate about socio-ecological systems has diffused − or not − among management scholars interested in sustainability.

3. CORPORATE SUSTAINABILITY FROM A PLANETARY PERSPECTIVE

While that the growing body of studies on corporate sustainability has been useful for understanding how companies, consumers, industries, and organizational fields are evolving, there is significantly less research that investigates how corporate and industry-wide actions affect, and are affected by, each of the nine planetary boundary processes. Indeed, the literature on corporate sustainability is uneven in terms of breadth and depth from a planetary perspective, and only a relatively small subset of studies on corporate sustainability attempt to quantitatively measure how corporate sustainability policies and practices impact upon various boundary processes. See Table 3.

INSERT TABLE 3 ABOUT HERE

There is very limited and fragmented understanding of how companies and industries contribute to declines in 6 out of the 9 key ecological processes. For example, studies have only occasionally investigated the relationship between corporate sustainability and biodiversity (Sharma and Nguan, 1999; Westley and Vredenburg, 1997), and even fewer assess the impact of organizations on biodiversity using quantitative measures (see Lin and Buongiorno, 1998; Meester et al. 2004 as exceptions). There has been some interest in understanding land use planning and industrial development (e.g., Andersen et al., 2004;

Brill, Chang and Hopkins, 1982; Garcia-Falcon and Mendina-Munoz, 1999; Holt, 2001; Howard-Grenville et al., 2011; Lin and Buongiorno, 1998; Van Leeuwen, Vermeulen and Glasbergen, 2003), yet this work remains widely disparate in terms of measurement and geographic scope. Even more incomplete is our understanding of corporate sustainability and ozone depletion, with only a handful of studies paying attention to ozone depletion at the policy level (e.g., Levy, 1997b) and on gathering corporate executive perceptions on the need to address ozone depletion (e.g., within the UK baking and refrigeration industries, see Drake et al., 2004). Regrettably, there is no research in core management journals on firm or industry-level impacts on atmospheric aerosol loading, ocean acidification, or addressing overloaded nitrogen and phosphorous cycles. (One study from the 1960s in *Management Science* assessed options for nitrogen fertilizer capacity *expansion* in India, but did not consider negative environmental effects. See Erlennkotter and Manne, 1968).

Encouragingly, the actions of companies and/or industries within three boundary processes have received more attention – toxic emissions (chemical pollution), climate change, and (to a lesser degree) water use. We discuss these in more detail below.

Chemical Pollution

It is notable that toxic release inventory (TRI) data in the USA is by far the most popularly used proxy of environmental performance measures (Etzion, 2007). Under EPA's Emergency-Right-to-Know Provision, industrial facilities with ten or more full-time employees that release any listed toxic substance in excess of the minimum reporting threshold via any of four different media (air, water, land, or underground injection) are required to collect and report data on environmental releases of 581 chemicals and 30 chemical categories. The data is publicly available online in EPA's TRI.NET system (www.epa.gov/tri/tridotnet/) and can be sorted by company, industry, chemical and geographical area. TRI thus offers researchers the advantage of consistently reported, output oriented, facility-level data that are mandated across a panel of thousands of facilities since 1987.

Even a cursory review of the management literature on corporate sustainability reveals that several studies utilize the TRI database for a number of purposes, namely (1) to measure the efficacy of pollution prevention programs and chemical-use reduction programs (e.g. Barnett and King, 2008, King and Lenox, 2000, 2002; King and Shaver, 2001, Klassen and Whybark, 1999); (2) to assess the efforts of corporations (e.g.; Berchicci et al., forthcoming; Dooley and Fryxell, 1999; Russo and Harrison, 2005) or family-owned firms (Berrone, Cruz, Gomez-Mejia and Larraza-Kintana, 2010) to improve their environmental performance records; and (3) to examine the relationship between environmental performance and executive compensation (e.g. Berrone and Gomez-Meji, 2009), financial performance (e.g. Stanwick and Stanwick, 1998) or stock-market reaction (e.g. Khanna, Quimio and Bojilova, 1998; Konar and Cohen, 2001). A key strength of this research stream is that studies quantitatively analyze how various social and institutional practices result in changes in firm environmental performance in terms of toxic releases. This approach provides valuable insights into the role of companies within a key planetary boundary process (chemical pollution), and provides a much needed template for corporate sustainability studies targeted towards other, less well measured planetary boundary processes.

However, as discussed in Gerde and Logdson (2001), Toffel and Marshall (2004) and Kraft, Stephan and Abel (2011), the use of TRI data remains a challenging endeavor. For example, different estimation methods and weighting schemes can be applied to correct for the variable toxicity levels of releases. A closer cooperation between management scholars and natural scientists would be thus highly beneficial to increase the accuracy and generalizability of complex analyses that rely on TRI emissions. We also note that while TRI data provides valuable understanding on corporate and geographic sources of chemical pollution (within different regions in the USA), it only partially measures one aspect of our planetary problems, and does not provide insight into global distribution patterns outside of the geographic boundaries of the USA. More research is therefore required using other databases, such as the Pollution Release and Transfer Register (PRTR), in order to capture effects globally (King, personal conversation, 2011).

In addition, the TRI data is not fully comprehensive even within US borders, and researchers are actively looking for ways to address various limitations (King, personal conversation, 2011). For instance, a recent study documents a significant variation in reporting patterns across type of facilities, industries and geographical location (Kraft, Stephan and Abel, 2011). Finally, companies have multiple effects on the natural environment, and single-issue studies on TRI miss more systemic effects across multiple planetary boundaries and from other forms of chemical pollution such as DDT (Maguire and Hardy, 2009) and nuclear spills such as Fukushima.

Climate Change

Studies on corporate sustainability and climate change have increased significantly over the last few years despite a slow start (Goodall, 2008). This is encouraging given that companies are key actors in global emissions. Furthermore, climate change is a strategically relevant issue for companies in terms of managing opportunities (Haanaes et al., 2011; Hoffman, 2007; Whiteman et al., 2011) and threats including operational risks (Linnenlueke, Griffiths and Winn, 2011) and institutional pressures (Cowan and Deegan, 2011; Hoffman, 2005, 2007; Jesawani et al, 2008; Kolk and Pinkse, 2005, 2008; Levy and Egan, 2003; Levy and Kolk, 2002; Reid and Toffel, 2009; Romilly, 2007).

Research on the disclosure patterns for S&P 500 firms also suggests that firms' disclosures become routine practices since once firms begin to make a disclosure they are 'locked in' in the provision of GHG emissions information in the years ahead (Stanny, 2010). Furthermore, increasing empirical evidence documents a positive association between the level of GHG disclosure and firm-value, thereby confirming the expectation that the capital market rewards those companies that are better able to manage their exposure to climate change risks (e.g. Dhaliwal, Li, Tsang and Yang, 2011; Johnston, Sefcik and Soderstrom, 2008). Companies thus adjust their strategies in order to generate firm-specific advantages and in response to institutional pressures (Kolk and Pinkse, 2008b; Pinkse, 2007; Hoffman and Ventresca, 2002), but not necessarily in response to feedback from Earth systems.

Corporate studies on climate change offer valuable knowledge about the social and institutional drivers of firm responses to this PB process in terms of corporate behaviour and corporate reporting. What is missing is an analysis of whether or not increased levels of GHG disclosure practices actually lead to an overall reduction in CO_2 emissions. In comparison with the research on chemical pollution, there are much fewer studies which attempt to quantitatively measure how levels of corporate emissions are reduced (or rise) according to various institutional drivers, perhaps due to data limitations. The availability of firm level data (albeit self-reported) from the Carbon Disclosure Project offers more opportunities for explaining the disaggregate sources of firm level emissions. In addition, other data sources need to be utilized, such as the global database on power plant emissions of more than 50,000 power plants and 4,000 power companies, which is available through the Carbon Monitoring for Action program in Washington. Given that “Power generation accounts for 40% of all carbon emissions in the United States and about one-quarter of global emissions” (CARMA website, no date), studies that measure how firms within this industry change performance is valuable.

Ertimur, Francis, Gonzalez and Schipper (2010) also argue that, while external commitment mechanisms like the Carbon Disclosure Project can enhance the credibility of firm’s voluntary GHG disclosure, the efficacy of these mechanisms depends nevertheless on how the issue of comparability will be addressed in the coming years. As an example, consider the disconnection between increasing corporate actions on CO_2 reduction and the reported rise of ‘climate capitalism’ (Lovins and Cohen, 2011), with the reality that aggregate emission levels were at record high levels in 2010 (International Energy Agency, 2011). Firms may implement more climate-related actions (and report more frequently on these activities), but absolute levels of GHGs continue to rise at the planetary level and much of this is linked to collective corporate behavior. Research on CO_2 performance at the firm or industry level that does not simultaneously examine aggregate emissions may unintentionally “disguise the fact that there has been no net change in emissions” (Busch, 2010, p. 374).

A one-dimensional focus on CO_2 emissions source also ignores the interrelated processes of ocean acidification, land and water use, aerosol loading and biodiversity (Walker et al., 2009). While CO_2 emission reduction is unquestionably valuable, the overall resilience of the planet depends upon corporate sustainability initiatives being eco-efficient but, at the same time, not negatively affecting these related processes (Walker et al., 2009). This remains an outstanding dilemma. Overall, most studies are firm and industry focused and few, if any, attempt to analyze cumulative, interrelated systemic impacts on the local, regional/continental or global scale.

Fresh Water Use

Despite the importance of water for business, there is a “paucity of studies” on water and corporate sustainability published in core management journals (Kurland and Zell, 2010, p. 316). Nevertheless, there are a few illuminating studies which look at corporate sustainability and fresh water use from a systemic perspective both in terms of collective firm action and environmental resource use, including but not restricted solely to water use.

For instance, Pitsis et al (2003) qualitatively studied collaboration within the construction of the Sydney Olympic complex. One of their findings was that innovation in water use (particularly in dealing with waste water) was achieved through collaboration, although they do not provide quantitative measures to support executive perceptions. In addition, Chertow and Miyata (2011, p. 266) examined 14 firms on the island of Oahu, Hawaii to assess whether industrial symbiosis helped reduce resource use and provide firms with strategic advantages. Using quantitative and qualitative data, they concluded that “The largest environmental benefits were found to be reduced landfilling and conservation of primary materials, including 40 million gallons of fresh water and approximately 17 800 tons of coal annually. The research finds that symbiotic solutions, when made visible, are often preferable, especially on an island. Indeed, company managers who fail to consider symbiotic solutions for resource issues risk overlooking the most effective strategic options.” At the regional level, Brimberg, Mehrez and Oron (1994) assessed optimal groundwater economic development given ecological constraints from the arid desert ecosystem.

4. IMPLICATIONS FOR RESEARCH

The concept of Planetary Boundaries challenges us to rethink management approaches to corporate sustainability, and triggers a shift in research focus away from vague notions of sustainability-as-a-journey (Milne et al., 2006) towards a systemic investigation of how companies and industries contribute to the degradation of the nine specific boundary processes at different focal scales. These shifts in focus allow new research questions to emerge, and provide us with a subset of concrete indicators of key threshold effects, some of which are not commonly used by business management scholars or multinational companies. We discuss this in more detail below.

Corporate Sustainability Research and the Planetary Boundary Framework

A first step in understanding how companies contribute individually and collectively to planetary processes is to conceptualize where corporate activity enters into the planetary boundaries framework.

INSERT FIGURE 2 ABOUT HERE

As illustrated in Figure 2, the nine planetary boundaries function differently in terms of their up-scaling effects and threshold effects occur at different scales. The boundaries also interact in non-linear complex ways. For the sake of discussion, we have drawn an oversimplified map showing how the planetary boundaries may interact. Within this planetary system, we have located company "X" and industry "Y", and suggest that this company and industry each affects several boundaries, at different scales. Within Figure 2, corporate sustainability is anchored within an analysis of how the company (and industry at a higher scale) affects all nine boundary processes within specific bounded geographies – at the local, regional, continental and planetary level. Furthermore, given the non-linear interaction between the various boundary processes, it is important to note that changes in corporate behavior that reduce one of the impacts (bold lines) might have the unintended effect of increasing another – OR, if done well, might be synergistic and reduce more than one in isolation.

To illustrate this point, we present one (again oversimplified) example which explores how a company such as Unilever interacts with three planetary boundaries at different scales – climate change, biodiversity depletion, and land use within a focal scale (Rockström et al., 2009b). As a recognized front-runner in corporate sustainability, there have been numerous past studies on Unilever's approach to corporate sustainability in terms of sustainable agriculture (Pretty et al., 2004), supply chain management (Roome, 2005), cross-organizational learning and collaboration (Senge et al., 2007), the establishment of multi-stakeholder Roundtables (e.g., on palm oil, and the Marine Stewardship Council; see Cumins, 2004; Nikoloyuk et al., 2010), and adversarial interactions with NGOs (Heugens, 2003). Recently, Paul Polman, the CEO of Unilever, announced one of the most progressive visions on sustainability (Elkington and Love, 2011), with a commitment to halve the environmental footprint of products, source 100% of agricultural raw materials sustainably, help 1 billion people improve well-being, and double revenue.

How can a planetary boundaries approach add value to existing research on firms such as Unilever? To illustrate the application of this framework, we do not adopt Unilever as our focal point, but rather adopt a geographic region (Borneo) as our preliminary focal scale, a place where Unilever is active in terms of palm oil production. From an ecological perspective, the Borneo rainforest is "driven by El Niño-induced droughts that trigger mass reproduction among trees and fauna. In this sense El Niño serves as a trigger for regenerating the rainforest and its biodiversity helps sustain forest resilience. The rainforest has evolved ecologically to turn crisis (El Niño Southern Oscillation events) into opportunity for continuous development" (Rockström et al., 2009: Appendix 1, page 6). However, land use change largely because of palm oil plantations and timber extraction has fragmented the forest and therefore eroded the ability of the Bornean rainforest to utilize El Niño events to enhance biodiversity, and now has the opposite effect and detracts from biodiversity at the regional scale. In addition, the rainforest is more vulnerable to extreme weather events (an interaction effect with the global climate boundary process), leading to more droughts and more fire, which in turn releases significant carbon back into the global scale. "Deterioration of the status of two planetary boundary parameters (land system change and biodiversity loss) interacts with the climate system, to cause a higher sensitivity to extreme climate events (erosion of resilience in land and biodiversity boundaries reduces the safe space for the climate boundary)… Page et al. (2002) estimated that the widespread El Niño related wildfires of Borneo in 1997 released between 0.81 and 2.57 Gt of carbon to the atmosphere, equivalent to 13–40% of the mean annual global carbon emissions from fossil fuels" (Rockström et al., 2009: Appendix 1, page 6).

Given that Unilever is the largest international buyer of palm oil, a PB approach encourages more systematic social-ecological research which assesses how firm actions affect land use and biodiversity in Borneo, and how these changes both reduce regional resilience (in Borneo) and how they feed back into the global climate system (e.g., through significant global-level carbon releases from regional wildfires). The planetary boundaries framework also encourages a multi-firm (and multi-value chain) study to assess the actions of timber companies such as The Samling Group (which is active in Borneo) alongside Unilever activities in palm oil. It also encourages action based research studies at the local level – how can local Unilever managers in Borneo implement resilience thinking into their environmental impact assessments? Figure 2 supports a multi-process approach to research design that is not limited to analyzing firm behavior with respect to single issues like toxic emissions or climate change, etc. While past studies illustrate that corporate actions can concretely address specific environmental issues (e.g., eco-efficiencies in manufacturing or supply chain logistics), there is less understanding of how firms are connected to cumulative, systemic environmental problems.

In addition, Table 3 provides preliminary direction on future research opportunities for each of the 9 Planetary Boundaries. In addition, we emphasize the need for more research on the collective role of firms in the rate of biodiversity loss, and the global nitrogen and phosphorous cycles which we discuss in more detail below.

Biodiversity

The rate of biodiversity loss is one of the major areas of concern – since this rate of loss is currently beyond estimates of a safe threshold. In 2007, environment ministers from G8+5 countries agreed to undertake a global study on the economic significance of biodiversity (and loss), resulting in the establishment of TEEB, now hosted by The United Nations Environment Program. The TEEB study highlights the economic benefits of biodiversity and the costs of biodiversity loss, and emphasizes the critical role of the private sectors: "Businesses must manage risks to reputation and the bottom line posed by environmental damage" (TEEB, 2010, p. 10). We need more studies of corporate sustainability that incorporate measures of biodiversity impact particularly using sectoral assessments, and from a regional geographic perspective.

N and P Cycles

Another critical area for future research on corporate sustainability is to consider the role of companies (and industrial agricultural complexes) within nitrogen and phosphorous overloads in land, fresh water and sea. Scientific data has indicated for a few decades that the human-produced levels of nitrogen far exceed naturally occurring levels (Vitousek et al., 1997). By taking a planetary focus, business and environment researchers could usefully analyze how industrial agricultural practices overload N and P cycles, which are not adequately addressed in current supply chain studies.

For example, an overload of nitrogen and phosphorous from industrial fertilizer use in western France results in (among other things) the excessive growth of green algae blooms in oceanic waters and coastlines (Morand and Merceron, 2005), which affects local marine and terrestrial biodiversity and fishery based businesses, which in turn affects local culture and the tourism industry. Thus, research on sustainable agriculture can be extended to include an analysis of fisheries and tourism, along with a discussion of economic, socio-cultural and ecosystem changes in terms of N cycles, and rate of biodiversity loss. Adding in another layer of complexity could be achieved by analyzing how a third boundary process – e.g., climate change -- is affecting both industrial agricultural practices in France and the local marine ecosystems which are simultaneously under siege by green algae. In addition, studying the feedback loops between energy-intensive industrial agricultural operations, conversion of forest land for agriculture (a 4^{th} boundary process), and greenhouse gas emissions globally would illustrate more of the systemic interactions between planetary boundaries and the activities of multinational companies. This type of corporate sustainability study would be significantly different than one which analyzed corporate sustainability reports of agricultural giants such as Cargill or Unilever in isolation.

Implications for Practice

Senior executives are not immune to the need for more systemic collective approaches to sustainability. According to Peter Bakker, former CEO of the multinational company TNT and President of the World Business Council for Sustainable Development, "As a company we can reduce our carbon footprint dramatically. But the world's still driving off a cliff. *We need a system change*" (quoted in Whiteman, 2010, p. 149). Even when companies actively try to implement radical change, environmental degradation is not avoided because most approaches are "limited in that its focus is the individual corporation rather than the complex organization-ecosystem interface" (Levy, 1997a, p. 134; see also Gray, 2010; Levy and Lichtenstein, 2011), and "few companies have the capacity or market power to alter unilaterally entire sociotechnical systems" (Hart, 1995: 1003).

The Planetary Boundaries framework encourages specific firms to situate their sustainability practices within the nine boundary processes governing the global commons. While firm or industry focused actions on corporate sustainability are unlikely to deal effectively with the tragedy of commons (Hardin, 1968; Levy, 1997a), greater awareness of thresholds provides individual firms and business associations like the World Business Council for Sustainable Development with a collective yardstick to measure global sustainable performance, and offers a strategic guideline for assessing the scope of corporate sustainability efforts – are firms addressing each of the boundary processes and in which ways? In particular, the Planetary Boundaries analysis highlights the urgency of three interrelated thresholds: climate change, rate of biodiversity loss, and impacts on the nitrogen cycle. This encourages firms to consider their impacts and actions on these three topics and to anchor sustainability reporting within the Planetary Boundaries framework.

There are also practical implications for other important corporate sustainability stakeholders such as the Carbon Disclosure Project, the not-for-profit organization working with 655 institutional investors (representing US$78 trillion in assets). While CDP originally sought greater disclosure on climate risks among firms, it has already expanded its focus to include water issue disclosures. The Planetary Boundaries threshold analysis underscores the additional need for greater disclosure on nitrogen emissions and rate of biodiversity loss related to the activities of multinational firms.

Greater attention to and disclosure on the impacts of firms and industries on the nine planetary boundaries is a starting point for action. However, there are a number of practical limitations that need to be overcome, not the least of which is access to new databases. In addition, greater knowledge of environmental degradation will not, on its own, create sufficient conditions for corporate action without appropriate firm- and market-based incentives closely tied to managerial effort (Berrone and Gomez-Mejia, 2009) and institutional pressures for change (Baron and Lyon, 2011; Hoffman, 1997). It is also tempting to suggest that firms need to determine their 'fair-share' of planetary problems, and to set individual targets for reduction and action. For example, "What is the 'right' target or maximum level for an individual organization along each of these nine dimensions?" While the downscaling of planetary boundary responsibility to individual firms is appealing in principle, it faces practical complexities in terms of the cumulative, collective and interrelated nature of the nine boundary processes (Persson et al., forthcoming). Because these are joint problems affecting the global commons (Hardin, 1968; Ostrom et al., 1999), individual firms can't easily set meaningful individual targets that will effectively solve the problem in isolation (although such target setting does get the 'ball rolling' in terms of focusing attention and action on priority areas, and establishing front-runners). Planetary Boundary thresholds need to be disaggregated in meaningful ways and this is a critical area for future research that is multidisciplinary in nature. Sectoral and firm level targets for reduction need to be developed and implemented jointly, with some targets likely remaining at the global aggregate level, with others (such as rate of biodiversity loss or impacts on the N cycle) also requiring collective targets at the regional and/or local level in order to avoid problem-shifting among actors and geographic regions. Addressing the question of burden-sharing will take time, and issues of accountability and the effectiveness of voluntary industry action needs to be simultaneously addressed (King and Lenox, 2000, 2002).

A related and critical global governance problem is the lack of appropriate institutions that allow individual firms and collections of firms to engage at local, national and global scales. The Planetary Boundaries framework therefore highlights the need for more practical experimentation in global governance (Baron and Lyon, 2011; Walker et al., 2009). While several societal institutions have been formed to address such collective action problems (Ostrom et al., 1999), governance issues regarding the commons remain (Dietz, Ostrom and Stern, 2003; Walker et al., 2009). The framework provokes top executives to consider if, and how, business and economic groups like the World Economic Forum or the World Business Council for Sustainable Development can contribute to better governance of our planetary boundaries.

CONCLUSION

Due to the centrality of corporations within modern economies and societies, multinationals have long been conceptualized as important sources of environmental degradation (Hart, 1995). Yet studies on corporate sustainability continue to remain disconnected from the declining state of Earth systems. In this paper, we argue that the scientific framework of Planetary Boundaries provides us with a rich and detailed foundation for management studies on corporate sustainability. To effectively address the ‘tragedy of the commons’, studies on corporate sustainability need a dual focus: on the firm (or industry) and on the Earth system. It is not an either, or. Indeed, Levy and Lichtenstein (2011, p. 602) note that: “Between these two poles, a number of approaches exist which suggest that a limited degree of prediction and managerial intervention is not only possible but necessary to steer our economic and environmental systems away from catastrophe”. The Planetary Boundaries framework encourages more research on the role of companies and biodiversity loss and the global nitrogen cycle, and on the systemic interaction between planetary processes and collections of firms instead of single-issue studies or firm or industry focused studies. Figure 2 and Table 3 provide initial direction for future integrated research.

In addition to the issues raised in our paper, we also emphasize certain limitations. In particular, we have not provided sufficient details on how inter-organizational dynamics and corporate governance structures link firm behavior with Earth systems at varying levels of scale. This is another important area for future research. Furthermore, the practical implementation of the Planetary Boundaries framework will require innovations in international governance (see Dietz et al., 2003; Walker et al., 2009), and management theory more generally may be able to make contributions to this area.

Finally, incorporating insights from the Planetary Boundaries framework demands greater eco-literacy and cross-disciplinary collaboration between business management scholars and our ecological counterparts. Cross disciplinary collaboration can enhance our ability to integrate the insights of the Planetary Boundary framework into studies of corporate sustainability, because natural scientists are experts on such ecological processes and have vast empirical data sets and indicators of ecosystem function (including the ability to access and analyze satellite data of observed ecosystem change). In addition, management scholars can offer important social, institutional and economic insights that can strengthen the approach of the natural sciences, particularly as it relates to governance and organizational change. Indeed, as Seager (2008, p. 447) writes, "[t]he locus of study in sustainability science is on *the interaction between human and natural systems*" (italics in original). This, by definition, requires multi-disciplinary integration.

Yet such collaboration is not easy, and we are not offering a naive or utopian message. Cultural, cognitive and institutional barriers detract from collaborative projects. In the words of one reviewer, "Scientists from different disciplines have a hard time understanding and appreciating knowledge and epistemic approaches from other disciplines. Also, they are discouraged to do so, given the relative monodisciplinarity of highly regarded academic journals and their academic home institutes (to which tenure-and-promotion decisions are related)." We also recognize that the quantitative approach of planetary boundaries as a means of 'measuring' sustainability may not be appealing to some scholars who adopt a more constructivist approach. Overcoming these barriers remains a challenge and is beyond the scope of our paper. However, social-ecological complexity can also be framed as an academic opportunity. In the words of Flannery and May (2000, p. 643) in the special issue of the *Academy of Management Journal*: "[T]he topic of organizations and the natural environment is complex – and exciting – because of its interdisciplinary, industry-specific, multilevel, and multisystem perspectives."

Academic excitement grows when scholars interact. From personal experience, we have found that the best way forward on this issue is for people to meet face-to-face and to take the time to share and learn. This paper in itself is an example of this – two of the authors are business management scholars (from different areas and with a mix of qualitative and quantitative expertise) and the second author is an ecologist. In addition, the scientific network, the Resilience Alliance, and its journal *Ecology & Society* are examples of a larger multi-disciplinary cluster of scholars who have learned over time how to look at social and ecological systems for mutual benefit. In addition, various universities such as Arizona State School of Sustainability and Ohio State University have multidisciplinary centres on sustainability and resilience, both of which include faculty from the business schools. In closing, we note various other ways to encourage further cross-disciplinary collaboration (see

Hicks, Fitzsimmons and Polunin, 2010; MacMynowski, 2007), including the organization of special issues, and academic symposium or panel debates using scholars from business and ecology. The 2010 panel on *Resilience and Business* at the Resilience Alliance conference in Arizona is one example: panelists included C.S. Holling, Andrew King, and Kathleen Sutcliffe. Similarly, discussions are under way with the World Business Council for Sustainable Development to convene a practical workshop on Planetary Boundaries with business scholars and ecologists.

We are encouraged by these and other initiatives. In the words of C.S. Holling (personal conversation), the father of resilience theory, “It’s not a crisis; it’s an opportunity.”

REFERENCES

Andersen, O., Lundli; H. E., and Hoyer, K. G. (2004). 'Transport scenarios in a company strategy'. *Business Strategy and the Environment*, **13**, 43-61.

Ansari, S., Gray, B. and Wijen, F. (2011). 'Fiddling while the ice melts? How organizational scholars can take a more active role in the climate change debate'. *Strategic Organization*, **9**, 1-7.

Baas, L. (2008). 'Industrial symbiosis in the Rotterdam Harbour and Industry Complex: Reflections on the interconnection of the techno-sphere with the social system'. *Business Strategy and the Environment*, **17**, 330–40.

Baas, L. and Boons, F. (2004). 'An industrial ecology project in practice: Exploring the boundaries of decision-making levels in regional industrial systems'. *Journal of Cleaner Production*, **12**, 1073–85.

Banerjee, S.B. (2003). 'Who sustains whose development? Sustainable development and the reinvention of nature'. *Organization Studies*, **24**, 143-180.

Bansal, P. and Hoffman, A. (2011). *Oxford Handbook of Business and the Natural Environment.* Oxford, Oxford University Press.

Barnett, M. L. and King, A. A. (2008). 'Good fences make good neighbors: A longitudinal analysis of an industry self-regulatory institution'. *Academy of Management Journal*, **51**, 1150-70.

Baron, D.P. and Lyon, T.P. (2011). 'Environmental governance'. In Bansal, P. and Hoffman, A. (Eds)., (pp. 122-139). Oxford: Oxford University Press, *Oxford Handbook of Business and the Natural Environment*. Oxford: Oxford University Press.

Bellwood,D .R., Hughes, T. P., Folke, C. and Nystrom, M. (2004). 'Confronting the coral reef crisis'. *Nature*, **429**, 827-33.

Berchicci, L. and King, A. A (2007). 'Postcards from the edge: A review of the business and environment literature'. *Academy of Management Annals*, **1**.

Berchicci, L., Dowell, G., and King, A.A. (forthcoming).'Environmental capabilities and corporate strategy: Exploring acquisitions among US manufacturing firms'. *Strategic Management Journal*.

Berrone, P., Cruz, C., Gomez-Mejia, L. R., and Larraza-Kintana, M. (2010). 'Socioemotional Wealth and Corporate Responses to Institutional Pressures: Do Family-Controlled Firms Pollute Less?' *Administrative Science Quarterly*, **55**, 82-113.

Berrone, P., and Gomez-Mejia, L. R. (2009). 'Environmental Performance and Executive Compensation: An Integrated Agency-Institutional Perspective'. *Academy of Management Journal*, **52**, 103-126.

Berthelot, S., Cormier, D., and Magnan, M. (2003). 'Environmental disclosure research: review and synthesis'. *Journal of Accounting Literature*, **22**, 1-44.

Boons, F. (2008). 'Self-organization and sustainability: The emergence of a regional industrial ecology'. *Emergence: Complexity and Organizations*, **10**, 41-8.

Boons, F. and Roome, N. (2005). 'Sustainable enterprise in clusters of innovation: New directions in corporate sustainability research and practice', in Sharma, S. and Aragón-Correa, J.A. (Eds), *Corporate environmental strategy and competitive advantage*, 259-85.

Brill, E.D., Chang, S-Y. and Hopkins, L.D. (1982). 'Modeling to generate alternatives: The HSJ approach and an illustration using a problem in land use planning.' *Management Science*, **28**, 221-35.

Brimberg, J., Mehrez, A., and Oron, G. (1994). 'Economic development of groundwater in arid zones with applications to the Negev desert, Israel'. *Management Science*, **40**, 353-63.

Busch, T. (2010). 'Corporate carbon performance indicators revisited'. *Journal of Industrial Ecology*, **14**, 374-7.

Cash, D. W. et al. (2006). 'Scale and cross-scale dynamics: Governance and information in a multilevel world'. *Ecology and Society*, **11**, 8. [online] URL: http://www.ecologyandsociety.org/vol11/iss2/art8/

Chapin, F. S. III., Kofinas, G.P. and Folke, C. (2009). *Principles of ecosystem stewardship: Resilience-based natural resource management in a changing world*. New York: Springer-Verlag.

Chertow, M., and Miyata, Y. (2011). 'Assessing collective firm behavior: Comparing industrial symbiosis with possible alternatives for individual companies in Oahu, HI'. *Business Strategy and the Environment*, **20**, 266-80.

Clemens, B., and Bakstran, L. (2010). A framework of theoretical lenses and strategic purposes to describe relationships among firm environmental strategy, financial performance, and environmental performance. *Management Research Review*, **33**, 393-405.

Cowan, S., and Deegan, C. (2011). 'Corporate disclosure reactions to Australia's first national emission reporting scheme'. *Accounting and Finance,* **51**, 409-436.

Cumins, A. (2004). 'The Marine Stewardship Council: A multistakeholder approach to sustainable fishing'. *Corporate Social Responsibility and Environmental Management*, **11**, 85-94.

Darnall, N., Henriques, I., and Sadorsky, P. (2010). 'Adopting proactive environmental strategy: The influence of stakeholders and firm size'. *Journal of Management Studies*, **47**, 1072-104.

Dewulf, J., and Van Langenhove, H. (2005). 'Integrating industrial ecology principles into a set of environmental sustainability indicators for technology assessment'. *Resources Conservation and Recycling,* **43**, 419-432.

Dhaliwal, D. S., Li, O. Z., Tsang, A., and Yang, Y. G. (2011). 'Voluntary Nonfinancial Disclosure and the Cost of Equity Capital: The Initiation of Corporate Social Responsibility Reporting'. *Accounting Review*, **86**, 59-100.

Dietz, T., Ostrom, E. and Stern, P.C. (2003). 'The struggle to govern the commons'. *Science*, **302,** 1902–12.

Dooley, R. S., and Fryxell, G. E. (1999). 'Are conglomerates less environmentally responsible? An empirical examination of diversification strategy and subsidiary pollution in the US chemical industry'. *Journal of Business Ethics,* **21**, 1-14.

Drake, F., Purvis, M. and Hunt, J. (2004). 'Meeting the environmental challenge: a case of win-win or lose-win? A study of the UK baking and refrigeration industries'. *Business Strategy and the Environment*, **13**, 172-86.

Dunford, R., and Jones, D. (2000). 'Narrative in strategic change'. *Human Relations*, **53**, 1207-26.

Elkington, J. and Love, C. (2011). 'Tomorrow's C-Suite Agenda'. In Bansal, P. and Hoffman, A. (Eds)., (pp. 639-646). Oxford: Oxford University Press, *Oxford Handbook of Business and the Natural Environment*. Oxford: Oxford University Press.

Erlennkotter, D. and Mann, A.S. (1968). 'Capacity expansion for India's nitrogenous fertilizer industry'. *Management Science*, **10**, B553-72.

Ernst & Young (2010). *Action amid uncertainty: The business response to climate change.* http://www.ey.com/Publication/vwLUAssets/Action_amid_uncertainty/$FILE/Action_amid_uncertainty.pdf

Ertimur, Y., J. Francis, A. Gonzales, and K. Schipper (2010). 'Credibility, Commitment and Voluntary Environmental Disclosures', *Duke University, working paper*.

Etzion D. (2007). 'Research on organizations and the natural environment, 1992-present: A review'. *Journal of Management,* **33**, 637-58.

Flannery, B. L. and May, D. R. (2000). 'Environmental ethical decision-making in the US metal-finishing industry'. *Academy of Management Journal*, **43,** 642-62.

Folke, C. et al. (2002). 'Resilience and sustainable development: Building adaptive capacity in a world of transformations'. *ICSU Series on Science for Sustainable Development,* **3**, 1-74.

Garcia-Falcon, J. M., and Mendina-Munoz, D. (1999). 'Sustainable tourism development in islands: A case study of Gran Canaria'. *Business Strategy and the Environment,* **8**, 336-57.

Gerde, V. W., and Logdson, J. M. (2001). ‘Measuring environmental performance: use of the Toxics Release Inventory (TRI) and other US environmental databases’. *Business Strategy and the Environment,* **10**, 269-285.

Gladwin, T.N., Kennelly, J. J., and Krause, T.S. (1995). ‘Shifting paradigms for sustainable development: Implications for management theory and research’. *Academy of Management Review*, **20,** 874-907.

Goldstein, D., Hilliard, R., and Parker, V. (2011). ‘Environmental performance and practice across sectors: methodology and preliminary results’. *Journal of Cleaner Production,* **19**, 946-957.

Goodall, A.H. (2008). ‘Why have the leading journals in management (and other social sciences) failed to respond to climate change?’ *Journal of Management Inquiry,* **17**, 408-20.

Gray, R. (2006). ‘Does sustainaiblity reporting improve corporate behaviour? Wrong question? Right time?’ *Accounting & Business Research*, **36,** 65-88.

Gray, R. (2010). ‘Is accounting for sustainability actually accounting for sustainability ... and how would we know? An exploration of narratives of organisations and the planet’. *Accounting Organizations and Society,* **35**, 47-62.

Gray, R., and Bebbington, J. (2000). ‘Environmental accounting, managerialism and sustainability: is the planet safe in the hands of business and accounting?’ *Advances in Environmental Accounting & Management,* **1,** 1-44.

Gray, R., and Milne, M. J. (2004). ‘Towards reporting on the Triple Bottom Line: Mirages, methods and myths’. In A. Henriques & J. Richardson, *The Triple Bottom Line: Does it all add up?*, London: Earthscan, 70-80.

Gunderson, L.H. and Holling, C.S. (2002). ‘*Panarchy: Understanding transformations in human and natural systems’.* Washington: Island Press.

Guthey G.T. and Whiteman, G. (2009). ‘Social and ecological transitions: Winemaking in California’. *Emergence: Complexity and Organization,* **11**, 37-48.

Haanaes, K., Arthur, D., Balagopal, B., Kong, M.T., Reeves, M., Velken, I., Hoppins, M.S., and Kruschwitz, N. (2011). 'Sustainability: The 'embracers' seize advantage'. *MIT Sloan Management Review Research Report*, 1 - 28.

Hardin, G. (1968). 'The tragedy of the commons'. *Science,* **162**, 1243-48.

Hart, S. L. (1995). 'A natural-resource based view of the firm'. *Academy of Management Review*, **20**, 986-1014.

Hart, S.L. and Dowell, G. (2011). 'A natural-resource-based view of the firm: Fifteen years after.' *Journal of Management,* **37**, 1464-79.

Heugens, P.M.A.R. (2003). 'Capacity building through adversarial relationships: A replication and extension of Clarke and Roome (1999)'. *Business Strategy and the Environment,* **12,** 300-312.

Hicks, C. C., Fitzsimmons, C., and Polunin, N.V C. (2010).'Interdisciplinarity in the environmental sciences: barriers and frontiers'. *Environmental Conservation,* **37**, 464-77.

Hoffman, A. J. (1997). *From heresy to dogma: An institutional history of corporate environmentalism*. San Francisco: New Lexington Press.

Hoffman, A.J. (2005). 'Climate change strategy: The business logic behind voluntary greenhouse gas reductions'. *California Management Review*, **47**, 21-46.

Hoffman, A.J. (2007). *Carbon strategies: How leading companies are reducing their climate change footprint.* Ann Arbor: University of Michigan Press.

Hoffman, A. J. (2011). *Thirty-Five Years of Research on Business and the Natural Environment. Part 1: A Statistical Synopsis*. http://oneaomonline.blogspot.com/2011/07/thirty-five-years-of-research-on.html

Hoffman, A. J. and Ventresca, M. J. (Eds.) (2002). *Organizations, policy and the natural environment: Institutional and strategic perspectives*. Stanford University Press.

Holling, C. S. (1986). 'Resilience of ecosystems: Local surprise and global change'. In Clark, W.C. and Munn, R.E. (Eds), *Sustainable development and the biosphere*, 292-317. Cambridge: Cambridge University Press.

Holt, R. (2001). 'Creating whole life value proxemics in construction projects'. *Business Strategy and the Environment,* **10**, 148-60.

Howard-Grenville, J., Golden-Biddle, K., Irwin, J., and Mao, J. (2011). 'Liminality for cultural process for cultural change'. *Organization Science*, **22,** 522-39.

Intergovernmental Panel on Climate Change (IPCC). (2007). *The AR4 Synthesis Report.* Geneva: IPCC.

International Energy Agency. (2011). *World Energy Outline*. http://www.iea.org/index_info.asp?id=1959

Jermier, J. M., Forbes, L. C., Benn, S., and Orsato, R.J. (2006). 'The new corporate environmentalism and green politics'. In Clegg, S.R., Hardy, C., Lawrence, T.B., and Nord, W.A. (Eds). *The Handbook of Organization Studies.* London: Sage.

Jesawani, H.K., Wehrmeyer, W., and Mulugetta, Y. (2008). 'How warm is the corporate response to climate change? Evidence from Pakistan and the UK'. *Business Strategy and the Environment,* **18**, 46-60.

Johnston, D., Sefcik, S. and Soderstrom, N. (2008). 'The value relevance of greenhouse gas emissions allowances: An exploratory study in the related United States SO_2 Market'. *European Accounting Review,* **17**, 747-64.

Kallio, T. J. and Nordberg, P. (2006). 'The evolution of organizations and natural environment discourse'. *Organization & Environment*, **19**, 439-57.

Khanna, M., Quimio, W. R. H., and Bojilova, D. (1998). 'Toxics Release Information: a policy tool for environmental protection'. *Journal of Environmental Economics and Management,* **36**, 243-66.

King, A. A., and Lenox, M. (2000). 'Industry self-regulation without sanctions: The chemical industry's Responsible Care program'. *Academy of Management Journal,* **43**, 698-716.

King, A., and Lenox, M. (2002). 'Exploring the locus of profitable pollution reduction'. *Management Science,* **48**, 289-99.

King, A.A., Prado, A.M., and Rivera, J. (2011). ‘ Industry self-regulation’. In Bansal, P. and Hoffman, A. (Eds)., *Oxford Handbook of Business and the Natural Environment*. Oxford: Oxford University Press.

King, A. A. and Shaver, J. M. (2001). ‘Are aliens green? Assessing foreign establishments' environmental conduct in the United States. *Strategic Management Journal,* **22**, 1069–85.

Klassen, R. D., and Whybark, D. C. (1999). ‘The impact of environmental technologies on manufacturing performance’. *Academy of Management Journal,* **42**, 599-615.

Kolk A. and Pinkse, J. (2005). ‘Business responses to climate change: Identifying emergent strategies’. *California Management Review,* **47**, 6-21.

Kolk A, and Pinkse J. (2008a). ‘Business and climate change: Emergent institutions in global governance’. *Corporate Governance,* **8,** 419–29.

Kolk A. and Pinkse, J. (2008b). ‘A perspective on multinational enterprises and climate change: Learning from “an inconvenient truth”?’’ *Journal of International Business Studies,* **39**, 1359-78.

Konar, S., and Cohen, R. A. (2001). ‘Does the market value environmental performance?’ *Review of Economics and Statistics,* **83**, 281-89.

Korhonen, J., and Seager, T.P. (2008). ‘Beyond eco-efficiency: A resilience perspective’. *Business Strategy and the Environment,* **17**, 411-19.

Kraft, M. E., Stephan, M., and Abel, T. D. (2011). *Coming clean. Information disclosure and environmental performance*: MIT Press.

Kurland, N.B. and Zell, D. (2010). Water and business: A taxonomy and review of the research’. *Organization & Environment,* **23**, 316-53.

Lee, T. M., and Hutchison, P. D. (2005). ‘The decision to disclose environmental information: A research review and agenda’. *Advances in Accounting,* ***21***, 83-111.

Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S. and Schellnhuber, H. J. (2008). ‘Tipping elements in the Earth’s climate system’. *Proceedings of the National Academy of Sciences (PNAS),* **105**, 1786-93.

Leopold, A. (1949/1970). *A Sand County Almanac*. New York: Oxford University Press.

Levy, D. L. (1997a). ‘Environmental management as polical sustainability’. *Organization & Environment*, **10**, 125-47.

Levy, D. L. (1997b). ‘Business and international environmental treaties: Ozone depletion and climate change’. *California Management Review,* **39**, 54-71.

Levy, D. L. and Egan, D. (2003). ‘A neo-Gramscian approach to corporate political strategy: Conflict and accommodation in the climate change negotiations’. *Journal of Management Studies,* **40**, 803–30.

Levy, D.L., and Kolk, A. (2002). ‘Strategic response to global climate change: Conflicting pressures in the oil industry’. *Business and Politics*, **4**, 275-300.

Levy, D. L., and Lichtenstein, B. 2011. ‘Approaching business and the environment with complexity theory’. In Bansal, P. and Hoffman, A. (Eds)., (pp. 591-608). Oxford: Oxford University Press, *Oxford Handbook of Business and the Natural Environment*. Oxford: Oxford University Press.

Lifset, R., and Boons, F. (2011). ‘Industrial ecology: Business management in a material world.’ In Bansal, P. and Hoffman, A. (Eds)., *Oxford Handbook of Business and the Natural Environment*. Oxford: Oxford University Press.

Lin, C. R., and Buongiorno, J. (1998). ‘Tree diversity, landscape diversity, and economics of maple-birch forests: Implications of Markovian models’. *Management Science,* **44**, 1351-66.

Linnenluecke, M. K., Griffiths, A., and Winn, M. (2011). ‘Extreme weather events and the critical importance of anticipatory adaptation and organizational resilience in responding to impacts’. *Business Strategy and the Environment,* online first.

Loorbach, D., van Bakel, J., Whiteman, G. and Rotmans, J. (2010). ‘Business strategies for transitions towards sustainable systems’. *Business Strategy and the Environment*, **19**, 133-46.

Lovins, L. H. and Cohen, B. (2011). *Climate Capitalism*. Hill and Wang.

MacMynowski, D. P. (2007). 'Pausing at the brink of interdisciplinarity: Power and knowledge at the meeting of social and biophysical science'. *Ecology and Society*, **12**, 20.

Maguire and Hardy, C. (2009). Discourse and deinstitutionalization: the decline of DDT. *Academy of Management Journal* **52**, 148-178.

Marcus, J., Kurucz, E., and Colbert, B. A. (2010). 'Conceptions of the business-society-nature Interface: Implications for management scholarship'. *Business & Society*, **49**, 402-38.

Meester, G. A., Mehrotra, A., Ault, J. S. and Baker, E. K. (2004). 'Designing marine reserves for fisheries management'. *Management Science*, **50**, 1031-43.

Milne, M. J., Ball, A., and Gray, R. (2008). 'Wither ecology? The triple bottom line, the Global Reporting Initiative, and the istitutionalization of corporate sustainability reporting'. *Paper presented to the American Accounting Association, Anaheim, August 2008*.

Milne, M. J., Kearins, K., and Walton, S. (2006). 'Creating adventures in Wonderland: The journey metaphor and environmental sustainability'. *Organization*, **13**, 801-39.

Milne, M. J., Tregidga, H., and Walton, S. (2009). 'Words not actions! The ideological role of sustainable development reporting'. *Accounting, Auditing & Accountability Journal*, **22**, 1211-57.

Morand, P. and Merceron, M., (2005). 'Macroalgal population and sustainability'. *Journal of Coastal Research*, **21**, 1009–20.

Nikoloyuk, J., Burns, T. R., and de Man, R. (2010). 'The promise and limitations of partnered governance: The case of sustainable palm oil'. *Corporate Governance*, **10,** 59-72.

Odum, E. P. (1959). *Fundamentals of ecology* (2nd ed.). Philadelphia: Saunders.

Ostrom, E., Burger, J., Field, C.B., Norgaard, R.B., and Policansky, D. (1999). 'Revisiting the commons: Local lessons, global challenges'. *Science*, **284**, 278-82.

Persson, A. et al. (forthcoming). 'Can Earth system interactions be governed? Governance functions for linking climate change mitigation with land use, freshwater and biodiversity protection'. *Ecological Economics*.

Pinkse, J. (2007). 'Corporate intentions to participate in emission trading'. *Business Strategy and the Environment*, **16**, 12-25.

Pitsis, T.S., Clegg, S.R., Marosszeky, M., and Rura-Polley, T. (2003). 'Constructing the Olympic dream: A future perfect strategy for corporate management'. *Organization Science*, **14**, 574-90.

Porter, T.B. (2006). 'Coevolution as a research framework for organizations and the natural environment'**.** *Organization and Environment*, **19**, 479-504.

Purser, R.E., Park, C., and Montuori, A. (1995). 'Limits to anthropocentrism: Toward an ecocentric organization paradigm'. *Academy of Management Review*, **20**, 1053-89.

Reid, E.M. and Toffel, M.W. (2009). 'Responding to public and private politics: Corporate disclosure of climate change strategies'. *Strategic Management Journal*, **20**, 1158-78.

Richardson, K. et al. (2009). *Synthesis report: Climate change -- Global risks, challenges and decisions.* Copenhagen: University of Copenhagen, http://climatecongress.ku.dk/pdf/synthesisreport/

Rockström, J. et al. (2009a). 'A safe operating space for humanity'. *Nature*, **461**, 472-5.

Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin, III, E. Lambin, T. M., Lenton, M. Scheffer,C. Folke, H. Schellnhuber, B. Nykvist, C. A. De Wit, T. Hughes, S. van der Leeuw,H. Rodhe, S. Sörlin, P.K. Snyder, R. Costanza, U. Svedin, M.Falkenmark, L. Karlberg, R. W. Corell, V. J.Fabry, J. Hansen, B.Walker, D. Liverman, K. Richardson, P. Crutzen, and J. Foley. (2009b). 'Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society* **14**(2): 32. [online] URL: http://www.ecologyandsociety.org/vol14/iss2/art32/

Romilly, P. (2007). 'Business and climate change risk: A regional time series analysis'. *Journal of International Business Studies*, **38**, 474-80.

Roome, N. (2005). 'Teaching sustainability in a global MBA: Insights from the OneMBA'. *Business Strategy and the Environment*, **14**, 161-170.

Russo, M. V., and Harrison, N.S. (2005). ‘Organizational design and environmental performance: Clues from the electronics industry’. *Academy of Management Journal*, **48**, 582-93.

Seager, T. P. (2008). ‘The sustainability spectrum and the sciences of sustainability’. *Business Strategy and the Environment*, **17**, 444–53.

Senge, P.M., Lichtenstein, B.B., Kaeufer, K., Bradbury, H. and

Carroll, J.S. (2004). ‘Sustainability: Collaborating for Systemic Change’. MIT Sloan Management Review, 44-53.

Sharma, S., and Nguan, O. (1999). ‘The biotechnology industry and strategies of biodiversity conservation: The influence of managerial interpretations and risk propensity’. *Business Strategy and the Environment*, **8**, 46-61.

Shrivastava, P. (1994). ‘Castrated environment: Greening organizational science’. *Organization Studies,* **20**, 70-26.

Shrivastava, P. (1995). ‘The role of corporations in achieving ecological sustainability’. *Academy of Management Review*, **20**, 936-60.

Stanny, E. (2010). 'Voluntary Disclosures of Emissions by US Firms ', *Working paper, Sonoma State University*.

Stanwick, P. A., and Stanwick, S. A. (1998). ‘The relationship between corporate social performance, and organizational size, financial performance, and environmental performance: An empirical examination’. *Journal of Business Ethics,* **17**, 195-204.

Starik, M. and Marcus, A. A. (2000). ‘Introduction to the Special Research forum on the Management of Organizations in the Natural Environment: A field emerging from multiple paths, with many challenges ahead’. *Academy of Management Journal,* **43**, 539-46.

Starik, M. and Rands, G.P. (1995). ‘Weaving an integrated web: Multilevel and multisystem perspectives of ecologically sustainable organizations’. *Academy of Management Review,* **20**, 905-35.

TEEB (2010). The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.

Toffel, M.W. and Marshall, J.D. (2004). 'Improving environmental performance assessment: Comparative analysis of weighting methods used to evaluate chemical release inventories'. *Journal of Industrial Ecology*, **8**, 143-72.

Valente, M. (2010). 'Demystifying the struggles of private sector paradigmatic change: Business as an agent in a complex adaptive system'. *Business & Society,* **49**, 439-76.

Van Leeuwen, M. G., Vermeulen, W. J. V., and Glasbergen, P. (2003). 'Planning eco-industrial parks: An analysis of Dutch planning methods'. *Business Strategy and the Environment,* **12**, 147-62.

Van Zeijl-Rozema, A., Ferraguto, L., and Caratti, P. (2011). 'Comparing region-specific sustainability assessments through indicator systems: Feasible or not?' *Ecological Economics,* **70**, 475-86.

Vitousek, P. M. et al. (1997). 'Human alteration of the global nitrogen cycle: causes and consequences'. *Issues in Ecology,* **1**, 4-6.

Walker, B.H. and Salt, D. (2006). *Resilience thinking: Sustaining ecosystems and people in a changing world*. Washington: Island Press.

Walker, B.H. et al., (2009). 'Looming global-scale failures and missing institutions'. *Science*, **325**, 1345-46.

Westley, F. and Vredenburg, H. (1997). 'Interorganizational collaboration and the prevention of global biodiversity'. *Organization Science*, **8**, 381-403.

Whiteman, G. (2010). 'Corporate greening falls short'. *Nature*, **273**, 149-50.

Whiteman, G. and Cooper, W.H. (2011). 'Ecological sensemaking'. *Academy of Management Journal.* **43**, 1265-82.

Whiteman, G. Forbes, B.C. Niemelä, J. and Chapin, F.S. (2004). 'Bringing feedback and resilience of high-latitude ecosystems into the corporate boardroom'. *Ambio,* **33**, 371-6.

Whiteman, G., de Vos, R., Chapin, F.S. III., Yli-Pelkonen, V., Niemelä, J., and Forbes, B. (2011). ‘Business strategies and the transition to low-carbon cities’. *Business Strategy and the Environment,* **20**, 251-65.

World Resources Institute. (2005). *Millennium ecosystem assessment: Ecosystems and human well-being: Synthesis.* Washington: Island Press.

Figure 1: The Earth's Planetary Boundaries (Source: Rockström et al., 2009a)

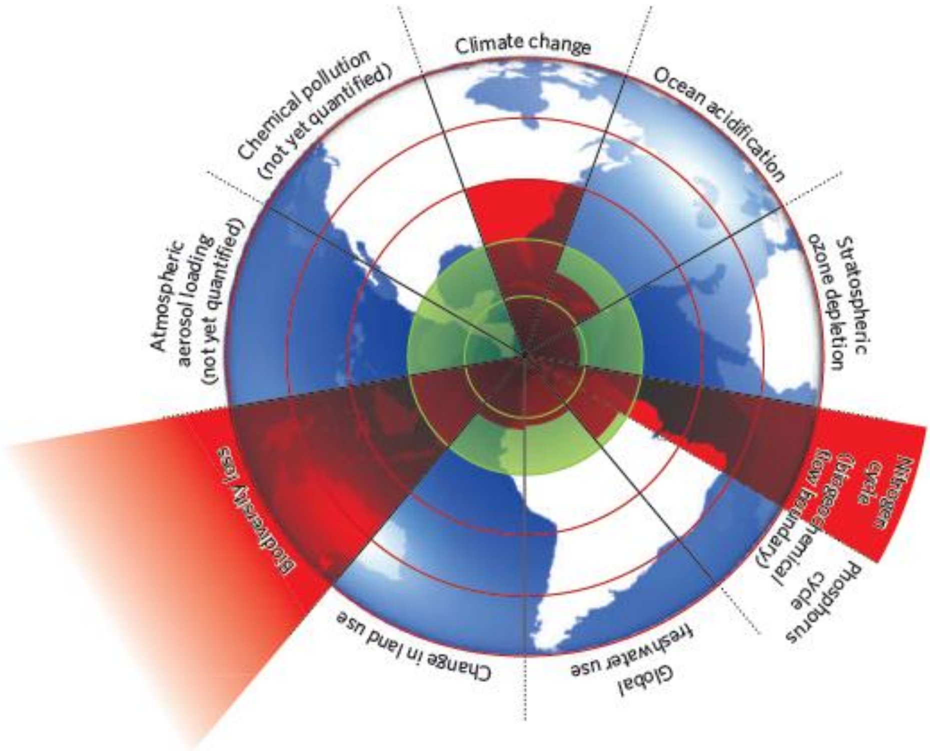

Figure 1 | Beyond the boundary. The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

Table 1: Categories of planetary boundaries (Source: Rockström et al., 2009b)

Boundary character / **Scale of process**	**Processes with global scale thresholds**	**Slow processes without known global scale thresholds**
Systemic processes at planetary scale	Climate Change	
	Ocean Acidification	
	Stratospheric Ozone	Stratospheric Ozone
Aggregated processes from local/regional scale	Global P and N Cycles	Global P and N Cycles
	Atmospheric Aerosol Loading	Atmospheric Aerosol Loading
	Freshwater Use	Freshwater Use
	Land Use Change	Land Use Change
		Biodiversity Loss
		Chemical Pollution

Table 2: Planetary Boundaries processes and the controlling variables determining threshold levels (Source: Rockström et al., 2009a)

PLANETARY BOUNDARIES

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1–1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5–9.5	~1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000	2,600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis		To be determined	
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof		To be determined	

Boundaries for processes in red have been crossed. Data sources: ref. 10 and supplementary information

Table 3: Overview of studies on corporate sustainability related to Planetary Boundary processes

Planetary Boundary	Representative articles	Level/unit of analysis	Core findings	Future research opportunities
Chemical Pollution	Baas (2008); Baas and Boons (2004); Barnett and King (2008); Berrone and Gomez-Mejia (2009); Berrone et al. (2010); Berchicci et al. (forthcoming); Boons (2004); Dooley and Fryxell (1999); King and Lenox (2000, 2002); King and Shaver (2001); Klassen and Whybark (1999); Konar and Cohen (2001); Maguire and Hardy (2009); Russo and Harrison (2005)	Regional/Local scale (I, F)	Good understanding of specific firm- and industry-level variable as antecedents of environmental management capabilities. Very good empirical understanding of toxic releases and corporate environmental performance in USA.	Examine additional firm-level variables as antecedents of environmental performance. Conduct longitudinal studies about drivers and effects of toxic releases outside USA. Understand toxic release effects in other areas of chemical pollution and on a global scale using other databases than TRI. Develop estimations methods and weighting schemes that correct for the variable toxicity levels of chemical releases. Conduct multi-level studies to disentangle the role of institutional and organizational factors in shaping environmental management capabilities.
Climate Change	Cowan and Deegan (2011); Hoffman and Ventresca (2002); Kolk and Pinkse (2005, 2008a/b); Jesawani et al. (2008); Johnston et al. (2008); Levy and Egan (2003); Levy and Kolk (2002); Linnenleuke et al. (2011); Reid and Toffel, (2009); Romilly (2007); Whiteman et al. (2011)	Regional/Local scale (I, F)	Good understanding of drivers of carbon reporting and lobbying/institutional drivers of carbon accounting regimes. Fragmented understanding of actual emission reductions by firm/industry/regions.	Analyse the conditions under which firms and industries reduce firm and system level CO_2 and other GHG emissions (e.g., within large cities). Analyse interactions of firm/industry level effects of CO_2 /GHG emissions, rate of biodiversity loss, land and freshwater use (e.g., using key geographic locations like Borneo, the Amazon, or the Arctic). Examine how ongoing climate change will compromise agricultural productivity (e.g. implications for the use of N and P, as well as land and water use change) and how food-sector companies will respond. Develop more comprehensive measurement approaches to address the issue of operational boundaries and aggregate effects of greenhouse gases at the regional level. Understand the effects of alternative measures of greenhouse gas emissions such as methane. Conduct cross-country empirical studies on corporate responses to climate change, especially in emerging countries. Explore the role of multi-stakeholder partnerships as novel form of climate change governance at firm- and industry-level.

Table 3 (continued)

Planetary Boundary	Representative articles	Level/unit of analysis	Core findings	Future research opportunities
Fresh Water Use	Brimberg et al (1994); Chertow and Minyata (2011); Pitsis et al. (2003)	Regional scale (I)	Fragmented understanding of water-related-issues in company and industry management, with a specific focus on water and wastewater companies. Increase in studies focusing on industry management, while relative decrease in articles on water quality and water use. Extensive reliance on computer based and simulation techniques.	Empirically extend the analysis on the environmental impact of the overuse of water resources or the implications of water scarcity for business. Analyse interactions of water use affected by land use change and shift to renewable sources of energy. Broaden the scope beyond water and wastewater industries to examine water-intensive industries (e.g. semiconductor, beverage and agriculture). Identify the secondary (knock-on) effects of altering water flow regimes on other PBs Understand the social, political, and governance implications of constrained water supplies across countries and legal regimes. Conduct empirical studies on the role of industry/national water standards and innovation in solving water problems.
Rate of Biodiversity Loss	Lin and Buongiorno (1998); Meester et al. (2004); Sharma and Nguan (1999); Westley and Vredenburg (1997)	Regional scale (I)	Very limited understanding of macro- and micro-scale effects of biodiversity loss. Lack of clarity in measurement and reporting practices on biodiversity loss.	Refine and critically assess cost-benefit tools like TEEB to ensure that company sustainability reports adequately reflect loss (or gain) of biodiversity related directly or indirectly to corporate activities. Critically assess the impact on ecosystem services of new corporate valuation and environmental accounting approaches such those used by PUMA and the PPR Group. Analyse the impact on ecosystem services of new market-based mechanisms such as biodiversity offsets. Analyse interactions between land and water use and GHG emissions caused by corporate or industry activities and biodiversity at both species and ecosystem level (e.g., Borneo rain forest).

Table 3 (continued)

Planetary Boundary	Representative articles	Level/unit of analysis	Core findings	Future research opportunities
Land Use	Andersen et al. (2004); Brill et al. (1982); Garcia-Falcon and Mendina-Munoz (1999); Holt (2001); Howard-Grenville et al. (2011); Lin and Buongiorno (1998); Van Leeuwen et al. (2003)	Local scale (I)	Fragmented understanding of land-use change in the context of space, time, and scale.	Develop integrated land use models with a greater emphasis on the flow of matter and energy in social-ecological ecosystems. Understand the relative effects of different social drivers (such as demography, markets, institutions, and technology) on land-use change in the context of different scales. Address interactions with other boundary processes such as freshwater use, climate change, biodiversity loss, and global N and P cycles Address issues of scale mismatch between physical and social (decision-making) systems, missing connections between levels of decision-making and inter-temporal preferences.
Global N and P Cycles	None		No empirical understanding despite dominance of multinationals in industrial agriculture and fertilizers production.	Quantify how industrial and agricultural practices overload N and P cycles across supply chains and identify regional hotspots. Investigate feasibility of P and N nutrient recycling. Study the effectiveness of new regulatory options on P and N usage, and consequent additions to the environment.
Atmospheric Aerosol Loading	None		No empirical understanding of how companies/industries are contributing to this problem.	Quantify the impact of companies on the cumulative aerosol emissions by large cities and industrial zones. Explore how industrial and agricultural practices contribute to raising levels of atmospheric aerosol loading.
Ozone Depletion	Drake et al. (2004); Levy (1997b)	Local/Cont. scale (I)	Very limited understanding of how companies/industries are contributing to this problem.	Establish measurement protocols for company/ industry contributions to this problem.

Table 3 (continued)

Planetary Boundary	Representative articles	Level/unit of analysis	Core findings	Future research opportunities
Ocean Acidification	None		No empirical understanding of how companies/industries contribute to and will be affected by this problem.	Explore the impacts of ocean acidification on ocean-dependent companies and industries such as fisheries and tourism. Develop relationships between CO2 emissions, consequent changes in ocean pH, and the likely consequences for society and ocean-dependent industries Investigate the interactive effects of chemical pollution (e.g. TRI), N and P emissions and rate of biodiversity loss from corporate actions and ocean acidification.

Note: the third column 'Level/unit of analysis' maps representative papers distinguishing planetary scale from continental/regional scale and local scale as level of analysis investigated. For the latter two levels, we indicate whether the effects examined refer to respectively industry (I) or firm (F) unit of analysis level.

Figure 2a: Firm-Level effects on PB at various Scales

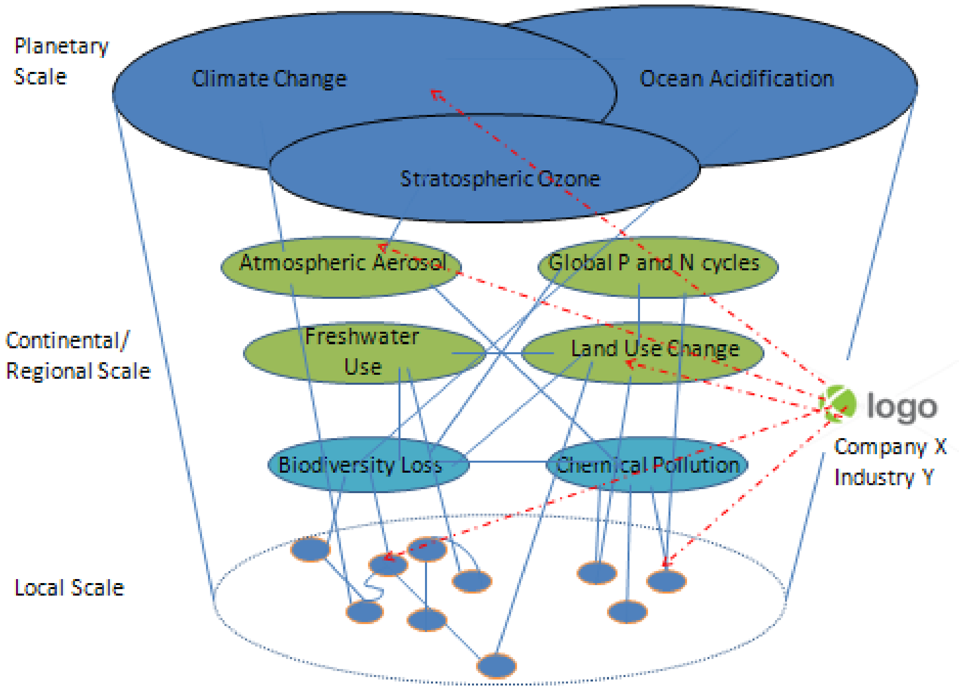

Figure 2b: Multi-Firm effects on PB from palm oil development in Borneo