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Review

Mimicking natural ecosystems to develop sustainable supply chains: A theory of socio-ecological intergradation

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ABSTRACT

For most firms, the development of sustainable supply chain practices remains challenging. Using a theory-building approach, we develop a theory of socio-ecological intergradation to provide managers with guidance in mimicking natural ecosystems to develop more local and thus sustainable supply chains. Socio-ecological intergradation refers to the gradual merging of social (organizational) and ecological (environmental) systems to shift a firm's focus from global supply chain optimization to building more regionally bound, socio-ecologically connected operations. Drawing on the natural and industrial ecology literature, the paper identifies five principles that mimic natural ecosystems and increase the environmental sustainability of supply chains, including the ecological systems they ultimately depend on. The paper further illustrates what these principles mean in both an environmental and a supply chain context and how, in concert, they can lead toward more sustainably designed and managed supply chains. In building a theory of socio-ecological intergradation, this research is one of the first attempts to apply ecological principles to supply chains, creating synergy and dialogue between the sustainable supply chain management, business ethics, and industrial ecology disciplines.

Contents

1. Introduction 252
2. Research background and theory development 252
   2.1. Research domain and key definitions 252
   2.2. Prior literature 253
      2.2.1. Sustainable supply chain management 253
      2.2.2. Industrial ecology 254
   2.3. The theory development process 254
3. Conceptual development: socio-ecological intergradation 254
   3.1. Socio-ecological intergradation in supply chains 254
   3.2. Underlying ecosystem principles from a systems perspective 255
4. Socio-ecological intergradation and its outcomes 257
5. Socio-ecological intergradation in practice 258
   5.1. Socio-ecological intergradation in an agricultural context 258
   5.2. Socio-ecological intergradation in hybrid operations 259
6. Discussion and implications 260
7. Future research and conclusions 261
References 262

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1. Introduction

A concept increasingly central to supply chain theory is sustainability. Calls to create more sustainable supply chain practices have led to significant theoretical advancements across the supply chain management, business ethics, and related fields (Korhonen, 2003; Morali and Searcy, 2013; Quarshie et al., 2016). Moreover, a variety of firm-driven sustainability efforts have been produced from these advancements, such as the design of eco-friendly products (Shang et al., 2010), product life extensions (Linton and Jayaraman, 2005), environmental life cycle inventory and assessment (Xing et al., 2016), and closed-loop supply chains (Guide Jr et al., 2003a). Nevertheless, important theoretical strides must be made if scholars are to direct research and practice toward the creation of sustainable supply chains that operate within the carrying capacity of their supporting natural ecosystems. Such theoretical strides are particularly important for increasingly globalized companies. In this context, it is crucial to mitigate or altogether avoid issues such as the exploitation of cross-country differences in environmental regulations, large environmental footprints, and compliance issues arising from implementing codes of conduct (Jiang, 2009).

To lead the way toward the creation of sustainable supply chains, we develop a theory of socio-ecological intergradation. In the context of supply chains, socio-ecological intergradation recognizes the link between the supply chain and the natural systems. Socio-ecological intergradation is the merger of the organizational (henceforth referred to as "social") and environmental (henceforth referred to as "ecological") dimensions. Socio-ecological intergradation is built on the acceptance of organizations as an integral part of ecosystems (Gladwin et al., 1995) and invokes nature as a source of new ideas for designing more sustainable operational processes. We employ "intergradation" rather than "integration" to capture the gradual merging of the social and ecological dimensions to result in a more harmonious interdependent and sustainable relationship. We borrow the term from zoology and related fields, where it refers to the way species can gradually share characteristics and merge (Mayr and Ashlock, 1969). During the intergradation process, a sharing of characteristics (overlap) precedes the merging of the social and ecological dimensions, as in the merging of economics and ecological principles occurring in the emerging field of ecological economics (Daly and Farley, 2011).

In this study, we define socio-ecological intergradation as supply chain processes that mimic natural ecosystems through a merger of the social and ecological dimensions of supply chain management and the creation of operations within defined organizational borders. We argue that socio-ecological intergradation in the supply chain can create and maintain resilient operations and ecosystems, or socio-ecological resilience. We define socio-ecological resilience as the ability of supply chains and their surrounding ecosystems to operate in harmony to adapt and thrive in the face of external stresses and disturbances to the natural or organizational environment (Adger, 2000; Pettit et al., 2010).

We apply socio-ecological intergradation as an umbrella construct that brings together five principles that we have distilled mainly from the natural and industrial ecology literature: *locality, steady state, gradualism, heterogeneity,* and *interdependence*. In a supply chain context, *locality* refers to a move toward more regionally bound operations (e.g., Howard-Grenville et al., 2014); *steady state* refers to the cyclicality and stability of its components (e.g., Ehrenfeld and Gertler, 1997); *gradualism* refers to deliberately slow and steady system change (e.g., Korhonen, 2001); *heterogeneity* refers to a variety of supply chain processes working together (e.g., Hunter and Price, 1992); and *interdependence* refers to the symbiotic relationship of these processes (e.g., Geyer and Jackson, 2004). We argue that the gradual merger of the social and ecological systems inherent in the theory can have a positive effect on socio-ecological resilience. We support our theory with practical examples such as vertical farms and eco-industrial development that go some way toward illustrating how the proposed principles can be used to achieve more sustainable operations.

The aim of this study is to extend knowledge relating to greener, more sustainable supply chain management and go some way in establishing a foundation for more theory building in this area (Sutton and Staw, 1995; Weick, 1995). The study's results contribute to the presently small body of research that challenges organizations' prevailing anthropocentric perspective, which is based on unlimited human progress and exuberant growth through the exploitation of nature (Catton Jr and Dunlap, 1978; Gladwin et al., 1995). Specifically, we explore the following research question: *What insights do natural ecosystems provide for guiding supply chain management toward a mutually beneficial intergradation with natural ecosystems that can create socio-ecological resilience?*

In addressing this question, we challenge the delineation between social and ecological systems (Berkes and Folke, 1998) and illustrate the significant potential of invoking nature as a source of ideas for redesigning supply chain processes. Our work thus fosters the creation of synergy and dialogue among three disciplines: sustainable supply chain management (including green supply chain management), business ethics, and industrial ecology (Jensen et al., 2011; Quarshie et al., 2016; Sarkis, 2003). We support our theory with illustrative examples of socio-ecological intergradation in practice. Vertical farms and other examples serve to show how the proposed principles can reshape supply chain systems to become more sustainable (Ehrenfeld and Gertler, 1997; Gruner et al., 2013). Socio-ecological intergradation holds the potential to create more resilient organizations (Carmeli and Markman, 2011) and mitigate forces that could eventually destroy the ecological resilience on which organizations ultimately depend for their survival. Addressing this question will help build the foundation for more cross-disciplinary business research and thereby put scholarship at the forefront of innovative sustainable development that stimulates organizational change and directs practice in a meaningful way (Pagell and Shevchenko, 2014).

We further propose that the judicious application of the outlined principles—where context will determine the importance of one principle over another—can help propagate managers' understanding of unsustainable aspects of their supply chains, and thus lead to more sustainably managed relationships within and between social and ecological systems.

This article proceeds as follows. In section 2, we provide a research background, in which we include definitions and assumptions that underlie our conceptual constructs and explore the literature on sustainable supply chain management and business ethics as well as industrial ecology. This section concludes with an overview of the theory-building approach. In section 3, we advance our conceptual development of socio-ecological intergradation and socio-ecological resilience, drawing mainly on the natural and industrial ecology literature to delineate the principles of socio-ecological intergradation. In section 4, we explicate the principles' relationships and outcomes, and follow with section 5 in which we provide examples of socio-ecological intergradation in practice. In section 6, we summarize the study's implications and again describe the practical application of our theory. We present future research avenues and concluding remarks in section 7.

2. Research background and theory development

2.1. Research domain and key definitions

The domain for our theory is sustainable development, which is typically defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 8). More specifically, the domain for our theory is sustainable organizational development in the context of supply chains within which organizations operate. At an abstract and generalizable level, supply chains can be defined as systems. Indeed, the earliest literature in the area comes directly from the control and systems literature (Forrester, 1961). Thus, to develop our theory, in line with other studies in this research area (e.g., Mentzer et al., 2001), we adopt a view of the supply chain as a system and define supply chains as integrated systems of trading partners. Scholars increasingly recognize that managers in supply chains and associated operations roles are particularly well positioned to influence sustainable development (Ashby et al., 2012). This influence is possible "through supplier selection and supplier development, modal and carrier selection, vehicle routing, location decisions, and packaging choices" (Carter and Easton, 2011, p. 47).

The two most commonly used terms used to describe sustainable development across trading partners are green supply chain management and sustainable supply chain management (for an overview of definitions used for both terms, we refer interested readers to Ahi and Searcy (2013)). Many authors use these terms interchangeably, but the definitions of green supply chain management are typically more narrowly focused on the environmental dimension than those of sustainable supply chain management (Ahi and Searcy, 2013; Malviya and Kant, 2016). Although our work too is focused on the environmental dimension, for the purposes of this paper, we use the more encompassing term sustainable supply chain management (which also captures green supply chain management), and adopt a representative definition of sustainable supply chain management as:

> "The creation of coordinated supply chains through the voluntary integration of economic, environmental, and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information, and capital flows associated with the procurement, production, and distribution of products or services in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over the short- and long-term (Ahi and Searcy, 2013, p. 339)."

We specifically acknowledge critical interactions across organizational and environmental system components (Liu et al., 2015) that aim to protect the resilience of supply chains and their supporting natural ecosystems. As mentioned, we refer to the resilience of supply chains and their supporting natural ecosystems as socio-ecological resilience.

2.2. Prior literature

2.2.1. Sustainable supply chain management

The literature on sustainability is vast and includes contributions from policy makers, practitioner literature (Lubin and Esty, 2010), and journals in both the natural and social sciences (e.g., Sovacool, 2014). An analysis through the Google Labs phrase-usage graphing tool n-grams (which has in its database over 5.2 million digitized books published between 1500 and 2008) confirms that the literature on sustainability has increased at a nearly exponential rate over the past four decades.[1]

The rapidly growing interest in sustainability is in line with sustainability research more specifically focused on the management of supply chains (Linton et al., 2007; Serrano et al., 2013; Seuring and Müller, 2008; Xing et al., 2016). In recent decades, sustainable supply chain management has been a popular topic not only within operations management but also within business ethics and related fields (Quarshie et al., 2016). Researchers in sustainable supply chain management have studied diverse issues, such as product design (Guide Jr et al., 2003a), sustainable supply chain integration (Wolf, 2011), governance mechanisms (Gimenez and Sierra, 2013), manufacturing strategy (Klassen and Whybark, 1999), hybrid decision making approaches (Malviya and Kant, 2016), and re-manufacturing (Guide Jr et al., 2003b).

A more detailed review of the literature on environmental sustainability and sustainable supply chain management is available elsewhere (Elliot, 2011; Gold et al., 2010; Hassini et al., 2012; Seuring and Müller, 2008). However, despite outstanding theoretical advances in this area, a number of important shortcomings remain. In the following section, we list the main shortcomings our theory aims to address. While scholars have previously identified many of these shortcomings, we primarily draw on Pagell and Shevchenko's (2014) review of the sustainable supply chain literature and their resulting summary of the main issues that future sustainable supply chain research should address.

First, current literature typically emphasizes retrospective methods and measures reflective of practice, yet fails to direct these in a meaningful way (Pagell and Shevchenko, 2014). Despite significant supply chain research progress, shifts toward more sustainable practices too often remain industry-led as empirical tools can stand in the way of creating more sustainable operating models. In particular, "quantitative empirical tools are more suited to what (is the relationship) type questions as opposed to how (to become sustainable) questions and will likely overlook those very supply chains that are most likely to be radically innovating" (Pagell and Shevchenko, 2014, p. 48).

The second shortcoming of much sustainable supply chain work is related to its limitation in exploring relationships between corporations' financial performance and their environmental and corporate social responsibility obligations (Pagell and Shevchenko, 2014). Many studies focus solely on the causal relationships between environmental and financial performance, asking questions such as whether it pays to be green (Golicic and Smith, 2013) or whether a form of sustainability exists that "even a CFO can love" (Kuehn and McIntire, 2014).

Third, most research on sustainable supply chains focuses on incremental standalone activities, such as ISO 14001 or environmental management systems that provide standards and guidance in material selection and design for development of sustainable products (Ljungberg, 2007). These activities can result in cost savings owing to reduced packaging and more effective design for reuse and recycling, as well as savings from more efficient transport, improved working conditions, and lower disposal costs (Carter and Rogers, 2008). Discussions of more proactive firm efforts that go beyond standalone incremental efforts to engage in environmentally sustainable behaviors are uncommon.

Finally, our planet is a system of complex interactions across various subsystems, but research typically isolates subsystems and thus fails to bridge the theory domains of supply chain management and ecology. However, linking understanding across organizational and natural disciplinary fields (i.e., the social and ecological dimensions) is essential to advancing theoretical knowledge (e.g., Ehrenfeld and Gertler, 1997). For instance, environmental footprints, the human–nature nexus, and planetary boundaries are all examples of influential integrated frameworks that have been developed and tested through interdisciplinary and

[1] To assess this growth rate we invite readers view https://books.google.com/ngrams (keyword: sustainability). We note, however, that the database contains only books and no records beyond 2008.

transdisciplinary inquiries (Liu et al., 2015).

As we show in the following sections, our theory combines ecological insights with what we know about supply chains to provide guidance in creating lasting change to firms' operating processes. In proposing this new theory of socio-ecological intergradation in the supply chain, we not only address the lack of interdisciplinary research and inquiry but also offer advice on how to adopt an innovative and potentially radical model of more local, sustainable operations that goes beyond the reduction of *un*sustainability (Ehrenfeld, 2005). We thus believe this theory makes a significant contribution to the wider sustainability agenda, particularly in light of "social, ecological, and technical change and uncertainty, highlighted by the wide-ranging effects of globalization processes and climate change" (Meerow and Newell, 2015, pp. 1–2). Next, we provide an overview of the industrial ecology field and its role in the development of our theory.

2.2.2. Industrial ecology

Natural ecology is typically concerned with the diversity, distribution, and number of organisms comprising a biological community, as well as the cooperation and competition between them. Ecosystems are regularly confronted with environmental disturbances—processes that remove biomass from a community—such as a fire, flood, drought, or predation (Grime, 1977). Thus, natural ecosystems have long developed strategies to evolve and survive, which can be relevant in considering notions of environmental sustainability and resilience. But while the science of ecology can lead to greater conservation of resources and wider environmental protection, this paper is specifically concerned with the metaphoric mimicry of natural ecosystems (Ehrenfeld, 2004; Korhonen, 2001). The importance of applying knowledge from biological systems to organizations (even though not explicitly applied to supply chains) is not new (e.g., Von Bertalanffy and Woodger, 1934). Specifically, the modeling of organizational processes on those observed within natural ecosystems—a field called industrial ecology—has provided a conceptual source for the sustainable development of businesses since the late 1980s (Ayres and Ayres, 2002; Ehrenfeld, 2004; Frosch and Gallopoulos, 1989; Graedel and Lifset, 2016; Sarkis, 2003).

From the early days of industrial ecology, companies have advocated an environmental ethic that goes beyond complying with regulations and extends to the adoption of initiatives in which industrial ecology serves as a new paradigm for process and product design (e.g., Ehrenfeld and Gertler, 1997). Examples of such initiatives are the simplification of product assembly and disassembly, designing for product recovery, and the recycling of components (Ehrenfeld and Gertler, 1997; Graedel and Lifset, 2016).

Despite industrial ecology's potential to bring about more sustainable organizational processes, scholars often lament its lack of progress, particularly in relation to its practical implementation. Some scholars claim that this lack of implementation occurs because natural ecosystems differ markedly from industrial ecosystems, and that biological ecology is thus unsuitable for informing greater sustainable industrial development (e.g., Ayres, 2004; McManus and Gibbs, 2008). Although "industrial ecosystems will never operate exactly as nature does" (Korhonen, 2001, p. 66), we argue that two other reasons are primarily responsible for the sketchy progress within the field of industrial ecology.

First, as in the previously outlined sustainable supply chain literature, scholars of industrial ecology often focus on developing less *un*sustainable operations (Ehrenfeld, 2005; Fiksel, 2006). The roots of unsustainability are often too deeply ingrained in business operations (particularly global supply chains), leading to a focus on treating the undesirable symptoms of these operations rather than changing their underlying structure. Second, the industrial ecology literature typically over-emphasizes the shifting of industrial systems from a linear model to a closed-loop model that resembles the cyclical flows of natural ecosystems (e.g., Gibbs, 2003). While the circular recycling of resources—including the efficient use of waste—is a crucial part of our model, in developing socio-ecological intergradation we look beyond this closed-loop characteristic of natural ecosystems to learn about and adopt other elements. We argue that rather than the field of industrial ecology per se, it is the theoretical work based on industrial ecology that is presently limited in offering practical guidance toward a more sustainable future of businesses. We therefore rely on industrial ecology as a basis for the development of our theory of socio-ecological intergradation. As mentioned, in developing our theory, we draw on and simultaneously consider the literature pertaining to natural and industrial ecology as well as the mentioned sustainable supply chain work.

2.3. The theory development process

The goal of our conceptual theory building is to generate theory. Theory has been defined as connections or relationships among phenomena, and good theory explains the nature of causal relationships (Sutton and Staw, 1995). "Conceptual theory building uses existing theory, literature and other data sources to both inductively and deductively advance the understanding of a particular phenomenon" (Ellram et al., 2013, p. 30). Conceptual theory building typically does not result in a fully developed theory such as game theory, agency theory, or social capital theory. Instead, theory typically unfolds as a process rather than appearing as a fully developed product, and serves a means for further development (Weick, 1995). This research is no exception.

Our goal is to develop a new theory of socio-ecological intergradation that provides managers with guidance in mimicking natural ecosystems to develop more local and sustainable supply chains. To achieve this goal, we have (1) limited and defined our theory-building domain, (2) identified shortcomings in current theory and knowledge, and (3) defined constructs and explained their relationships and predictions (Carter and Easton, 2011; Ellram et al., 2013). In adopting this approach, we have followed a strong scholarly tradition of theory building in operations and supply chain management research (e.g., Ketchen Jr and Hult, 2011).

3. Conceptual development: socio-ecological intergradation

The main purpose of this section is to provide an overview of what socio-ecological intergradation means, and how its five principles were distilled.

3.1. Socio-ecological intergradation in supply chains

We define socio-ecological intergradation as supply chain processes that not only mimic natural ecosystems but merge the social and ecological systems of supply chain management to create operations within defined organizational borders. Socio-ecological intergradation brings together the outlined principles of natural and industrial ecology and seeks to advance supply chain theory and integrate supply chain operations with the biophysical world (Frosch, 1992; Gladwin, 1993; Starkey and Crane, 2003; Stead and Stead, 1992).

In this study, we define a supply chain as an integrated system of trading partners. Problematically, each trading partner is motivated by its own set of organizational goals, such as cost savings, efficiencies, and growth rates (Gunasekaran et al., 2004). Moreover, managers often view themselves as autonomous and isolated, operating in environments where self-interest prevails and where their main responsibility is to maximize profits for *their* firm (Power and Gruner, 2016). However, if a supply chain is a true system, then interdependence, continuity, and shared destinies of the components comprising the system could lead to synergistic effects and multifaceted benefits, even if each component continues to have its own goals and divergent objectives exist. To achieve a true supply chain system, intergradation of the processes, functions, and objectives of the organizations within the wider system is paramount. We propose socio-ecological intergradation in the supply chain as a theory that can help managers achieve such intergradation, hence overcoming the conceptual division and disassociation between organizations and the natural world (Gladwin et al., 1995).

Drawing on our literature review, we distill five socio-ecological intergradation principles in the supply chain: *locality, steady state, gradualism, heterogeneity,* and *interdependence*. A full account of the research procedures used in identifying the five principles is provided in the Appendix. In step 1, we identified 20 ecological principles from an analysis of the literature mainly pertaining to industrial and natural ecology. Principles of natural ecology were only included in this initial set of dimensions if they were potentially relevant and applicable beyond natural ecological systems. The briefly described principles pertaining to supply chain management and the view of supply chains as systems guided this selection process. These principles include characteristics of interdependence, cooperation, continuity, and shared destinies of diverse components; these supply chain principles have been previously captured and summarized (e.g., Mentzer et al., 2001). Additional guidance in the selection of socio-ecological principles stems from the reviewed supply chain literature in the context of sustainable organizational development, and our adopted definition of sustainable supply chain management (e.g., Ahi and Searcy, 2013). In step 2, multiple discussion rounds among the authors (and another review specifically of the sustainable supply chain literature) led to the exclusion of all but six principles. Following step 3—namely two semi-structured discussion rounds with six managers each—only five principles remained. In selecting these managers, three main criteria were applied. First, we exclusively sought managers with supply chain responsibilities or who had generalist backgrounds. Second, to add external validity, we ensured that the sample of six managers included a broad spectrum of product lines (Choi and Hong, 2002). Third, to increase the internal validity of our model, we made sure that the majority of managers work at manufacturing firms, while their engagement in different industries (e.g., media, construction, and electronics) enhanced generalizability.

The socio-ecological principles identified in step 1 formed the basis of the steps that followed, including the development of a research protocol. While the 20 socio-ecological principles provided sufficient structure for the discussion rounds among the authors (step 2), a research protocol was useful in provided some structure and guidance for the two discussion rounds between the authors and managers (step 3). In addition to the 20 socio-ecological principles and explanations thereof, this protocol outlined some of the questions that we asked to engage managers in a discussion. Following Voss et al. (2002), we started with broad questions such as whether managers had ever used (or thought of using) ecological principles or biomimicry in their day-to-day operations.

All three steps were conducted by two researchers to add reliability or reproducibility, which represents a distinguishing characteristic of a content analysis (Kassarjian, 1977). While inter-judge reliability between the authors was high, the complex nature of the task led to difficulty in calculating an accurate coefficient of reliability. However, we individually accessed and resolved different judgments and are confident that reliability lies above the 90th percentile (Kassarjian, 1977). Primary reasons for the exclusion of principles were (1) the principle is to a large extent already captured through a different principle; (2) the principle describes consequences (results) rather than the nature and features of ecosystems; and (3) the principle is not suited for the description of a social phenomenon such as organizational behavior and thus is not useful to describe *socio*-ecological intergradation.

3.2. Underlying ecosystem principles from a systems perspective

Table 1 presents an overview of the principles underpinning socio-ecological intergradation in supply chains, including a comparison with biological ecosystems and examples of each principle in action in both supply chains and natural ecosystems. The main limitations of each principle are also listed.

Although the outlined principles overlap at points, collectively, they help define the concept of socio-ecological intergradation. The principles are inter-related and inter-dependent and can reinforce one another, such that in combination they provide the blueprint for a sustainable supply chain. However, whether supply chains can adopt socio-ecological intergradation depends on an understanding of these principles and how they operate in concert. In developing this intergradation, we have simplified and reduced the complex and nuanced processes and principles that make up natural ecosystems, so as to create a theory that through future research efforts can be operationalized, tested, and falsified, as good theory depends on the possibility of refutation (Popper, 1957; Wacker, 1998).

Socio-ecological intergradation requires rethinking conventional supply chain wisdom by boosting the efficiency of the system as a whole rather than reducing the cost and inefficiencies of each part and process (Haanaes et al., 2013). This notion is at the very core of how socio-ecological intergradation functions and aligns with systems thinking, which has long been one of the underlying paradigms within industrial ecology. As systems theory concerns the way organizations exchange resources (Mingers and White, 2010), systems thinking is not only a logical outgrowth of isolated sustainability practices prevalent across organizations, but is also important to the development of a more holistic understanding of socio-ecological intergradation's principles and how they operate together.

Complex systems, such as global supply chains, comprise many interdependent flows, stocks, and processes. If we throw natural ecosystems into the mix, the result is too many variables and dependencies for managers to process, which can lead to confusion and suboptimal decision-making based on readily available but incomplete information. Further, the self-centric need to strive for business growth can obstruct the planned development of networked, interacting, industrial ecosystems, particularly on a global scale (Jensen et al., 2011). However, under socio-ecological intergradation, managers can deconstruct and separate complex supply chain systems into smaller local systems to explore these in their own right and specificities and understand how they work together, and then integrate those systems into a simplified whole (Von Bertalanffy, 1972).

Deconstructing and separating complex supply chain systems into smaller local systems is possible because socio-ecological intergradation simplifies and homeostatically balances and contains the processes occurring in a supply chain—creating a limited, more manageable local system ("locality"). Technological infrastructure often resides at the core of this self-contained system, leading to the redesign of operational processes that produce closed-loop cycles where waste becomes both output and input ("steady state"). In systems theory, a system in a steady state has

Table 1
Overview of socio-ecological intergradation principles.

Description	Natural ecosystem	Supply chain	Limitation
Locality			
Locality refers to local, decentralized industrial systems that resemble natural (regionally bound) ecosystems. Locality represents a shift away from traditional industrial systems that aim to substitute the local natural limiting factors, for instance of energy with imported fossil fuels. This factor acknowledges that ecosystems need to respect the local natural limiting factors (Wackernagel and Rees, 1997). Locality is part of the socio-ecological intergradation's steady state status with industrial processes resembling more self-sustainable closed-loop systems with fewer operations happening outside a specified area.	In natural ecosystems, locality refers to an area where groups of organisms experience similar conditions. Locality makes the energy transfer of these groups of organisms possible. Organisms naturally live together and adapt to the immediate nearby environment. It thus recognizes the importance of organisms' cooperation with their surroundings in diverse interdependent relationships (Korhonen, 2001). Indeed, natural ecosystems "maintain their identity throughout environmental storms and travails, so they can remain and evolve, in place" (Benyus, 1997, p. 274).	Supply chains that follow the locality principle replace imported resources with local renewables and local waste material where possible (Zhu and Cote, 2004). The entire industrial system would adapt to the local natural limiting factors. As a result, transportation would be reduced and cooperation with regional actors enhanced. "Rather than moving raw materials and finished goods long distances, companies may seek to produce closer to the point of consumption, for example" (Howard-Grenville et al., 2014, p. 619). Farmers' markets and advances in 3-D printing are examples of locality in action.	Despite geographical constraints inherent in local systems, the locality principle does not imply that supply chains need to be completely contained. In fact, it is difficult to clearly establish what local means because "ecosystems grade into one another and are nested within a matrix of larger ecosystems" (Szaro et al., 1998, p. 2). Similarly, most supply chains have both global and local elements. For example, even predominantly local operating models will likely access global information networks such as the Internet.
Steady state			
Steady state refers to a shift from linear industrial systems to cyclical systems that resemble the flow of natural ecosystems (Bakshi and Fiksel, 2003). An important part of socio-ecological intergradation is its focus on employing innovations to integrate operational processes into a self-reinforcing steady state condition. Steady state systems are closed-loop practices with little or no waste that cannot function as input for new processes (Xing et al., 2016). In other words, steady state describes a dynamic stability of operational processes that naturally minimize wasteful output. This principle also captures the notion that businesses do not have to grow indefinitely to be successful.	Most natural ecosystems are at a steady state, with exceptions usually due to anthropogenic influences. Growth and expansion are largely human concepts. For example, predators like lions have no interest in hunting more prey than they need for sustenance. In natural ecosystems, steady state can be described as a dynamic balance. For example, negative feedback associated with food scarcity can constrain changes in the population size of a species (Chapin III et al., 1996). The populations of the individual species rise and fall, but balance within the system is usually not in danger.	Most supply chains rely on high rates of productivity and growth stemming from a linear stream of materials that quickly move from manufactured item to waste. Supply chains that follow the steady state principle operate in a more cyclical manner. For instance, the operations increase their reliance on renewable resources and allow for feeding waste materials back into the system (recycling of matter/asset recovery) (Korhonen, 2001). As an example, companies are clustered in eco-industrial parks, where clusters of firms minimize entropy through the symbiotic exchange of waste and energy (Ehrenfeld and Gertler, 1997). If one trading partner drops out of these steady state systems, there is usually a backup, allowing the supply chain to stay whole.	Despite the stability inherent in steady state systems, the principle accepts temporal and spatial variations as a normal aspect of ecosystems (natural and industrial). Change is integral to most systems. Bushfires, for instance, are nature's way of managing overgrowth. Similarly, organizations change even when they are at a steady state; no organization or supply chain forever remains the same. Further, not every product or component can be recycled. In natural ecosystems, only nutrients and minerals can be circulated; energy cannot. Energy is converted to heat (the second law of thermodynamics) and is thus unavailable to do more work.
Gradualism			
Gradualism refers to industrial systems' slow and steady rate of change. An important part of socio-ecological intergradation is that variation is gradual in nature. This aspect is comparable to incrementalism—a method that promotes many small and sometimes unplanned changes instead of a few large jumps (Quinn, 1978). Socio-ecological intergradation shifts industrial processes that constantly and rapidly change and innovate to more stable and only gradually moving ones. For instance, when annual yield is lower than annual growth, systems can live off of interest rather than non-renewable capital (Korhonen, 2001).	In natural ecosystems, gradualism holds that profound change is the cumulative product of slow but continuous processes, often contrasted with catastrophism, saltations, and extreme deviations. "Many natural ecosystems are self-sustaining, maintaining a characteristic mosaic of vegetation types for hundreds to thousands of years" (Chapin III et al., 1996, p. 1016). Ecosystems are resilient because their flow rates are slow, allowing all parts in an ecosystem to adapt as the environment changes.	Supply chain managers are usually interested in speeding up processes and increasing the throughput of materials. Gradualism slows down these processes, which could yield higher quality products, significantly reduce waste, and use up no more energy resources than can be restored. In the forest industry, this principle is captured through the notion of sustained yield—only what has grown in any given year is harvested in that year (Korhonen, 2001). Thus, gradualism can be interpreted as increasing the reliance on renewable resources flow.	In systems, change can be abrupt and at times unavoidable. Mergers are an example of such change in an industrial system. Natural disasters, on the other hand, are an example of such change in a natural ecosystem. However, natural systems typically respect the renewal rate of the immediate environment they depend on. This characteristic contrasts with supply chains where, for instance, a rapid increase in demand for a certain product can lead to the depletion of the natural resource required for its production.
Heterogeneity			
Heterogeneity is a characteristic of a population exhibiting a variety of dissimilar elements or parts. It can be used to describe a shift in industrial systems. This diversity pertains to both firms' output (produce) and different operational processes. In natural ecosystems, the benefits of heterogeneity are related to every organism (biotic and abiotic) having a unique purpose and role to play (Hunter and Price, 1992). This diversity does not typically stem	In natural ecosystems, heterogeneity refers to accommodating many different organisms present in various ecosystems. Nature is inherently diverse; it would struggle to sustain life otherwise. While inert uniformity (the absence of heterogeneity) can be found in nature, an exploration of these cases helps underline the importance of heterogeneity. Deserts, for instance, lack ecological diversity (they receive an abundance of solar energy), but are capable of supporting little life	Traditional supply chains often seek to maximize profits without regard for the interactions among various subsystems (including trading partners). Heterogeneous companies acknowledge, actively support, and link these interactions. A network of companies in Denmark exemplifies this principle: "[this industrial ecosystem] consists of a power plant, an enzyme plant, a refinery, a chemical plant, a cement plant, a wallboard plant, and some farms. These plants use one	Heterogeneity is relative rather than absolute. In natural ecosystems, it can refer to the number of species and/or their interactions within their own or other ecosystems. Similarly, in a supply chain context, heterogeneity is a broad concept pertaining to both operations and products. Further, heterogeneity is rarely evenly distributed and differs from system to system. Supply chains in different industries and countries will face varying abilities and opportunities

Table 1 (*continued*)

Description	Natural ecosystem	Supply chain	Limitation
from more global operations, but often from diversity within (local) businesses and/or their produce (Levin, 1998).	compared to more heterogeneous ecosystems such as the Amazon rainforest.	another's wastes and by-products as raw materials" (Shrivastava, 1995, p. 128). Heterogeneous firms also avoid product homogenization (aimed at creating operational efficiencies).	to diversify, especially within regionally constrained boundaries.
Interdependence			
Interdependence refers to a shift from largely independent, opportunistic business relationships to more symbiotic, collaborating ones (Zhu and Cote, 2004). Interdependent systems have supportive operations that emphasize connectivity within and between systems including the natural environment. This principle captures systems' inherent cooperation stemming from diverse interdependent relationships (Korhonen, 2001). Socio-ecological intergradation consists of highly interactive, interdependent processes and agents arranged in a purposeful way. "The exchange of wastes and by-products among closely situated firms" (Ehrenfeld and Gertler, 1997, p. 67) is an example of this principle.	Natural ecosystems are inherently interdependent, as nature recognizes that each system is an integrated whole while also being part of larger systems. Changes within a system can affect other systems and vice versa. Also, each organism contributes to the life, maintenance, and sustenance of the whole system. Within interdependent systems, the output of one process becomes input for others. The wastes of one species provide resources for other species. For example, plants absorb carbon dioxide and give off oxygen, while animals do the opposite. The mutually beneficial nature of such interdependent relationships leads to many synergistic effects within natural ecosystems.	Where relationships are strong and systems are complex (as in ecological but also economic systems such as supply chains), ignoring interdependencies can have critical consequences. Interdependence captures supply chains' cooperative approach and ability to recycle and reuse materials (Geyer and Jackson, 2004). Interdependence in the supply chain requires feedback links not only between entities within a supply chain but also between firms and their environments. Current *modi operandi* rarely acknowledge this interdependence. Most firms' KPIs typically ring positive when organizations use up many resources without considering interdependencies (in this case exhibited as environmental and/or social costs).	Despite being interdependent, natural and ecological systems are inherently competitive. However, this competition should not extend to the environment. The environment should be protected, possibly in a joint effort between otherwise competing organizations or supply chains. For example, some manufacturers cooperate in the design phase of their product development: in their vehicle recycling partnership, Chrysler, Ford, and General Motors "put aside their normally fierce competition to develop common labeling and material standards which will allow them to reuse each other's parts" (Benyus, 1997, p. 260) and created significant sustainable efficiencies.

properties that are largely stable and unperturbed over time ("gradualism") (Von Bertalanffy, 1972). This stability means that for those properties p of the system, the partial derivative with respect to time is:

$$0 < \delta p/\delta t < 1$$

As each partial system and process consists of potentially unlimited variety, the purpose of socio-ecological intergradation is to tap that variety ("heterogeneity"). Once tapped, the variety must be organized, selected, and integrated to significantly decrease the system's complexity and ultimately lower the environmental impact of supply chain operations from extraction of raw materials to eventual disposal or deposit into landfill, typically measured through a life cycle assessment (Matos and Hall, 2007; Xing et al., 2016). Highly integrated localized operations also foster a sense of community, collaboration, and rootedness among interdependent agents in ecosystems ("interdependence") that creates socio-ecological resilience. Socio-ecological intergradation takes into account spillover effects of supply chain activities on both socio-economic and environmental effects and considers all components of its larger system. Although other studies (in particular, those specifically concerned with green supply chain management) have previously suggested a more synergetic and integrated approach between trading partners to improve firms' waste reduction and operational efficiencies (e.g., Malviya and Kant, 2016; Xing et al., 2016; Zhu and Cote, 2004), our work differs from these in that we propose more sustainable *modi operandi* based on a combination of the outlined socio-ecological principles.

4. Socio-ecological intergradation and its outcomes

Sustainability depends on supply chain partners' ability to operate in harmony with one another and their ecosystems, and to resist and respond to internal and external disturbances over time (Ahi and Searcy, 2013). We refer to this ability as socio-ecological resilience. Resilience is a cornerstone notion in ecosystem management and is a key concept in systems thinking, equally applicable to the natural and social sciences (Blewitt, 2009; Fiksel, 2006). Supply chains and natural ecosystems are complex and will accommodate significant disturbance, but with limits and thresholds.

> A threshold may arrive when one relatively stable state, or regime, flips into another. In social-ecological systems [like a supply chain] resilience will inevitably be the product of human agency, of individual and institutional leadership, of the capacity to remember past mistakes and not repeat them (Blewitt, 2009, p. 57).

Socio-ecological intergradation increases these thresholds, and therefore exhibits a positive effect on socio-ecological resilience.

To date, most supply chains remain unsustainable, dependent on external partners and lacking in socio-ecological resilience (Pagell and Shevchenko, 2014). Although some organizations have begun to not only meet but exceed the environmental requirements of government regulations (Christmann, 2004)—a phenomenon that has been shown to extend to low-regulation countries in global supply chains (Christmann and Taylor, 2001)—the development of theory on proactive corporate strategy for managing the business–natural environment interface remains largely missing (Aragon-Correa and Sharma, 2003). Further, various supply chain scholars have unwittingly contributed to a loss of socio-ecological resilience by exploring only parts of systems (both natural and supply chain) and dealing with "experiments that narrow uncertainty to the point of acceptance by peers; [the results are] conservative and unambiguous by being incomplete and fragmentary" (Gunderson, 2000, p. 433). Through the conceptual development of socio-ecological intergradation, we enter new theoretical ground that is more integrative and holistic, allowing for simple structures and relationships that explain much of the complexity of both nature and the supply chain. In this development, we lay the theoretical foundations for a proactive corporate strategy aimed at managing the business–natural environment interface.

Although socio-ecological intergradation is based on long-term durability and resilience, ecosystems are complex adaptive systems that partially maintain a relationship among system components in equilibrium (Fiksel, 2006; Folke et al., 2005). We challenge the notion that change necessarily leads to rapid system decay exemplified through stages of collapse or release inherent, as for instance in the theory of the adaptive cycle (Gunderson and Holling, 2001), or that such dramatic perturbations are natural and inevitable.

The local supply chain processes of socio-ecological intergradation can significantly reduce the carbon footprint of distribution- and logistics-related activities. For instance, fewer ships transporting produce from overseas means using less fuel and reducing the amount of refrigeration needed for transported produce. Socio-ecological intergradation can also support manufacturing in a way that can be maintained virtually indefinitely, leading to sustainability-related improvements across a firm's entire value chain. Socio-ecological intergradation includes the creation of structures with resources that enhance community well-being and a decreased dependence on external inputs, technology, and markets by drawing on local expertise and raw materials, which can significantly reduce (but not eliminate) management's need to continually modify policies and operations to new situations.

Importantly, we do not suggest that organizations undertake socio-ecological intergradation exclusively in pursuit of socio-ecological resilience, which is associated with myriad environmental goals. Although not the focus of our work, building the operational capabilities necessary for socio-ecological intergradation could also increase the value, rarity, inimitability, and non-substitutability of resources (Barney, 1991), improving a firm's resource base and translating into operational capital.

In the main, global supply chains are more complex to manage than local ones (MacCarthy and Atthirawong, 2003). Substantial geographical distance between trading partners not only increases transportation costs but also "complicates decisions because of inventory cost tradeoffs due to increased lead-time in the supply chain" (Meixell and Gargeya, 2005, p. 533). Globally dispersed supply chains also lead to uncertainty related to currency exchange rates, economic and political instability, and changes in the regulatory environment, posing significant risks that can offset advantages such as tariff and trade concessions or low-cost labor. In addition, global supply chains tend to exhibit a social or cultural distance among supply chain partners. "These proximal, social, and cultural dissociations create problems of firms communicating one another's environmentally focused supply requirements, and thus the conditions for high information asymmetry and possible opportunism exist" (Sarkis et al., 2011, p. 6).

We propose that, in the long term, the outlined disadvantages pertaining to global supply chains—such as information asymmetry, opportunism, environmental footprints, and compliance issues related to implementing codes of conduct—can be significantly reduced through the adoption of socio-ecological intergradation. As proponents of the resource-based view argue, "competitive advantage results from those resources and capabilities that are owned and controlled by a single firm" (Dyer and Singh, 1998, p. 660). The idiosyncratic inter-firm linkages formed under socio-ecological intergradation may also represent a source of relational rents and competitive advantage.

Competitive advantages are not limited to the upstream (supplier management) stages of the supply chain but are also found in the downstream (customer) stages. Indeed, improvement of reputation and image (considered another significant resource) goes hand in hand with the environmental and even social benefits of socio-ecological intergradation and likely constitutes a significant unique selling proposition of socio-ecological intergradation-produced goods (Barney, 1991). Consumers are increasingly interested in the working conditions under which products are manufactured and transported (Carter and Rogers, 2008). How materials are created is no longer "a matter of indifference to the customers," as claimed in seminal work on how sustainable growth depends on gauging customers' needs (Levitt, 1960, p. 13). Consumers' interest in production methods is illustrated by widespread negative reactions to genetically modified food and largely positive reactions to locally produced food, which is perceived as safe, pure, and natural (Edwards-Jones et al., 2008). Organizations that create and deliver customer value through more sustainable product offerings could benefit considerably. Further, as restructuring or building a supply chain based on socio-ecological intergradation is a complex undertaking that is difficult to imitate and thus consistent with the resource-based view, it is likely to generate sustainable performance improvements.

On the basis of what we have theorized about the nature and outcomes of socio-ecological intergradation, we put forth the following proposition:

> **Fundamental proposition:** socio-ecological intergradation in the supply chain is based on an interplay of five socio-ecological principles—locality, steady state, gradualism, heterogeneity, and interdependence—which together can create conditions conducive to socio-ecologically resilient supply chains.

5. Socio-ecological intergradation in practice

In this section, we provide examples of socio-ecological intergradation in practice. We also explain why organizational adoption of socio-ecological intergradation will vary from firm to firm, and how consequently socio-ecological intergradation can emerge in hybrid forms.

5.1. Socio-ecological intergradation in an agricultural context

A number of examples illustrate successful systems intergradation. Table 1 offers traditional supply chain examples, and Table 2 provides an instance of socio-ecological intergradation in a farming context. Because agriculture plays a crucial role in the development of any economy, it is an important context to consider in addition to more traditional manufacturing. While farming has been touted as the backbone of a socially and economically stable nation, providing food and employment to many people (World Employment Report, 2004–05), scholars also blame unsustainable, profit-driven agricultural supply chains for much of the past and current environmental and social degradation (e.g., Goodland, 1997). Monocultures disturb natural soil processes such as nutrient cycling—the release and uptake of nutrients in various crops. As the environmental consequences of traditional farming mount, they challenge our ability to continue producing and transporting food for increasing urban populations (Hamprecht et al., 2005). In Table 2, we thus outline what an alternative food supply chain based on socio-ecological intergradation might look like. Using the example of vertical farms, we illustrate how the various socio-ecological intergradation principles can work together to achieve socio-ecological resilience in the supply chain.

Vertical farming is the practice of cultivating food within a skyscraper greenhouse or on vertically inclined surfaces. Vertical farms have been promoted as the future of urban cultivation, integrating innovative indoor farming techniques with sustainable architecture (Despommier, 2010). "These farming skyscrapers are local, self-sustained supply chains that produce high-quality goods at minimal social and environmental costs" (Gruner et al., 2013, p. 24). Food is produced year round "using significantly less water, producing little waste, with less risk of infectious diseases, and no

Table 2
Socio-ecological intergradation principles in vertical farms.

Locality	
In line with this socio-ecological intergradation principle, vertical farms represent a shift away from traditional farming systems, which require vast tracts of land, and a move toward local, bio-regionally bounded ecosystems. Vertical farms stack multiple farm levels in a single location (a building) where all stages of the production process take place. Unlike more traditional farming, this business model respects local natural limiting factors and resembles more self-sustaining closed-loop systems. The regional focus of these organizations usually results in a 40–50% reduction in wasted crops owing to less transport, as well as minimal CO_2 emissions and very little destruction of hardwood forests (Despommier, 2010).	
Steady state	
In line with this socio-ecological intergradation principle, vertical farms operate not in a linear fashion but in a cyclical manner that resembles the flow of natural ecosystems (Bakshi and Fiksel, 2003). Vertical farms employ innovations such as hydroponics and solar technology to integrate operational processes into a self-reinforcing steady state condition. As a result, waste is minimal: inputs become outputs and vice versa. Green waste is used either as a fertilizer or to produce biomass fuel. Gray water is also recycled. Additionally, cultivations are not soil-based, but are hydroponic, aeroponic, or aquaponic. No topsoil is eroded, leading to largely self-sufficient systems (Despommier, 2010). In addition to reducing waste, steady state operations allow for year-round production.	
Gradualism	
In line with this socio-ecological intergradation principle, vertical farms seek to create steady state systems that do not require change and growth for success. While change will continue to occur—especially in the technology that supports production processes—variation in the business itself is gradual. Variation is limited by the regionally bound business model, where foods are both produced and sold locally, typically to nearby urban populations. Vertical farms are entirely self-sufficient and respectful of the renewal rate of the ecosystem, which further regulates their growth. Waste emissions do not exceed natural assimilative capacity, and harvest rates for renewable resources do not exceed natural regeneration rates (Costanza and Daly, 1992). For example, solar energy may be harnessed in an increasingly efficient manner, but the input of energy remains consistent unless it is supplemented with energy from non-renewable sources.	
Heterogeneity	
In line with this socio-ecological intergradation principle, vertical farms exhibit a variety of dissimilar elements within their local operations. While the operational processes sustaining vertical farms are more heterogeneous than other traditional local businesses, vertical farms work as a cohesive whole, potentially leaving a lot of land and soil untouched, which facilitates recovery of natural ecosystems and an increase in biodiversity (Gruner et al., 2013). However, the innovations inherent in vertical farms (such as hydro- and aeroponics) remain limited in their ability to lead to true heterogeneity in the output they generate. To date, vertical farms have been used mainly to produce leafy greens rather than more diverse plants and possibly even animals.	
Interdependence	
In line with this socio-ecological intergradation principle, vertical farms depend on highly interactive, interdependent processes and agents located within a skyscraper greenhouse, with every operational process closely and immediately linked to the next. Involved parties are typically acutely aware of the relationships between processes, leading to a highly ordered and connected system that optimizes the use of natural capacities for resources, energy, and markets. Vertical farms illustrate how innovations can lead to integration of production and distribution processes that goes beyond supporting the technical goals of generic systems, as is typically the case in the business and sustainability literature (Elliot, 2011).	

need for fossil-fueled machinery or transport from distant rural farms" (Despommier, 2009, p. 82). This innovative model for producing food offers a more sustainable alternative to the complexities inherent in global food supply chains, in which products often originate from far away even if they are also produced locally (Ferrão and Fernández, 2013). Many benefits from vertical farms flow from the adoption of socio-ecological intergradation principles. Vertical farms are well suited to the application of socio-ecological intergradation principles; however, as we illustrate next, some organizations may not be able to integrate subsystems locally to the same extent as vertical farms.

5.2. *Socio-ecological intergradation in hybrid operations*

Socio-ecological intergradation does not inform industrial development in an all-encompassing way, nor are its principles normatively applicable across firms and industries. The principles of socio-ecological intergradation are not universally applicable mainly because of the idiosyncrasies inherent within organizations and their supply chains. Even within the field of natural ecology, many scholars admit that they have only begun to scratch the surface, and many disagree that principles exist that apply to *every* organism or system (Jensen et al., 2011).[2] For example, the characteristics of vertical farms facilitate their deconstruction and the separation of the supply chain system into smaller subsystems that can be integrated into a simplified, more regionally bound sustainable whole. Similarly, companies clustered in eco-industrial parks illustrate socio-ecological intergradation in practice. In eco-industrial parks, "wastes from one process typically serve as materials for other processes or are recycled for further production, mimicking food webs in natural systems" (Gibbs, 2003, p. 224). An often-cited example of a particularly environmentally efficient industrial park is Denmark's Kalundborg industrial system (Ehrenfeld and Gertler, 1997). At Kalundborg, highly cooperating industrial facilities (illustrating "interdependence") are located in close proximity (illustrating "locality") to generate stable systems of closed-loop material and energy flows (illustrating "steady state"). However, organizations that rely on more globally dispersed and centralized operations may not be able to integrate subsystems locally to the same extent, and even vertical farms and eco-industrial parks rely heavily on technology that is sourced globally, at least in the set-up stages.

Consequently, there is a growing trend toward the adoption of socio-ecological intergradation even if operations only follow a select few of its principles. For example, global corporations such as Ikea increasingly build long-term relationships with fewer, more local suppliers (aligned with "locality" and "interdependence") rather than engaging in short-term relationships with companies spread across the world, where the focus is on reducing costs to obtain operational rather than sustainable efficiencies (Andersen and Skjoett-Larsen, 2009). Similarly, to counter instability and become more socio-ecologically resilient, Wal-Mart has decided to move much of its supply chain infrastructure in-house (Ellram et al., 2013). Other examples include Hewlett–Packard, IBM, Xerox, and Digital Equipment Corporation who have "introduced initiatives for greening their supply chains including the integration of suppliers, distributors, and reclamation facilities" (Sarkis, 2003, p. 398). This integration is aligned with some but not all principles of socio-ecological intergradation ("interdependence", "locality", and "steady state").

Microbreweries also follow some socio-ecological intergradation principles (mainly "locality"). In contrast to multinational breweries, which tend to depend on global distribution and sales, microbreweries typically use local raw material to produce a small amount of beer that is sold close to the point of production. Nonetheless, they often fail to operate in a cyclical fashion, where

[2] Jørgensen's (2002) discussion of universal ecosystem processes and properties is a noteworthy exception.

outputs become inputs (thus falling short of following "steady state").

The extent to which socio-ecological intergradation can be adopted also depends on a firm's willingness and ability to adopt information and communication technologies—including cloud computing, collaborative communication, and the Internet of Things (Xing et al., 2016). In particular, trading partners in developing countries may not always have the means and expertise to adopt technologically advanced socio-ecological intergraded businesses. In such cases, firms will likely adopt socio-ecological intergradation to different degrees and pursue hybrid models between the extremes of full ecological intergradation and none at all. Further, although (information) technologies often reside at the core of socio-ecological intergraded operational processes, it is not a prerequisite. For example, seaweed farms on China's Fujian coast produce 12 million tons of food a year without much human activity, or any technology while still following most socio-ecological intergradation principles (National Geographic June 2014).

6. Discussion and implications

We have argued that despite widespread consensus that organizations need to embrace sustainable practices, few existing theoretical frameworks guide practice in this direction. In contrast, we have applied the principles of ecology to industrial systems in line with research on industrial ecology (e.g., Korhonen, 2005), and have focused specifically on bridging supply chain theory and the biophysical world (Gladwin, 1993; Stead and Stead, 1992) to propose a new theory: socio-ecological intergradation in the supply chain.

A number of theoretical and practical implications emerge from this theory. First, our aim in this article has been to augment the small pool of studies that question organizations' human-centric perspective that progress depends on the exploitation of nature (Catton Jr and Dunlap, 1978; Gladwin et al., 1995). Instead, through the development of socio-ecological intergradation, we challenge the delineation between social (organizational) and ecological (environmental) systems (Berkes and Folke, 1998) and illustrate the significant potential of invoking nature as a source of ideas for redesigning operational processes. Such reconfiguration efforts differ significantly from more traditional isolated sustainability initiatives. For example, life cycle assessment measures only the level of environmental damage caused, where closed-loop initiatives and similar effort to achieve a greener supply chain often ignore fruitful natural ecological principles beyond locality and steady state (see Ehrenfeld and Gertler, 1997; Guide Jr et al., 2003a; Xing et al., 2016). We contend that knowledge of a combination of ecological principles (and about how they inter-relate and reinforce each other) can lead to more radical new operating models rather than isolated initiatives.

We show that natural ecosystems can guide thinking and create understanding. We have used this insight to build new theory aimed at optimizing businesses through more sustainably designed and managed supply chains. In developing the socio-ecological intergradation theory, we show the relationships and similarities between supply chains and natural ecosystems and illustrate how empirically useful theory can be derived from these insights. Socio-ecological intergradation not only mimics natural ecosystems but also protects ecosystem services for organizational development, which has increasingly become vulnerable to change and no longer can be taken for granted. In building our theory, we respond to calls for the creation of synergy and dialogue between the fields of sustainable supply chain management, business ethics, and industrial ecology (Jensen et al., 2011; Quarshie et al., 2016).

A second implication relates to closing the gap between sustainable supply chain practices' desirability and their implementation (Andersen and Skjoett-Larsen, 2009). Our work helps managers shift the overriding objective of the supply chain from operational efficiency to sustainable effectiveness. For instance, socio-ecological intergradation challenges conventional wisdom about the benefits organizations derive from globalizing their operations. Instead, socio-ecological intergradation reflects the merits of developing integrated, regionally bound supply chain operations over choosing trading partners and supply chain processes on the basis of operational efficiencies, with environmental considerations being little more than an afterthought (Ferrão and Fernández, 2013).

A third and key practical implication relates to the proposed theory's ability to help decision makers deconstruct and disentangle various operational processes. As complex systems, supply chains consist of many interdependent flows, stocks, and processes. Under socio-ecological intergradation, organizations can become more transparent than traditional global supply chains, in which typically no individual trading partner has full knowledge of the products, processes, and material flows that make up the value chain. Issues relating to opportunism, environmental footprints, and compliance with codes of conduct have been recognized as problematic features of global supply chains (Christmann, 2004; Jiang, 2009). We suggest that, in part, these problems can be traced back to the presence of too many variables and dependencies that overstretch managers' cognitive capacities, leading to confusion and suboptimal decision-making. Socio-ecological intergradation gives decision makers the chance to separate complex supply chain systems into smaller subsystems, helping to explicate how supply chains work as a whole and allowing managers to integrate various subsystems into a simpler, more regionally bound totality. Therefore, we go some way toward answering the call to explore sustainability issues "with a magnified resolution for the particular system or sector being studied" (Fiksel, 2006, p. 14).

Overall, we formulate a largely emerging form of organization (Staw, 1984) and adopt a prescientific approach in that we anticipate, conceptualize, and attempt to influence significant future problem domains (Corley and Gioia, 2011). We intend to provide theory that not only helps organizations to realize that they exist as part of the living and inanimate world (i.e., that they are part of an interconnected and interdependent system) (Ehrenfeld, 2005), but also suggests a way to transform this realization into everyday operations of supply chains. A key strength of this approach is to offer a new perspective on structuring and operating supply chains, which is intended to "facilitate an understanding of how a newly emergent [theoretical model of supply chain systems] might challenge mental models regarding the link between management and ecosystems" (Starkey and Crane, 2003, p. 220). Rather than simply showing how to reduce the negative impacts associated with current operations, our theory offers guidance on how to solve environmental problems (Ehrenfeld, 2005; Hart and Dowell, 2011; Pagell and Shevchenko, 2014). Our intention is to aid managers in adopting radical thinking and action to embark upon a sustainable trajectory that is not limited to fixing symptoms of unsustainability. An understanding of socio-ecological intergradation in the supply chain may require a paradigm shift in the way many managers understand the scope and current operating models of their organizations, how they are run, how results are assessed, and, importantly, how they communicate and connect with various trading partners. Theoretically, adopting the principles of industrial ecology in organizations could one day lie at the center of all sustainable business models.

7. Future research and conclusions

More work is necessary if socio-ecological intergradation is to advance to a full-fledged theory. Although we have begun to address three crucial building blocks of theory development: the what (explaining which variables and concepts logically should be considered), the how (explaining how the chosen variables are related), and the why (explaining what underlying dynamics justify the selection of variables) (Whetten, 1989), significant future research efforts are necessary to do these building blocks justice. Future scholars should also explore the who, where, and when—conditions that place limitations on any theory (Whetten, 1989).

Development of more testable propositions is therefore crucial, particularly propositions that focus on the many boundary conditions of socio-ecological intergradation in supply chains. For instance, as the development of more ethical, socio-ecologically intergraded supply chains is not limited to developed countries, future research should explore the conditions conducive to its full—or hybrid—adoption across countries and different cultures. Thus although we suggest the adoption of more local operating processes to create socio-ecological resilience, research should continue to operate at a global level and assess the myriad complex boundary conditions (including firm structure and industry background), interdependencies, and consequences of adopting socio-ecologically intergraded *modi operandi*. As part of these research efforts, scholars could also explore when one principle becomes more important than another.

Contextual factors set the boundary for theoretical models. For example, restructuring inter-organizational relationships may require numerous regulatory, infrastructural, and market-related changes (Shrivastava, 1995). Other research questions include the following: Do managers need public relations and marketing skills to successfully communicate the benefits of goods produced through socio-ecologically intergraded processes? What role does financial and process auditing play in increasing the confidence of shareholders, investors, and regulatory bodies regarding socio-ecological intergradation? How important are venture capitalists and other funding bodies to the support of socio-ecological intergradation? How important are international technology-oriented agreements and cooperation in driving these changes? These and many other questions remain to be answered.

The short- and long-term performance implications of various industries' adoption of socio-ecological intergradation should also be explored and tested empirically. What steps will be necessary to get to socio-ecological intergradation? Firms will likely choose different paths, but researchers have not yet explored the nature and nuances of these paths. What are the outcomes at different stages of socio-ecological intergradation adoption? What are the material and energy balances at these stages? Can energy requirements and scraps and waste outputs be quantified (Albino et al., 2002)? Because our theory rejects the one-way relationship of ecosystems for organizations, and instead envisages an intergraded and multilayered relationship between organizations and natural ecosystems, the variables are difficult to define, conceptualize, and measure. More effective intergradation requires developing and using powerful tools to overcome troublesome barriers (for example, mathematical and computational challenges, quantification of impacts of socio-ecological intergradation on various socio-ecological dimensions, and relationships among patterns and processes). Our theory is far from fully specified, and to be predictive the constructs and their underlying relationships require greater precision.

Slow progress regarding the practical implementation of industrial ecology has often been attributed to the fundamental differences between social and ecological systems (Ayres, 2004; Korhonen, 2005; McManus and Gibbs, 2008). However, even though supply chain systems may seem far removed from natural ecosystems, their processes reflect and shape our relationship with nature. Each time an organization fulfills a customer request, its relationship to the physical and biological world surfaces (Benyus, 1997). Continued exploration and deeper understanding of this relationship are essential if research is to lead organizational practices in a meaningful way.

APPENDIX

Socio-ecological Intergradation Principles: The Identification and Elimination Process.

Step 1: Literature review led to the identification of the following socio-ecological principles		Description of Principle:	Selected Source(s)
		Principle refers to ecosystems' …	
1	Circularity	… capacity to recover and reuse resources and energy that another organism considers waste or by-product.	Howard-Grenville et al. (2014); Ayres and Ayres (1996)
2	Community	… ability over time to put the survival of the ecosystem as a whole above the individual survival of the organisms contained within.	DeWitt (1992)
3	Connectivity	… organisms and resources that can move between or enact on habitats or populations that can be isolated in space and time.	Sheaves (2009)
4	Continuity	… ability to maintain organisms and processes—descended from previous generations—within its system over a long time.	Nordén and Appelqvist (2001)
5	Diversity	… complexity where multiple attributes prevail and the genetic information of any living organism, population, or species is a specific carrier of information.	Naeem and Li (1997); Mayer (2008); Zhu and Cote (2004)
6	Elasticity	… adaptability to change (e.g. restoration of the ecosystem following external disturbances).	Westman (1978)
7	Frugality	… organisms that use only the amount of resources necessary to sustain themselves within the carrying capacity of the ecosystem.	DeWitt (1992)
8	Gradualism	… existence and evolution of organisms that are bound by the rate of renewal of resources and energy within the ecosystem.	Korhonen (2001)
9	Heterogeneity	… degree of variation of different or dissimilar elements and parts (biotic and abiotic).	Hunter and Price (1992); Levin (1992)
10	Homeostasis	… organisms and processes that are self-controlled and self-regulated to maintain their integrity and stability.	Ernest and Brown (2001)

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Step 1: Literature review led to the identification of the following socio-ecological principles		Description of Principle:	Selected Source(s)
11	Hysteresis	… degree to which the pattern of recovery of an ecosystem is not simply a reversal of the pattern of initial alteration.	Westman (1978)
12	Integrity	… supportive, self-regulative operational processes that persists between organisms.	Allee et al. (1949)
13	Interconnectedness	… diversity of elements, represented as the full array of physical habitats and environmental gradients in an interrelated network.	Hart (1995); Christensen et al. (1996)
14	Interdependence	… symbiotic, mutually beneficial processes that are connected within and between systems leading, for example, to the exchanges of by-products and energy.	Colwell (1998); Geyer and Jackson (2004)
15	Locality	… processes that are occurring locally, in a decentralized fashion, with organisms adapting and cooperating within natural limiting factors.	Korhonen (2001); Zhu and Cote (2004)
16	Reciprocity	… multiple organisms that—by production and consumption of products to and from the external environment—play an active role in the maintenance and homeostasis of that environment.	DeWitt (1992)
17	Recovery	… organisms contained within a system that "engage in self-reproduction, rejuvenation, regeneration and restoration" (p. 9).	DeWitt (1992); Ehrenfeld and Gertler (1997)
18	Regeneration	… extent to which external forces causing disturbance can be restored/re-established to previous system states.	Adger et al. (2005)
19	Roundput	… ability to recycle matter and allow for energy to cascade between elements of the system.	Korhonen (2001); Fiksel (2006)
20	Steady state	… ability to operate in a cyclical manner where every organism and process purposefully results in a self-reinforcing, equilibrated, and stable condition.	Ginzburg and Akçakaya (1992); Ehrenfeld and Gertler (1997)

Step 2: Literature review and multiple discussion rounds among the authors led to the exclusion of the following socio-ecological principles		Main Reason for Exclusion:
		Fails to meaningfully differentiate itself from other principle(s):
1	Circularity	Principles 1–6 are largely captured through "steady state"
2	Continuity	
3	Frugality	
4	Homeostasis	
5	Roundput	
6	Integrity	
7	Diversity	Principle is largely captured through "heterogeneity"
8	Connectivity	Principle is largely captured through "steady state," " interdependence," and "homeostasis"
9	Interconnectedness	Principle is largely captured through "steady state" and "interdependence".
10	Reciprocity	Principle is largely captured through "interdependence"
		Describes ecosystem consequences rather than their nature:
11	Elasticity	Principles 11–14 do not describe ecosystems, but how they respond to external influences (typically disturbances). These consequences are largely captured in the dependent variable—ecological resilience.
12	Hysteresis	
13	Recovery	
14	Regeneration	

Step 3: Two semi-structured discussion rounds with six managers confirmed the relevance of the remaining six socio-ecological principles and led to the exclusion of "community"		**Main Reasons for Exclusion/Inclusion:**
15	Community	Some disagreement ensued about whether to include this principle. However, in the end, subjects agreed that, as per the definition provided, "community" is not an adequate concept to describe socio-ecological systems (organizations). In other words, "community" fails to provide a meaningful dimension in a supply chain/organizational context. The authors also believe that the different definitions and connotations pertaining to the notion of "community" make it cumbersome and confusing to include as part of the socio-ecological intergradation principles.
16	Gradualism	The managers agreed with the authors that the remaining five ecological principles potentially describe organizations and *modi operandi* (i.e., a *socio*-ecological phenomenon). The main rationale for inclusion mirrors the above outlined reasons for exclusion.
17	Heterogeneity	
18	Interdependence	
19	Locality	
20	Steady state	

Note: The identification and elimination process did not include biological processes—instead of properties—of natural ecosystems such as immobilization, photosynthesis, respiration and decomposition (e.g., Harte and Kinzig, 1993).

References

Adger, W.N., 2000. Social and ecological resilience: are they related? Prog. Hum. Geogr. 24 (3), 347–364. http://dx.doi.org/10.1191/030913200701540465.

Adger, W.N., Hughes, T., Folke, C., Carpenter, S., Rockström, J., 2005. Social-ecological resilience to coastal disasters. Science 309 (5737), 1036–1039. http://dx.doi.org/10.1126/science.1112122.

Ahi, P., Searcy, C., 2013. A comparative literature analysis of definitions for green and sustainable supply chain management. J. Clean. Prod. 52, 329–341. http://dx.doi.org/10.1016/j.jclepro.2013.02.018.

Albino, V., Izzo, C., Kühtz, S., 2002. Input–output models for the analysis of a local/global supply chain. Int. J. Prod. Econ. 78 (2), 119–131. http://dx.doi.org/10.1016/S0925-5273(01)00216-X.

Allee, W.C., Park, O., Emerson, A.E., Park, T., Schmidt, K.P., 1949. Principles of Animal Ecology. WB Saundere Co. Ltd.

Andersen, M., Skjoett-Larsen, T., 2009. Corporate social responsibility in global

supply chains. Supply Chain Manag. Int. J. 14 (2), 75–86. http://dx.doi.org/10.1108/13598540910941948.
Aragon-Correa, J.A., Sharma, S., 2003. A contingent resource-based view of proactive corporate environmental strategy. Acad. Manag. Rev. 28 (1), 71–88. http://dx.doi.org/10.5465/AMR.2003.8925233.
Ashby, A., Leat, M., Hudson-Smith, M., 2012. Making connections: a review of supply chain management and sustainability literature. Supply Chain Manag. Int. J. 17 (5), 497–516. http://dx.doi.org/10.1108/13598541211258573.
Ayres, R., 2004. On the life cycle metaphor: where ecology and economics diverge. Ecol. Econ. 48 (4), 425–438. http://dx.doi.org/10.1016/j.ecolecon.2003.10.018.
Ayres, R., Ayres, L., 1996. Industrial Ecology: Towards Closing the Materials Cycle. Edward Elgar, Cheltenham, pp. 278–280.
Ayres, R., Ayres, L., 2002. A Handbook of Industrial Ecology. Edward Elgar Publishing, Cheltenham.
Bakshi, B.R., Fiksel, J., 2003. The quest for sustainability: challenges for process systems engineering. AIChE J. 49 (6), 1350–1358. http://dx.doi.org/10.1002/aic.690490602.
Barney, J., 1991. Firm resources and sustained competitive advantage. J. Manag. 17 (1), 99–120. http://dx.doi.org/10.1177/014920639101700108.
Benyus, J.M., 1997. Biomimicry. William Morrow, New York.
Berkes, F., Folke, C., 1998. Linking Social and Ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge.
Blewitt, J., 2009. Understanding Sustainable Development. Earthscan, London.
Carmeli, A., Markman, G.D., 2011. Capture, governance, and resilience: strategy implications from the history of Rome. Strategic Manag. J. 32 (3), 322–341. http://dx.doi.org/10.1002/smj.880.
Carter, C.R., Easton, P.L., 2011. Sustainable supply chain management: evolution and future directions. Int. J. Phys. Distrib. Logist. Manag. 41 (1), 46–62. http://dx.doi.org/10.1108/09600031111101420.
Carter, C.R., Rogers, D.S., 2008. A framework of sustainable supply chain management: moving toward new theory. Int. J. Phys. Distrib. Logist. Manag. 38 (5), 360–387. http://dx.doi.org/10.1108/09600030810882816.
Catton Jr., W.R., Dunlap, R.E., 1978. Environmental sociology: a new paradigm. Am. Sociol. 13 (1), 41–49. http://www.jstor.org/stable/27702311.
Chapin III, F.S., Torn, M.S., Tateno, M., 1996. Principles of ecosystem sustainability. Am. Nat. 148 (6), 1016–1037.
Choi, T., Hong, Y., 2002. Unveiling the structure of supply networks: case studies in Honda, Acura, and Daimler Chrysler. J. Oper. Manag. 20 (5), 469–493. http://dx.doi.org/10.1016/S0272-6963(02)00025-6.
Christensen, N.L., Bartuska, A.M., Brown, J.H., Carpenter, S., D'Antonio, C., Francis, R., Franklin, J.F., MacMahon, J.A., Noss, R.F., Parsons, D.J., 1996. The report of the ecological society of America committee on the scientific basis for ecosystem management. Ecol. Appl. 6 (3), 665–691. http://dx.doi.org/10.2307/2269460.
Christmann, P., 2004. Multinational companies and the natural environment: determinants of global environmental policy. Acad. Manag. J. 47 (5), 747–760. http://dx.doi.org/10.2307/2269460.
Christmann, P., Taylor, G., 2001. Globalization and the environment: determinants of firm self-regulation in China. J. Int. Bus. Stud. 32 (3), 439–458. http://dx.doi.org/10.2307/2269460.
Colwell, R., 1998. Balancing the biocomplexity of the planet's living systems: a 21st century task for science. BioScience 48 (10), 786–787.
Corley, K.G., Gioia, D.A., 2011. Building theory about theory building: what constitutes a theoretical contribution? Acad. Manag. Rev. 36 (1), 12–32. http://dx.doi.org/10.5465/AMR.2011.55662499.
Costanza, R., Daly, H.E., 1992. Natural capital and sustainable development. Conserv. Biol. 6 (1), 37–46. http://dx.doi.org/10.1046/j.1523-1739.1992.610037.x.
Daly, H.E., Farley, J., 2011. Ecological Economics: Principles and Applications, second ed. Island Press, Washington DC.
Despommier, D., 2009. The rise of vertical farms. Sci. Am. 301 (5), 80–87. http://dx.doi.org/10.1038/scientificamerican1109-80.
Despommier, D., 2010. The Vertical Farm: Feeding the World in the 21st Century. Thomas Dunne Books, New York, NY.
DeWitt, C.B., 1992. Ethics, ecosystems and enterprise: discovering the meaning of food security and development. In: Smith, K., Yamaori, T. (Eds.), Growing Our Future: Food Security and the Environment. Kumarian Press, West Hartford, CT, pp. 6–26.
Dyer, J.H., Singh, H., 1998. The relational view: cooperative strategy and sources of interorganizational competitive advantage. Acad. Manag. Rev. 23 (4), 660–679. http://dx.doi.org/10.5465/AMR.1998.1255632.
Edwards-Jones, G., Canals, L.M., Hounsome, N., Truninger, M., Koerber, G., Hounsome, B., Cross, P., York, E.H., Hospido, A., Plassmann, K., 2008. Testing the assertion that 'local food is best': the challenges of an evidence-based approach. Trends Food Sci. Technol. 19 (5), 265–274. http://dx.doi.org/10.1016/j.tifs.2008.01.008.
Ehrenfeld, J., 2004. Industrial ecology: a new field or only a metaphor? J. Clean. Prod. 12 (8), 825–831. http://dx.doi.org/10.1016/j.jclepro.2004.02.003.
Ehrenfeld, J., 2005. The roots of sustainability. MIT Sloan Manag. Rev. 46 (2), 23–25.
Ehrenfeld, J., Gertler, N., 1997. Industrial ecology in practice: the evolution of interdependence at Kalundborg. J. Ind. Ecol. 1 (1), 67–79. http://dx.doi.org/10.1162/jiec.1997.1.1.67.
Elliot, S., 2011. Transdisciplinary perspectives on environmental sustainability: a resource base and framework for IT-enabled business transformation. MIS Q. 35 (1), 197–236.
Ellram, L.M., Tate, W.L., Feitzinger, E.G., 2013. Factor-market rivalry and competition for supply chain resources. J. Supply Chain Manag. 49 (1), 29–46. http://dx.doi.org/10.1111/jscm.12001.
Ernest, S.M., Brown, J.H., 2001. Homeostasis and compensation: the role of species and resources in ecosystem stability. Ecology 82 (8), 2118–2132. http://dx.doi.org/10.1890/0012-9658.
Ferrão, P., Fernández, J.E., 2013. Sustainable Urban Metabolism. MIT Press, Cambridge, MA.
Fiksel, J., 2006. Sustainability and resilience: toward a systems approach. Sustain. Sci. Pract. Policy 2 (2), 14–21. http://search.proquest.com/docview/1428620021?accountid=14681.
Folke, C., Hahn, T., Olsson, P., Norberg, J., 2005. Adaptive governance of social-ecological systems. Annu. Rev. Environ. Resour. 30, 441–473. http://dx.doi.org/10.1146/annurev.energy.30.050504.144511.
Forrester, J.W., 1961. Industrial Dynamics. MIT Press., Cambridge, MA.
Frosch, R., 1992. Industrial ecology: a philosophical introduction. Proc. Natl. Acad. Sci. 89 (3), 800–803. http://dx.doi.org/10.1073/pnas.89.3.800.
Frosch, R., Gallopoulos, N., 1989. Strategies for manufacturing. Sci. Am. 261 (3), 144–152.
Geyer, R., Jackson, T., 2004. Supply loops and their constraints: the industrial ecology of recycling and reuse. Calif. Manag. Rev. 46 (2), 55–73. http://dx.doi.org/10.2307/41166210.
Gibbs, D., 2003. Trust and networking in inter-firm relations: the case of eco-industrial development. Local Econ. 18 (3), 222–236. http://dx.doi.org/10.1080/0269094032000114595.
Gimenez, C., Sierra, V., 2013. Sustainable supply chains: governance mechanisms to greening suppliers. J. Bus. Ethics 116 (1), 189–203. http://dx.doi.org/10.1007/s10551-012-1458-4.
Ginzburg, L.R., Akçakaya, H.R., 1992. Consequences of ratio-dependent predation for steady-state properties of ecosystems. Ecology 73 (5), 1536–1543. http://dx.doi.org/10.2307/1940006.
Gladwin, T., 1993. The Meaning of Greening: a Plea for Organizational Theory. Island Press, Washington DC.
Gladwin, T., Kennelly, J., Krause, T.-S., 1995. Shifting paradigms for sustainable development: implications for management theory and research. Acad. Manag. Rev. 20 (4), 874–907. http://dx.doi.org/10.5465/AMR.1995.9512280024.
Gold, S., Seuring, S., Beske, P., 2010. Sustainable supply chain management and inter-organizational resources: a literature review. Corp. Soc. Responsib. Environ. Manag. 17 (4), 230–245. http://dx.doi.org/10.1002/csr.207.
Golicic, S.L., Smith, C.D., 2013. A meta-analysis of environmentally sustainable supply chain management practices and firm performance. J. Supply Chain Manag. 49 (2), 78–95. http://dx.doi.org/10.1111/jscm.12006.
Goodland, R., 1997. Environmental sustainability in agriculture: diet matters. Ecol. Econ. 23 (3), 189–200. http://dx.doi.org/10.1016/S0921-8009(97)00579-X.
Graedel, T., Lifset, R., 2016. Industrial ecology's first decade. In: Clift, A.D. (Ed.), Taking Stock of Industrial Ecology. Springer, pp. 3–20.
Grime, J., 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. Am. Nat. 111 (982), 1169–1194. http://www.jstor.org/stable/2460262.
Gruner, R., Orazi, D., Power, D., 2013. Global versus local: an exploration on how vertical farms can lead the way to more sustainable supply chains. IEEE Eng. Manag. Rev. 41 (2), 23–29. http://dx.doi.org/10.1109/EMR.2013.2259979.
Guide Jr., V.D.R., Jayaraman, V., Linton, J.D., 2003a. Building contingency planning for closed-loop supply chains with product recovery. J. Oper. Manag. 21 (3), 259–279. http://dx.doi.org/10.1109/EMR.2013.2259979.
Guide Jr., V.D.R., Teunter, R.H., Van Wassenhove, L.N., 2003b. Matching demand and supply to maximize profits from remanufacturing. Manuf. Serv. Oper. Manag. 5 (4), 303–316. http://dx.doi.org/10.1287/msom.5.4.303.24883.
Gunasekaran, A., Patel, C., McGaughey, R.E., 2004. A framework for supply chain performance measurement. Int. J. Prod. Econ. 87 (3), 333–347. http://dx.doi.org/10.1016/j.ijpe.2003.08.003.
Gunderson, L., 2000. Ecological resilience—in theory and application. Annu. Rev. Ecol. Syst. 31, 425–439. http://www.jstor.org/stable/221739.
Gunderson, L., Holling, C.S., 2001. Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington (DC).
Haanaes, K., Michael, D., Jurgens, J., Rangan, S., 2013. Making sustainability profitable. Harv. Bus. Rev. 91 (3), 110–115.
Hamprecht, J., Corsten, D., Noll, M., Meier, E., 2005. Controlling the sustainability of food supply chains. Supply Chain Manag. Int. J. 10 (1), 7–10. http://dx.doi.org/10.1108/13598540510578315.
Hart, S.L., 1995. A natural-resource-based view of the firm. Acad. Manag. Rev. 20 (4), 986–1014. http://dx.doi.org/10.5465/AMR.1995.9512280033.
Hart, S.L., Dowell, G., 2011. Invited editorial: a natural-resource-based view of the firm fifteen years after. J. Manag. 37 (5), 1464–1479.
Harte, J., Kinzig, A.P., 1993. Mutualism and competition between plants and decomposers: implications for nutrient allocation in ecosystems. Am. Nat. 141 (6), 829–846. http://www.jstor.org/stable/2462841.
Hassini, E., Surti, C., Searcy, C., 2012. A literature review and a case study of sustainable supply chains with a focus on metrics. Int. J. Prod. Econ. 140 (1), 69–82. http://dx.doi.org/10.1016/j.ijpe.2012.01.042.
Howard-Grenville, J., Buckle, S.J., Hoskins, B.J., George, G., 2014. Climate change and management. Acad. Manag. J. 57 (3), 615–623. http://dx.doi.org/10.5465/amj.2014.4003.
Hunter, M.D., Price, P.W., 1992. Playing chutes and ladders: heterogeneity and the relative roles of bottom-up and top-down forces in natural communities. Ecology 73 (3), 723–732.
Jensen, P.D., Basson, L., Leach, M., 2011. Reinterpreting industrial ecology. J. Ind. Ecol.

15 (5), 680–692. http://dx.doi.org/10.1111/j.1530-9290.2011.00377.x.
Jiang, B., 2009. Implementing supplier codes of conduct in global supply chains: process explanations from theoretic and empirical perspectives. J. Bus. Ethics 85 (1), 77–92. http://dx.doi.org/10.1007/s10551-008-9750-z.
Jørgensen, S.E., 2002. Integration of Ecosystem Theories: a Pattern, third ed. Springer Science and Business Media, Dordrecht.
Kassarjian, H., 1977. Content analysis in consumer research. J. Consum. Res. 4 (1), 8–18.
Ketchen Jr., D.J., Hult, G.T.M., 2011. Building theory about supply chain management: some tools from the organizational sciences. J. Supply Chain Manag. 47 (2), 12–18. http://dx.doi.org/10.1111/j.1745-493X.2011.03220.x.
Klassen, R.D., Whybark, D.C., 1999. The impact of environmental technologies on manufacturing performance. Acad. Manag. J. 42 (6), 599–615. http://dx.doi.org/10.2307/256982.
Korhonen, J., 2001. Four ecosystem principles for an industrial ecosystem. J. Clean. Prod. 9 (3), 253–259. http://dx.doi.org/10.1016/S0959-6526(00)00058-5.
Korhonen, J., 2003. On the ethics of corporate social responsibility–considering the paradigm of industrial metabolism. J. Bus. Ethics 48 (4), 301–315. http://dx.doi.org/10.1023/B:BUSI.0000005798.88294.31.
Korhonen, J., 2005. Theory of industrial ecology: the case of the concept of diversity. Prog. Ind. Ecol. Int. J. 2 (1), 35–72. http://dx.doi.org/10.1504/PIE.2005.006782.
Kuehn, K., McIntire, L., 2014. Sustainability a CFO can love. Harv. Bus. Rev. 92 (4), 66–74.
Levin, S., 1992. The problem of pattern and scale in ecology: the Robert H. MacArthur award lecture. Ecology 73 (6), 1943–1967. http://dx.doi.org/10.2307/1941447.
Levin, S., 1998. Ecosystems and the biosphere as complex adaptive systems. Ecosystems 1 (5), 431–436. http://dx.doi.org/10.1007/s100219900037.
Levitt, T., 1960. Marketing myopia. Harv. Bus. Rev. 38 (4), 24–47.
Linton, J., Jayaraman, V., 2005. A framework for identifying differences and similarities in the managerial competencies associated with different modes of product life extension. Int. J. Prod. Res. 43 (9), 1807–1829. http://dx.doi.org/10.1080/13528160512331326440.
Linton, J., Klassen, R., Jayaraman, V., 2007. Sustainable supply chains: an introduction. J. Oper. Manag. 25 (6), 1075–1082. http://dx.doi.org/10.1016/j.jom.2007.01.012.
Liu, J., Mooney, H., Hull, V., Davis, S.J., Gaskell, J., Hertel, T., Lubchenco, J., Seto, K.C., Gleick, P., Kremen, C., 2015. Systems integration for global sustainability. Science 347 (6225), 1–7. http://dx.doi.org/10.1126/science.1258832.
Ljungberg, L.Y., 2007. Materials selection and design for development of sustainable products. Mater. Des. 28 (2), 466–479. http://dx.doi.org/10.1016/j.matdes.2005.09.006.
Lubin, D.A., Esty, D.C., 2010. The sustainability imperative. Harv. Bus. Rev. 88 (5), 42–50.
MacCarthy, B.L., Atthirawong, W., 2003. Factors affecting location decisions in international operations-a Delphi study. Int. J. Oper. Prod. Manag. 23 (7), 794–818. http://dx.doi.org/10.1108/01443570310481568.
Malviya, R.K., Kant, R., 2016. Hybrid decision making approach to predict and measure the success possibility of green supply chain management implementation. J. Clean. Prod. 135, 387–409. http://dx.doi.org/10.1016/j.jclepro.2016.06.046.
Matos, S., Hall, J., 2007. Integrating sustainable development in the supply chain: the case of life cycle assessment in oil and gas and agricultural biotechnology. J. Oper. Manag. 25 (6), 1083–1102. http://dx.doi.org/10.1016/j.jom.2007.01.013.
Mayer, A., 2008. Ecologically-based approaches to evaluate the sustainability of industrial systems. Int. J. Sustain. Soc. 1 (2), 117–133. http://dx.doi.org/10.1504/IJSSoc.2008.022569.
Mayr, E., Ashlock, P.D., 1969. Principles of Systematic Zoology, second ed. McGraw Hill, New York.
McManus, P., Gibbs, D., 2008. Industrial ecosystems? The use of tropes in the literature of industrial ecology and eco-industrial parks. Prog. Hum. Geogr. 32 (4), 525–540. http://dx.doi.org/10.1177/0309132507088118.
Meerow, S., Newell, J., 2015. Resilience and complexity: a bibliometric review and prospects for industrial ecology. J. Ind. Ecol. 19 (2), 236–251. http://dx.doi.org/10.1111/jiec.12252.
Meixell, M.J., Gargeya, V.B., 2005. Global supply chain design: a literature review and critique. Transp. Res. Part E Logist. Transp. Rev. 41 (6), 531–550. http://dx.doi.org/10.1016/j.tre.2005.06.003.
Mentzer, J.T., DeWitt, W., Keebler, J.S., Min, S., Nix, N.W., Smith, C.D., Zacharia, Z.G., 2001. Defining supply chain management. J. Bus. Logist. 22 (2), 1–25. http://dx.doi.org/10.1002/j.2158-1592.2001.tb00001.x.
Mingers, J., White, L., 2010. A review of the recent contribution of systems thinking to operational research and management science. Eur. J. Oper. Res. 207 (3), 1147–1161. http://dx.doi.org/10.1016/j.ejor.2009.12.019.
Morali, O., Searcy, C., 2013. A review of sustainable supply chain management practices in Canada. J. Bus. Ethics 117 (3), 635–658. http://dx.doi.org/10.1007/s10551-012-1539-4.
Naeem, S., Li, S., 1997. Biodiversity enhances ecosystem reliability. Nature 390 (6659), 507–509. http://dx.doi.org/10.1038/37348.
Nordén, B., Appelqvist, T., 2001. Conceptual problems of ecological continuity and its bioindicators. Biodivers. Conserv. 10 (5), 779–791. http://dx.doi.org/10.1023/A:1016675103935.
Pagell, M., Shevchenko, A., 2014. Why research in sustainable supply chain management should have no future. J. Supply Chain Manag. 50 (1), 44–55. http://dx.doi.org/10.1111/jscm.12037.
Pettit, T.J., Fiksel, J., Croxton, K.L., 2010. Ensuring supply chain resilience: development of a conceptual framework. J. Bus. Logist. 31 (1), 1–21. http://dx.doi.org/10.1002/j.2158-1592.2010.tb00125.x.
Popper, S.K., 1957. Philosophy of science: a personal report. In: Mace, C.A. (Ed.), British Philosophy in Mid-Century.
Power, D., Gruner, R.L., 2016. Towards a calculative model of supply chain enabling IT implementation. Int. J. Oper. Prod. Manag. 36 (5), 490–511. http://dx.doi.org/10.1108/IJOPM-02-2014-0068.
Quarshie, A.M., Salmi, A., Leuschner, R., 2016. Sustainability and corporate social responsibility in supply chains: the state of research in supply chain management and business ethics journals. J. Purch. Supply Manag. 22 (2), 82–97. http://dx.doi.org/10.1016/j.pursup.2015.11.001.
Quinn, J.B., 1978. Strategic change:"logical incrementalism". Sloan Manag. Rev. 20 (1), 7–19.
Sarkis, J., 2003. A strategic decision framework for green supply chain management. J. Clean. Prod. 11 (4), 397–409. http://dx.doi.org/10.1016/S0959-6526(02)00062-8.
Sarkis, J., Zhu, Q., Lai, K., 2011. An organizational theoretic review of green supply chain management literature. Int. J. Prod. Econ. 130 (1), 1–15. http://dx.doi.org/10.1016/j.ijpe.2010.11.010.
Serrano, C., Aggoune-Mtalaa, W., Sauer, N., 2013. Dynamic models for green logistic networks design. IFAC Proc. 46 (9), 736–741. http://dx.doi.org/10.3182/20130619-3-RU-3018.00101.
Seuring, S., Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. J. Clean. Prod. 16 (15), 1699–1710. http://dx.doi.org/10.1016/j.jclepro.2008.04.020.
Shang, K., Lu, C., Li, S., 2010. A taxonomy of green supply chain management capability among electronics-related manufacturing firms in Taiwan. J. Environ. Manag. 91 (5), 1218–1226. http://dx.doi.org/10.1016/j.jenvman.2010.01.016.
Sheaves, M., 2009. Consequences of ecological connectivity: the coastal ecosystem mosaic. Mar. Ecol. Prog. Ser. 391, 107–115. http://dx.doi.org/10.3354/meps08121.
Shrivastava, P., 1995. The role of corporations in achieving ecological sustainability. Acad. Manag. Rev. 20 (4), 936–960. http://dx.doi.org/10.5465/AMR.1995.9512280026.
Sovacool, B.K., 2014. What are we doing here? analyzing fifteen years of energy scholarship and proposing a social science research agenda. Energy Res. Soc. Sci. 1 (3), 1–29. http://dx.doi.org/10.1016/j.erss.2014.02.003.
Starkey, K., Crane, A., 2003. Toward green narrative: management and the evolutionary epic. Acad. Manag. Rev. 28 (2), 220–237. http://dx.doi.org/10.5465/AMR.2003.9416086.
Staw, B.M., 1984. Organizational behavior: a review and reformulation of the field's outcome variables. Annu. Rev. Psychol. 35 (1), 627–666.
Stead, W.E., Stead, J.C., 1992. Management for a Small Planet: Strategic Decision Making and the Environment. Sage Publications Inc, Newbury Park, CA.
Sutton, R.I., Staw, B.M., 1995. What theory is not. Adm. Sci. Q. 40 (3), 371–384.
Szaro, R.C., Sexton, W.T., Malone, C.R., 1998. The emergence of ecosystem management as a tool for meeting people's needs and sustaining ecosystems. Landsc. Urban Plan. 40 (1), 1–7. http://dx.doi.org/10.1016/S0169-2046(97)00093-5.
Von Bertalanffy, L., 1972. The history and status of general systems theory. Acad. Manag. J. 15 (4), 407–426. http://dx.doi.org/10.2307/255139.
Von Bertalanffy, L., Woodger, J.H., 1934. Modern Theories of Development. Oxford University Press, Oxford.
Voss, C., Tsikriktsis, N., Frohlich, M., 2002. Case research in operations management. Int. J. Oper. Prod. Manag. 22 (2), 195–219. http://dx.doi.org/10.1108/01443570210414329.
Wacker, J.G., 1998. A definition of theory: research guidelines for different theory-building research methods in operations management. J. Oper. Manag. 16 (4), 361–385. http://dx.doi.org/10.1016/S0272-6963(98)00019-9.
Wackernagel, M., Rees, W.E., 1997. Perceptual and structural barriers to investing in natural capital: economics from an ecological footprint perspective. Ecol. Econ. 20 (1), 3–24. http://dx.doi.org/10.1016/S0921-8009(96)00077-8.
WCED, 1987. Our Common Future. Oxford University Press, Oxford and New York.
Weick, K.E., 1995. What theory is not, theorizing is. Adm. Sci. Q. 40 (3), 385–390.
Westman, W.E., 1978. Measuring the inertia and resilience of ecosystems. BioScience 28 (11), 705–710. http://dx.doi.org/10.2307/1307321.
Whetten, D.A., 1989. What constitutes a theoretical contribution? Acad. Manag. Rev. 14 (4), 490–495. http://dx.doi.org/10.5465/AMR.1989.4308371.
Wolf, J., 2011. Sustainable supply chain management integration: a qualitative analysis of the German manufacturing industry. J. Bus. Ethics 102 (2), 221–235. http://dx.doi.org/10.1007/s10551-011-0806-0.
Xing, K., Qian, W., Zaman, A.U., 2016. Development of a cloud-based platform for footprint assessment in green supply chain management. J. Clean. Prod. 139, 191–203. http://dx.doi.org/10.1016/j.jclepro.2016.08.042.
Zhu, Q., Cote, R.P., 2004. Integrating green supply chain management into an embryonic eco-industrial development: a case study of the Guitang Group. J. Clean. Prod. 12 (8), 1025–1035. http://dx.doi.org/10.1016/j.jclepro.2004.02.030.