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REVIEW ARTICLE

Towards an umbrella science of sustainability

Hardi Shahadu[1]

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Abstract Sustainability research has gained scholarly attention since the 1980s as the new science investigating the changes in social, environmental and economic systems and their impacts on the future of planetary life support systems. Whilst broad literature on sustainability has expanded significantly over the past decades, academic literature developing sustainability as a distinct science has received little attention. After more than two decades of sustainability research, the time has come for us to begin asking reflective questions about what sort of science we call sustainability science. How has the broader research on sustainability contributed to developing sustainability science as a unique discipline within the past two decades? How has the label science promoted or hindered the interdisciplinary project of integrating the natural and social sciences as well as arts and humanities in addressing human nature problems? I argue in this review paper that special efforts need to be made towards the building and positioning of sustainability as an umbrella science for global sustainability research. The benefits of the new sustainability science advocated for in this paper are that; a) it offers a universal definition of sustainability that accounts for both the needs of life and the capacity of planetary life support systems to provide for those needs and b) proposes ways of bridging gaps among different research traditions, facilitating cross disciplinary communication and addressing the challenge of multiple meanings and definitions of concepts facing sustainability research today.

Handled by Yuya Kajikawa, Tokyo Institute of Technology, Japan.

✉ Hardi Shahadu
hardi.shahadu@usask.ca

[1] School of Environment and Sustainability, College of Graduate Studies, University of Saskatchewan, 117 Science Place, Saskatoon S7N 5C8, Canada

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Introduction

Sustainability emerged in the 1980s as an interdisciplinary science seeking to explain the interdependencies and interconnections between nature and society (Clark and Dickson 2003; Kates et al. 2001). The publication of the United Nations sponsored World Commission on Environment and Development report, *Our Common Future*, also known as the Brundtland Report, set the stage for the widespread recognition of the need for sustainability (Bettencourt and Kaur 2011; Kates 2011; Mebratu 1998). The report recognized that global environmental changes resulting from human interactions with, and management of, the environment and related resources represents a significant threat to the continued existence and sustenance of the planetary life support systems and all life that depend on them (Brundtland 1987; Mebratu 1998; Pirages 1994).

The logical conclusion from the above is that to ensure that current and future generations are all able to meet their needs without compromising the planetary life support systems, the human–environment interactions and environmental resource management philosophies need to take sustainable approaches (Turner et al. 2003; Bosselmann 2008). This realization marked the birth of sustainability science as a new field of research and practice. Inspired by the complex challenges facing humanity, sustainability science is focused on practical application of theories, tools and methodologies from different disciplines and bringing together scientists and stakeholders to define important research questions and objectives in dealing with

sustainability challenges from local, national, regional and international scales (Miller et al. 2014; Bettencourt and Kaur 2011; Kates 2011; Berkes 2004).

In this paper, I review the literature to interrogate questions such as: a) How has the broader research on sustainability contributed to developing sustainability science as a distinct discipline from its inception to the present? b) How can we position sustainability as an umbrella science in framing and guiding global sustainability research? I argue that to develop sustainability as a distinct scientific discipline, we need to recognize it as an umbrella science guiding global sustainability research in three broad areas, namely social–ecological resiliency, disaster vulnerability and adaptation (climate and other forms). As such, I review the literature on disaster vulnerability, climate adaptation and social–ecological resiliency to identify complementary notions of sustainability represented in these broad literature areas and to examine how evolutions in theory and methods in these fields can support better framing of sustainability science. The review focuses on resilience, adaptation and vulnerability because these are interconnected in their focus on stressors and shocks within the coupled human–nature systems (Adger 2006; Turner 2010). Turner (2010, p. 570) notes that both vulnerability and resilience have "shared understanding of which holds the potential to inform sustainability science inasmuch as either is consistent with the thematic foundation of this science". Therefore, these are best suited in framing and representing sustainability science. The approach is consistent with Turner's (2010) review of the complementary and overlapping roles of vulnerability and resilience in framing sustainability science. It is also consistent with recent studies looking at how research on climate change, biodiversity, water, energy, resources and economic development inform and represent the science of sustainability (Jerneck et al. 2011; Kajikawa 2008).

Emerging ideas on sustainability science

Following Kates et al's (2001) publication of 'sustainability Science' in the Journal of Science more than a decade ago, a lot of academic publications using the label sustainability or sustainability science have emerged globally. However, after more than two decades of the emergence of sustainability research, there is neither universally acceptable definition of sustainability nor universal criteria by which to identify the science of sustainability. Research in the field is therefore fragmented, whereby different definitions of sustainability inform and are being informed by different research agendas (Miller 2013). The use of the label science in the pursuit of a distinct disciplinary science of sustainability requires special efforts to provide and standardize a scientific definition of sustainability as well as delimit, structure and bound the discipline. Bounding and standardization will help provide a core set of ideas, understanding, assumptions and concepts that will transcend all enquiries using the sustainability science label in both temporal and spatial scales. By standardization, I do not mean standard prescriptions of how sustainability research should be conducted, but rather providing common understanding and definitions of concepts for use across varied sustainability research approaches. Therefore, standardization is not to deny diversity and multiplicity of approaches in sustainability research, but rather to improve cross-disciplinary understanding of concepts and to offer communicative opportunities for connecting the diverse researches and approaches towards achieving the goals of sustainability.

This review paper seeks to complement efforts at building a distinct disciplinary science of sustainability. Sustainability research has grown phenomenally over the past few decades with an estimated annual publication of journal articles in excess of 3000 (Bettencourt and Kaur 2011; Kajikawa 2008; Kates 2011). However, this exceptional growth is not reflective of the limited studies focused on building the science of sustainability (Spangenberg 2011). Studies examining and promoting sustainability as a distinct science are either special features (e.g. Clark and Dickson 2003; Turner et al. 2003), editorials (see, Komiyama and Takeuchi 2006) or less than six-page summaries (see, Bettencourt and Kaur 2011; Kates et al. 2001; Kates 2011). Currently, there are only few known journals dedicated to promoting research aimed at building sustainability as a distinct field of science (Kajikawa 2008). The importance of a distinct interdisciplinary science of sustainability is widely recognized (see, Jerneck et al. 2011; Kajikawa 2008; Kates et al. 2001; Kates 2011; Komiyama and Takeuchi 2006), but only a few studies have gone beyond the general commentaries to raise questions of structuring and framing sustainability as a distinct field of science (see, Miller 2013; Jerneck et al. 2011; Spangenberg 2011; Turner 2010; Kajikawa 2008). Kates and colleagues' publication of "sustainability science" (2001) was the pioneering attempt to set the academic agenda on sustainability research. The paper outlined three important pathways of sustainability research including discussions on key research questions, methodologies and institutional needs, connections between the science and politics of sustainability and a focus on the character of nature–society interactions. Such a foundational paper created an agenda for an applied sustainability research, thereby neglecting the need to develop a discipline to fit the label of sustainability science. It was therefore essential that Kates followed up after a decade (2011) with a paper addressing the question, "What

kind of science is sustainability science?" as an important step towards identifying the characteristics of the science of sustainability. Other scholars have contributed towards building distinct disciplinary science of sustainability in various ways. Komiyama and Takeuchi (2006) examined the question of building sustainability science as a new and distinct discipline in which they discussed how clarity in understanding the concept of sustainability and knowledge structuring and transdisciplinary approaches can provide useful opportunities for the pursuit of sustainability goals. Miller (2013) reviews the developments of the field of sustainability by examining how inter-linkages between definitions of sustainability, research agenda setting and notions of the contributions of science to sustainability inform different sustainability research trajectories. Other important publications have addressed the questions of building sustainability discipline from different angles including transdisciplinarity (see, Hadorn et al. 2006; Lang et al. 2012; Schodl et al. 2015; Scholz and Steiner 2015; Steelman et al. 2015), holistic integration and cooperation between scientists and stakeholders (Kauffman and Arico 2014), envisioning the future of sustainability (Wiek and Iwaniec 2013), and assessing sustainability curriculum structure and contents (O'Byrne et al. 2014).

In another twist, Redman (2014) asks whether sustainability science and resilience theory can be combined or pursued distinctly as separate domains of research. Redman argues that there are benefits in combining these two approaches as well as keeping them separate. In this paper, I am not only supporting the need to combine resilience and sustainability science, but I am also advancing an argument that resilience research needs to be understood as a subfield of research under a broader sustainability science. This argument is supported by Turner's assertion that "vulnerability and resilience applied to CHES (coupled human–environment systems) constitute different but complementary framings" of sustainability (2010, p. 573).

A recent Journal Sustainability Science review paper takes a futuristic and solutions-oriented approach to strengthening sustainability science by proposing the development of sustainability science along "four research pathways focused on mapping and deliberating sustainability values, creating and pursuing desirable futures, exploring and fostering socio-technical change and enabling social and institutional learning for sustainable development" (Miller et al. 2014, p. 239; 243). The multi-pathways approach proposed by Miller and colleagues is strongly aligned with the vision of an umbrella science of sustainability advocated in this paper.

This review therefore complements the above important research endeavours and seeks to contribute to the ongoing debates on building a distinct science of sustainability by examining how sustainability science and practice are represented and framed by global sustainability literature on resilience, vulnerability and adaptation. The main goals here are to argue for the positioning of sustainability as an umbrella science that can guide and direct the future development of global sustainability research and to interrogate how sustainability research over the past few decades has contributed to building a distinct science of sustainability. The key expected contributions of this paper in advancing knowledge on sustainability science research are that it offers focused definition of sustainability science that takes into account both the natural and human components and proposes a guided global sustainability research under sustainability science that can standardize conceptual developments and definitions. The paper also raises questions about the role of the label science in promoting global sustainability research and practice agendas.

It is important to note at this point that literature that seeks to promote sustainability as a science is yet to engage with the question of how the label science has promoted or hindered the interdisciplinary project of integrating the natural and social sciences as well as the arts and humanities in addressing human–nature problems. Interdisciplinarity and transdisciplinarity have become widely accepted as important concepts in addressing the questions of sustainability, but less is written on how the efforts to label sustainability as a science can influence the project of integrating the sciences, arts and humanities in sustainability research and practice. The importance of the integration of the arts and sciences in promoting sustainability education has been strongly articulated (see, Clark and Button 2011; Crinall and Henry 2008; Miner 2008). But Clark and Button (2011) notes that educational models unifying the arts and sciences in thinking about sustainability are still lacking in literature. It is also argued that the humanities should play important roles in the transdisciplinary projects addressing "key normative questions facing modern consumer societies" as we attempt to achieve global sustainability goals (Fischer et al. 2007, p. 621). It is important therefore that in our efforts at building a distinct disciplinary science of sustainability, we must be aware of the implications of the use of the science label as far as the goal of integrating research on the arts, humanities and the sciences is concerned.

Towards an inclusive definition of sustainability science

Researchers working towards promoting the distinctiveness of the science of sustainability need to pay special attention to issues of definitions. An interdisciplinary and umbrella science of sustainability requires a focused definition that is specific enough to be distinct and meaningful, but also broad enough to capture all its subfields or domains of

research. The focus of the Brundtland commission's definition on meeting human generational needs has received a fair amount of criticism for its human-centeredness (Bosselmann 2008). To this end, I define sustainability science in this paper as *a problem inspired, interdisciplinary science of systematic enquiry into the interconnections and relations between the past, present and future of life and its support systems, with the goal of keeping the productive capacity of life support systems in harmony with the demands placed on them, at all times.*

This definition offers new insights and advances the sustainability discourse, in that it expands on the subject from its development and human focus to include broader research areas on changes within the coupled social–ecological systems. It also points out the importance of time, not only in terms of the present and future, but also of the past. For instance, the present climate science research draws on data as far back as the pre-human era to explain the events of today and to also project future events.

Definitional challenges within sustainability also raise questions of conceptual usages and clarity. Sustainability science, sustainable development and sustainability lack standardized definitions and are used interchangeably in the literature (See for instance, Mebratu 1998; Bettencourt and Kaur 2011; Kates 2011). It is therefore important to clarify the differences between sustainability and sustainable development for instance. Development by definition is oriented towards the promotion of socioeconomic growth with the goal of ensuring social and material well-being of the human family (Spangenberg 2011; Turner 2010). As such, development is human centred and considers the natural subsystem as a necessary support resource for human well-being. This human centeredness has been the major cause of criticism of the Bruntland's definition of sustainable development (Bosselmann 2008; Mebratu 1998). This paper considers sustainable development as a subfield of sustainability science that applies social–ecological systems principles towards the goals of economic growth and human development. This is different from traditional development approaches, because unlike traditional development, sustainable development recognizes the coupled nature of human–environment systems, the limits to the capacity of natural systems and the resultant trade-offs that results from the pursuit of development goals (Spangenberg 2011; Turner 2010).

Foundations of contemporary sustainability science

Since the 1970s, concepts such as resilience, social–ecological systems, social vulnerability, adaptation, adaptive capacity and climate change have gained prominence in the research agenda on the coupled human–ecological systems. These have been in response to the threats, risks and uncertainties resulting from the rapid changes in the socioeconomic and environmental systems. The roots of these concepts date back to the risks/hazards research in the 1940s (Cutter et al. 2009). The pioneering work of Gilbert F. White shaped the birth of a new paradigm known as risk/hazards research that focused on understanding the impacts of natural hazards on human communities and the key drivers of losses from natural hazards (Cutter et al. 2009).

The hazard-exposure focus as the key driver of vulnerability thinking within risks/hazards research had significant limitations. One of the key early critiques of the emerging vulnerability thinking was the seminal paper on "Taking the naturalness out of natural disasters" by O'Keefe et al. (1976). The paper noted that greater losses from disasters were occurring from the developing world compared to the developed world as a result of structural imbalances, socioeconomic inequities and individual and family context among others. These socioeconomic factors were recognized as equally important variables in assessing the vulnerability (Zakour and Gillespie 2013; O'Keefe et al. 1976). This realization was significant in a sense that it pointed out inherent connections between human and natural systems that have become a core area of present sustainability research.

The research on coupled human and natural systems has evolved to reflect the complexity, uncertainty and surprise in the human–nature interactions. Current research trajectories on the coupled social–ecological system include disaster vulnerability, climate change adaptation and social–ecological resilience, among others. Each of these traditions represents a version of sustainability research and collectively inform the broader science and practice of sustainability. The theories, methods and concepts embedded and emergent in these research traditions reflect the broader field of sustainability science. By examining these research trajectories, sustainability scientists are then able to provide a better understanding of the developments, challenges and opportunities in sustainability science research and practice.

Disaster vulnerability

Vulnerability researchers are increasingly concerned about the need to develop robust assessment methodologies that enable capturing both human and environmental factors affecting the vulnerability of a coupled system (Polsky et al. 2007; Schröter et al. 2005). Such concerns are reflective of evolutions in vulnerability thinking from the earliest focus on separation of human from natural systems to those recognizing the importance of human–nature

interconnectedness (Adger 2006; Adger et al. 2005). This realization has led to the emergence of a new sustainability focused vulnerability research philosophy that is now leading the way to the development of vulnerability assessment tools, concepts and theories as discussed in this section.

Vulnerability is defined as a degree of susceptibility to harm by a system occasioned by its exposure and sensitivity to a hazard and its capacity to adapt (Turner et al. 2003; Adger 2006; Gallopín 2006; Zakour and Gillespie 2013). Disaster vulnerability theories have undergone significant transformations since their origins in the 1940s to reflect improved understanding of the underlying causes of disasters and the coupled nature of human–environment systems (Blaikie et al. 1994; Adger 2006). New understanding, mainly from theories of entitlement of livelihoods, pressure and release and social vulnerability, emerged in response to the failure of the natural hazards' theory to account for the political ecological causes of vulnerability.

Entitlements of livelihoods theory recognizes vulnerability as a function of the lack of legal or customary rights by individuals or groups to command over income or bundles of resources they can use or exchange to satisfy their needs (Blaikie et al. 1994; Turner et al. 2003; Adger 2006). The emphasis here is that vulnerability can occur even in the absence of significant disturbance or natural disasters, but as a result of failures in entitlements that limits people's ability to cope with declining livelihoods. The Pressure and Release Model (PAR)[1] proposed by Blaikie et al., (1994) conceptualized vulnerability as a function of the socioeconomic and political conditions that weaken people's coping and livelihood enhancement capabilities and which interact with natural hazards to cause disasters. Social vulnerability theory addresses the social impacts of disasters by assessing redistributive justice issues as well as disaster mitigating and exacerbating (capabilities and liabilities) that lead to differential impacts from hazards between different sections of societies and across geographical regions (Cutter et al. 2009; Zakour and Gillespie 2013). The theoretical evolution in disaster vulnerability research is consistent with and presents challenges for evolutions in methodologies that make for the practical applications of these theories.

[1] The Pressure and Release Model by Blaikie et al. conceptualizes disaster vulnerability as a function of interactions between natural hazards on one hand and socioeconomic and politico-ecological factors ranging from root cause through dynamic pressures to unsafe conditions on the other. The model is used to explain how different social groups subject to different economic, social, political and other circumstances are affected by natural disasters (Blaikie et al. 1994; Adger 2006; Cutter et al. 2009).

Moving vulnerability thinking from the exposure sensitivity approaches to those that encompass complex interconnected coupled human–environment systems, especially in global sustainability research, comes with methodological challenges (Duit et al. 2010). Methodological frameworks developed to assess the vulnerability of the complex coupled human–nature systems are either beyond the scope of most research projects or they are simply non-operationalizable in their entirety (Polsky et al. 2007; Turner et al. 2003). Polsky et al. (2007, p. 473) note that "the novelty of global change vulnerability assessments lies not so much in the development of new conceptual domains as in the methodological integration across existing research traditions". A recent study on the categorization of sustainability assessment tools and methods discovered that "only a minority of tools that exist today are capable of integrating nature-society facets" in generating balanced assessment outputs and results (Ness et al. 2007, p. 505). The vulnerability assessment frameworks presented by Turner et al. (2003) and Schröter et al. (2005) represent novel attempts to facilitate integrated assessment of vulnerability in the coupled social–ecological system, but these methods appear quite complex and also do not allow for the production of assessment results that can be compared across different studies (Polsky et al. 2007). The vulnerability framework by Turner et al. (2003) proposes an expansion in vulnerability assessment to include both the human and biophysical systems, the interactions between the hazards and the system at multiple functional, spatial and temporal scales, as well as both human and environmental influences external to the system (see Turner et al. 2003 for framework illustration). The eight-step vulnerability assessment framework by Schröter et al. (2005) is focused on the research process to guide researchers in conducting comprehensive vulnerability assessments that capture all aspects of vulnerability, including both the human and environmental factors. The guiding steps through the assessment process include problem conceptualization with stakeholders, knowledge of the place, vulnerability causal modeling and indicator setting among others.

The above frameworks represent methodological innovations in terms of contributing to sustainability research, but their key limitation is that they are rather complex and do not allow for comparing vulnerability assessment results of different vulnerability studies across different spatial scales (Polsky et al. 2007). The vulnerability scoping diagram (VSD) by Polsky et al. (2007) was designed to overcome the challenge presented in the frameworks of Turner et al. (2003) and Schröter et al. (2005). The VSD is primarily intended to facilitate the comparison of vulnerability assessment results across multiple assessment projects and exposure units through the development of

indicators for the vulnerability components (Polsky et al. 2007). Whilst the possibility of comparing vulnerability study results from different spatial and temporal scales advances the broader understanding of progress in sustainability research, the process of reducing vulnerability assessment data to develop indicators often involve the loss of critical vulnerability information (Smit and Wandel 2006; Malone 2009). Hence, the quantitative indicator studies need to be combined with more qualitative studies that present unreduced assessment results, so as to ensure that the benefits of both comparable and non-comparable studies are optimized in sustainable decision-making about social–ecological systems.

Climate change adaptation

The primary goals of adaptation research are to expand scholarly understanding of how coupled human–nature systems respond to rapid changes brought about by external stressors and internal processes and to inform changes in policy and management of human–nature interactions. Theories and their application for the above purposes have evolved over the past decades. This section examines the evolution in theory, concepts and methods on climate change adaptation as it fits within the broader sustainability science research and practice.

Adaptation as a concept originated from evolutionary biology to characterize the behavioural and genetic features of organisms that enables them to cope with environmental change for survival and sustained reproduction (Smit and Wandel 2006; Gallopín 2006). The concept has been used by researchers in various fields such as cultural anthropology, natural hazards and political ecology and entered into climate change research at about the same time climate change awareness was beginning to grow within and outside academia (Smit and Wandel 2006). Like vulnerability and resilience, adaptation has varied definitions within the climate change literature. Adaptation has been defined "as an adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change or take advantage of new opportunities" (Adger et al. 2005, p. 78). Smit and Wandel (2006) offer a comprehensive review of adaptation that need not be repeated here.

The methodology and measurement constitute the bridging components in the adaptation research between theory and practice. Different methodological approaches have been developed and applied to measure vulnerability or project future climate impacts, develop adaptation options, assess relative adaptive capacity of countries, regions, communities and examine implementation and decision processes that go into actual adaptation (Smit and Wandel 2006). Adaptation methods and approaches in this sense can be divided into two: those focused on developing indicators and scenarios to influence national, regional and international policies and the local-level, small scale, case study approaches that seek to examine the actual adaptation processes (Smit and Wandel 2006; Malone 2009).

Researchers in the first category are oriented towards constructing aggregate scores of vulnerability for countries, communities and regions, mapping vulnerability hot spots and developing scenarios of alternative adaptation options that make country-, regional- and community-level comparisons possible. The goal is to influence national, regional and international policy initiatives (Brooks et al. 2005; Smit and Wandel 2006; Malone 2009). This category of research has dominated the adaptation research (Smit and Wandel 2006) inspired by the IPCC. Examples of research on this category of adaptation include among others Brooks et al.'s (2005) national-level vulnerability investigation for global adaptation, Cutter et al.'s (2003) social vulnerability index (SoVI) for the USA. Others include O'Brien et al.'s (2004) climate sensitivity and vulnerability mapping of districts in India, and Swanson, et al.'s (2007) study on the indicators of adaptive capacity to climate change for agriculture in the prairie region of Canada. While national- or regional-scale and indicator-based studies are useful for providing understanding of the bigger picture and projecting future possibilities, these often lead to the loss of critical information (indicator studies) or fail to capture the variations in adaptation requirements at the community or local levels (national or regional studies) (Smit and Wandel 2006; Cutter et al. 2009).

There is growing interest among climate change adaptation researchers to contribute to what Smit and Wandel (2006) calls practical adaptation initiatives; initiatives that focus on local-level and small-scale adaptation measures and decision processes impacting community adaptation to climate and related changes. This new direction in adaptation research moves away from the top-down approaches to emphasize contextual research approaches that identify specific adaptation measures and decision processes aimed at building adaptive capacity at the community level. Such bottom-up practical research approaches recognize the importance of the principles of subsidiarity where decisions are influenced by those experiencing the challenges (Berkes 2010) and mainstreaming where adaptation decisions are incorporated into existing management and policy frameworks on economics, politics, resources management and sustainable development (Smit and Wandel 2006). These approaches are also dominated by case studies (Berkes and Jolly 2002; Pearce et al. 2009; Wall and Marzall 2006) and encourages participatory approaches that utilize local knowledge in setting research agendas (Berkes 2004).

Social–ecological resilience

Resilience as a concept that provides understanding of ecosystem structure, functioning and dynamics, originated from studies in ecology in the 1960s (Gallopín 2006; Folke 2006; Folke et al. 2010). The initial conceptualization of ecosystem response to perturbations within the ecology literature was dominated by a paradigm that viewed ecosystems as stable systems responding to external disturbances in a linear manner and operating within singular stability domains (Holling 1973; Folke et al. 2002; Folke 2006). The notion of measuring ecosystem response to perturbations within this paradigm was based on the time required to return the system to its original equilibrium after a disturbance (Folke et al. 2010; Holling and Meffe 1996; Herrfahrdt-Pähle and Pahl-Wostl 2012). The publication of Holling's seminal paper in 1973, which introduced the notion of multiple basins of attraction, nonlinearity, regeneration, self-organization, diversity and the adaptive cycle, changed prevailing ecosystem understanding significantly. This notion recognized change as an important component of ecosystem response to disturbance and highlighted the complexity, dynamism and surprises of real-world ecosystems (Holling 1973; Peterson et al. 1998; Folke 2006, Folke et al. 2010; Stokols et al. 2013).

Subsequent research on resilience expanded on the insights Holling brought into the field, leading to the development of complex adaptive systems (CAS) theories (Norberg and Cummin 2008; Levin 1998). The most significant revolution in resilience thinking was the conceptualization of social and natural systems together into what is now called the social–ecological system (SES). The concept of humans-in-nature recognized the artificiality, arbitrariness and the error of treating human and natural systems as separate entities (Folke et al. 2002; Folke 2006).

Resilience within the SES takes on expanded meanings and applications and the SES response to perturbations involves resilience as well as adaptability and transformability (Folke et al. 2002; Walker et al. 2004; Folke 2006; Folke et al. 2010). Resilience in its contemporary usage refers to the "capacity of a system to absorb disturbance while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks" (Walker et al. 2004, p. 5). Carpenter et al. (2001) describe resilience within the SES as (1) the degree of shock a system can absorb and still remain within a particular basin of attraction; (2) the degree of self-organization of the system; and (3) the degree to which the system can build and enhance its capacity for adaptation and learning. Adaptability is defined as the ability of the human actors in the SES to influence or manage resilience. This influence can be positive (i.e. enhances the resilience of the SES) or negative (weakening resilience and promoting collapse). Transformability refers to the capacity of creating fundamentally new systems when the conditions (ecological, economic and social) make the existing system undesirable. This means causing critical transition of the system from one basin of attraction to a new basin of attraction (Folke et al. 2010).

Current resilience research aspires to reshape natural resource management and policy at the local, national, regional and international scales. This is done through proposing new management and policy approaches such as multi-level collaborative governance and active adaptive management (Almstedt and Reed 2013): approaches that move away from the ineffective command and control, top-down methods and are more consistent with the evolving and complex nature of the SES (Holling and Meffe 1996; Kofinas 2009; Westley 2002). Another purpose of resilience research is to improve decision-making capabilities through the use of structured scenarios to develop indicators and predict future desirable and undesirable states of social–ecological systems (Folke et al. 2002).

Norberg and Cummin (2008) note that the primary purpose of resilience theory within the SES is to guide thought, but is not a conceptual tool to be tested. However, this does not mean that specific tools cannot be developed to measure aspects of resilience or that such measurements are not possible (Norberg and Cummin 2008). Norbgerg and Cummin's observation above is consistent with research on resilience within the SES, where practical tools and methods for measuring resilience are largely undeveloped. Methodological tools for the purposes of assessing resilience are mainly developed within research domains in health and psychology (see Ahern et al. 2006; Jeffcott et al. 2009; Mane et al. 2010; Masten and Powell 2003; O'Neal 1999; Westman 1978), disciplines beyond the scope of this review.

The main driving question for sustainability science and practice has been: how has humanity exercised its stewardship of the earth and its resources and what have been the results of this exercise? The answers as presented in the Millennium Ecosystems Assessment and the Brundtland reports demonstrate undesirable results and consequences of the way humanity have managed the natural resources of the Earth. Therefore, sustainability initiatives are concerned about changing the human–nature relationships and re-conceptualizing human–environment interactions in ways that reflect interdependency and complexity. Resilience theories are at the forefront of this thinking, proposing new management approaches consistent with the new management requirements.

Connecting the themes: a case for an umbrella science of sustainability

The concepts of resilience, adaptation and vulnerability have varied definitions, meanings and applications across different subject areas such as geography, physics, engineering and environmental studies (Gallopín 2006; Füssel 2007; Howe et al. 2013). These differences in meanings characterized the different intellectual traditions within which these concepts are situated and can undermine cross-disciplinary communication and understanding (Adger 2006; Gallopín 2006). In a recent study, Gallopín (2006) concludes from a review of the relational characteristics of the concepts of resilience, vulnerability and adaptive capacity within SES research that these concepts are strongly related, but the lack of clarity in the specific nature of the relationships among them can undermine progress and lead to epistemological challenges in research on global environmental change.

Developing common meanings and defining relationships between these concepts challenge interdisciplinary research on the coupled SES. Overcoming these challenges can be difficult, but one possible solution is to identify specific definitions or particular concepts within specific research domains or traditions for adoption across disciplines. Therefore, the focus of this review on the disaster aspect of vulnerability, the social–ecological domain of resilience and the climate change aspect of adaptation enabled focused analysis on the key concepts drawing on their specific meanings and definitions from the three domains of research.

The review also demonstrates the breadth and diversity of literature on the changes—responses in coupled social ecological systems as well as the evolution of theories and concepts guiding research in this area over the past half-century. This has implications for the science and practice of sustainability. Different themes have emerged in the review above that provides the common characteristics of sustainability by the different research trajectories under this review. This section discusses these thematic characteristics to explain the challenges, opportunities and insights they present for the present and future of the science and practice of sustainability.

Unity of focus

The first sustainability theme uncovered in the review above is what I will term the unity of focus. Despite the difference in definitions and approaches adopted by the various traditions of research represented in this review, all of them are united in their focus on social–ecological systems' response to external stressors, shocks or perturbations and internal processes. According to Adger (2006, p. 269), resilience, vulnerability and adaptation research are united in their distinctive focus on "shocks and stresses, response of the system" to these shocks and stresses and "the capacity for adaptive action". Gallopín (2006, p. 301) agrees that these concepts are bounded together in "non-trivial ways". This distinctive focus brings these disparate research traditions under the umbrella of sustainability science and provides a strong case for the primary argument of this paper. Despite shocks and stressors and social–ecological systems response to them being the underlying focus of research in these three fields of research, there are limited efforts in academia to integrate research across these traditions that, according to Adger (2006), hold the potential of producing beneficial insights. Some of the barriers for integrating research across the three traditions may include the difficulties in common definitions and meanings, theoretical dominance and methodological complexity as discussed below.

Convergence of perspectives

Closely related to the unity of focus is what I call convergence of perspectives. The three research trajectories reviewed above all demonstrate an evolution of theoretical and conceptual perspectives from simple, predictable, linear and separatist (social and ecosystems or human and nature) orientations to new perspectives that embrace complexity, non-predictability, non-linearity and interconnectedness in addressing the threats, risks and uncertainties in the coupled human–nature systems (Norberg and Cummin 2008; Levin 1998). The concepts of mainstreaming within climate change adaptation (Smit and Wandel 2006), the humans-in-nature and the complex adaptive systems conceptions within the social–ecological research (Holling 1973; Levin 1998; Folke 2006; Folke et al. 2010) and the expansion of vulnerability research from disaster exposure to political ecology (O'keefe et al. 1976; Turner et al. 2003; Adger 2006; Gallopín 2006; Cutter et al. 2009; Tate 2013; Lin and Chang 2013) perspectives provided the guiding principles towards this convergence across the different research traditions.

The convergence of perspectives theme is of particular importance to the science and practice of sustainability, because it produces insights that recognize the complexity dynamism and surprises embedded in real social–ecological systems (Holling 1973) and provide a comprehensive framework for an interdisciplinary approach to dealing with changes within the coupled social–ecological systems. The key positive realization here is that single disciplinary approaches to solving complex global change problems have severe limitations. Therefore, interdisciplinary

research is needed to guide emerging and new policy and management approaches such as multi-level collaborative governance and active adaptive management that are dynamic, inclusive and flexible enough to deal with the challenges resulting from social–ecological changes.

Methodological complexity

Closely associated with the convergence of perspectives is the theme of methodological complexity that has been observed from the literature in the review above. Connecting human and natural systems to form a single unit of analysis in global sustainability research has resulted in complex measurements of risks, threats and uncertainties as well as human perceptions of these. Adger (2006), for instance, argues that the three fields of research on resilience, vulnerability and adaptation are challenged fundamentally by issues of measurability; addressing perceptions of risk and vulnerability and problems of governance. Researchers working in these fields are currently challenged with identifying suitable methodologies to guide investigations of risks, threats and uncertainties (Duit et al. 2010).

The methodologies that have been developed to measure both the macro- and microcomponents of the social–ecological system are either complex and applicable to only large research projects (Polsky et al. 2007), or their entire applications in practical research projects are less likely (Turner et al. 2003). The wider methodological approaches have often focused on influencing high-level policy through indicator, scenario or mapping analysis (Smit and Wandel 2006; Cutter et al. 2009). Such methodologies reduce complex social–ecological systems and their subunits into simple aggregate indicators, representing only the macro situation of the systems (Smit and Wandel 2006; Adger, 2006). The case study and local context methodologies also tend to offer deeper insights into the local specificities of the challenges of global change, but these are not subject to comparisons thereby limiting global-scale understanding of the problems (Smit and Wandel 2006). Sustainability researchers need to work towards creating an appropriate balance between the two methodological approaches.

Theoretical focus

Linked to the themes identified in this review is the observation by previous work that the work on vulnerability, resilience and adaptation are theoretically focused with limited applicability in practical research (see, Cutter et al. 2009). Norberg and Cummin (2008) note that social–ecological resilience is primarily geared towards guiding thought much more than providing testable theories and concepts. The focus on theory with limited application and testing in real-world situations can be attributed partly to the methodological complexity as discussed above or the lack of conceptual clarity and definitions as discussed below. This presents both a challenge and opportunity for sustainability research. As a challenge, it demonstrates how much still needs to be done in terms of translating theory to practice in the broader sustainability research. As an opportunity, this allows for the testing and application of these theories into emerging sustainability initiatives across the globe.

Definitional challenges

As stated earlier in this paper, the issues of definitions and conceptual clarity constitute one of the key challenges of sustainability and cut across the three main trajectories of research in this review. The concepts of resilience, vulnerability, adaptation as well as sustainability or sustainable development have been defined variously by different researchers within and across disciplines (Adger 2006; Gallopín 2006; Cutter et al. 2008). These 'multi-definitionality' and meanings represent key limitations for cross-disciplinary communications and collaborations (Adger 2006; Smit and Wandel 2006; Gallopín 2006). Gallopín (2006) argues that there is the need and benefit to develop clear and mutually compatible definitions of these concepts as critical tools for enhancing natural–social science interactions within the coupled SES and other levels.

One way of dealing with the challenge of definition of concepts as adopted in this paper is to intentionally and systematically allow the theoretical and conceptual development of certain concepts to be spearheaded and guided by specific research traditions. For instance, vulnerability theories and concepts such as the pressure and release model (Blaikie et al. 1994), the vulnerability assessment framework (Turner et al. 2003) and hazard-of-place model (Cutter 1996) can be used to guide conceptual development and definitions within the disaster vulnerability research tradition, whilst resilience and adaptation theories and concepts can be guided by the social–ecological research and climate change, respectively. This is not to suggest that these concepts and theories should be limited to specific research traditions, but that their meanings and definitions as developed by the guiding fields be adopted and used consistently across the broader research areas. This approach can help to ensure that a concept such as resilience has a common understanding whether used in climate change, vulnerability or social–ecological research. The idea here is to facilitate cross-disciplinary communication within global sustainability research.

Conclusion

This paper reviewed the literature on disaster vulnerability, climate change adaptation and social–ecological resiliency to identify complementary notions of sustainability represented in these broad literature areas. The first objective was to examine how evolutions in theory and methods in these research domains can support an argument for the positioning of sustainability as an umbrella science guiding global sustainability research. The second objective was to contribute to research seeking to develop sustainability as a distinct discipline. The review uncovered key themes from the broad literature that support the framing of sustainability as an umbrella science. The unity of focus and convergence of perspectives themes, in particular, offers strong support for the case of an umbrella sustainability science. The unity of focus theme for instance reveals how these different research areas are united in their distinctive focus on the coupled human–nature systems' responses to all kinds of shocks and system stressors and the adaptive capacity of the systems (Gallopín 2006). The convergence of perspectives theme uncovers improvements in current systems thinking that embraces complexity and surprise in social–ecological systems and the need for integrated interdisciplinary approaches to addressing such complex problems.

An umbrella sustainability science can facilitate cross-disciplinary communication, provide standard definitions of concepts for use across different disciplines and promote integrated interdisciplinary research. This can be effectively done by promoting a standard definition of sustainability science that is specific enough to be meaningful and broad enough to encompass all subfields under it. The definition offered in this paper represents an attempt towards this goal of standardization. The added advantage of an umbrella sustainability science is that it can address the challenge of integrating the different fields of research under sustainability science, as opposed to the current situation where some of the literature treats sustainability as just another branch and complementary research field to resilience, vulnerability adaptation among others (see for instance, Malone 2009; Redman 2014).

The paper also calls the attention of sustainability researchers to undertake special research initiatives that support the building of sustainability as a distinct scientific discipline. Such critical initiatives will complement the few, but important efforts already taking place in this direction (see Bettencourt and Kaur 2011; Clark and Dickson 2003; Jerneck et al. 2011; Kajikawa 2008; Kates et al. 2001; Kates 2011; Komiyama and Takeuchi 2006; Miller 2013; Miller et al. 2014; Redman 2014; Spangenberg 2011; Turner 2010). But as noted earlier in this paper, developing sustainability as a distinct science will require deep reflections and answers to key questions. For instance, when we talk of sustainability science, what kind of science are we referring to? Is it a natural science, social science or different sort of science all together? Also, why should sustainability be considered a science rather than an art and how could the use of one label include or exclude the other (s)? Sustainability scientists need to also understand that the bigger questions for the field of sustainability will not be limited only to how the field promotes long-term sustainability of societies, but it must also involve questions related to understanding and predicting the changing visions of what sustainability means in different temporal and spatial scales. This is important to the questions of how the discipline of sustainability science evolves and what it teaches to future generations of sustainability scientists. Pirages (1994, p. 201) for instance notes, "visions of necessary and desirable changes 20 years from now will be quite different from those which present predominate". Just as Miller et al. (2014) argue that scenario and visioning methodologies are critical in fostering broad-level actor engagements and developing of alternative futures in producing beneficial practical sustainability outcomes, such scenario and visioning methodologies should play critically important roles when considering questions of the future development and teaching of sustainability science as a discipline.

It is also important that the existing journals on sustainability encourage works that investigate the development of a distinct science of sustainability to guide the future development of global sustainability research. This is particularly important because among the varied journals on the field, only Journal of Sustainability Science specifically aims at building sustainability as a distinct and new academic discipline in its purpose statement. The phenomenal growth in sustainability research is both encouraging and provides the motivations as argued in this paper for the development of a distinct science that can direct global sustainability research agenda.

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