The contributions of resilience to reshaping sustainable development

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Abstract

We review the past decade's widespread application of resilience science in sustainable development practice and examine whether and how resilience is reshaping this practice to better engage in complex contexts. We analyze six shifts in practice from: capitals to capacities; objects to relations; outcomes to processes; closed to open systems; generic interventions to context-sensitivity; and linear to complex causality. Innovative complexity-oriented practices have emerged, but dominant applications diverge substantially from the science, including its theoretical and methodological orientations. We highlight aspects of the six shifts that are proving challenging in practice and what is required from sustainability science.

Main

Current approaches to sustainable development will not be sufficient to achieve equitable and sustainable human wellbeing and development, especially in the light of increasingly turbulent, complex and globally interconnected challenges[1]. The search is now on for innovative and transformative approaches that can meet the complex, dynamic and interconnected challenges of sustainable development. Resilience is one such approach which has proven popular, albeit contentious, for sustainability scientists to engage with complex problems in novel ways[2–5]. With roots and applications in multiple disciplines ranging from ecology to psychology and international development (reviewed in [6]), resilience continues to grow as a central concept in sustainability science attracting wide attention[7].

While resilience science has a long history[6], in the last decade the term has become mainstream in sustainable development practice, particularly for addressing complex challenges such as disaster risks, food insecurity, or climate change impacts[8]. It is also proving popular in global policy arenas, including the UN's 2030 Agenda for Sustainable Development which calls for "an inclusive, sustainable and resilient future for people and planet"[9].

Over this past decade, substantial investments, large multi-country programs, global initiatives and long-term commitments by donors and governments around the world have been made under the banner of resilience[8]. Given the recent launch of the UN's Decade of Action, a review that draws together the emerging findings from resilience applications in sustainable development can help clarify contributions, constraints and the future role of resilience science in accelerating global efforts to achieve the Sustainable Development Goals (SDGs) by 2030; especially in ensuring these efforts are attentive to the turbulent contexts and complex dynamics in which they play out.

Within the wide and diverse applications of resilience in sustainable development, we focus this review on the use of theories and methods from social-ecological systems (SES) resilience

(Figure 1). SES resilience has been highlighted as one of the longest standing and more dominant “schools” of resilience[10], which emerged from ecology in the 1970s[11] and has been strongly influenced by theories and methods from the study of complex adaptive systems[12] and more recently by a strong inter- and transdisciplinary engagement to account for factors such as agency, innovation, governance, power, and inequality (see reviews in[13,14]).

Unlike several other schools of resilience, SES resilience adopts a unique emphasis on the inseparability of people and nature[15] depicting these systems as networks of relations and interactions between humans and nonhuman entities[16]. Resilience is viewed as an emergent system property[3] shaped by the interplay between local and system level social-ecological interactions and processes[17]. By acknowledging the complex adaptive and multilevel causal processes of SES resilience, it offers a set of theories and methods to study and engage in complex systems of people and nature in the face of disturbances, surprises and uncertainty[6,17–19]. From this perspective SES resilience is understood to represent the ability of people, communities, societies, or systems to live and develop with change - incremental and abrupt, expected and surprising - and with ever-changing environments[6,13]. It is not limited to the ability to absorb or adapt to change; but also includes the ability to transform with change - to create a fundamentally new system[18].

It is these foundations of (1) complex adaptive systems dynamics and (2) an intertwined perspective on the social and ecological processes needed to live and develop with change (Figure 1) that makes SES resilience science relevant to understanding how to innovatively engage in, and shape the future of uncertain and dynamic contexts of sustainable development efforts[20].

Resilience for sustainable development

As Constas *et al*.[8] suggest, if resilience science is truly innovative and able to create new understanding and actions for sustainable development, then practice that is guided by this science should be distinguishable from mainstream sustainable development practice. To explore these differentiated contributions of resilience further, we analyze and organize our review using Preiser *et al*.'s[21] typology of six organizing principles of complex SES (Table 1).

This typology is developed to offer a framework for identifying approaches that account for the key features and attributes of complex SES. Preiser *et al*.[21] describe different kinds of shifts that would support a move away from the linear approaches commonly used in sustainable development that focus too narrowly on parts of the system towards innovative approaches able to account for complex SES dynamics. From their findings we summarize six respective shifts needed to move the focus of sustainable development from: (1) capitals to capacities; (2) objects to relations; (3) outcomes to processes; (4) closed to open systems; (5) generic interventions to context sensitivity; and (6) linear to complex causality (Table 1 details these organizing principles and resultant shifts).

We describe these six shifts (Figure 2) and use them to analyze and organize our review which focuses on existing reviews in the literature (including evaluations, cross-case comparisons, practice guides and meta-analyses) of the use of resilience in sustainable development practice. Beginning with reviews of large international resilience programs spanning the past decade[22–25], complemented by keyword searches and snowballing from reference lists, we found >40 reviews spanning six continents, multiple scales and diverse sectors of sustainable development.

Using the six shifts, we analyze across these reviews whether, and how, resilience science is helping sustainable development practice to engage with complex problems in novel or distinctive ways that help to capture important dynamics. We further identify areas of unrealized

potential and barriers hampering progress in each shift needed to do sustainable development differently. In line with the UN's Agenda 2030, we have treated sustainable development as more than environmental sustainability and include international and other development efforts and specifically their engagement with the concept of resilience[8].

Six shifts for sustainable development

From capitals to capacities (shift 1). Sustainable development has long focused on measures of natural and anthropogenic capital or assets as the productive base upon which human wellbeing rests[5]. However, in acknowledging the dynamic nature of sustainable development challenges such as disaster risk, SES resilience science focuses instead on diverse capacities required to navigate and respond to such complex dynamics, as well as longer term dynamics. While it may make sense to take stock of the capital that exists and that might serve as resources or buffers to unexpected events, from a complex SES perspective these matter only to the extent they create a dynamic capacity within the system to self-organize, to maintain diversity and redundancies, and to co-evolve in relation to change[21]. This shift describes the need to move away from the conventional static approaches in sustainable development focused on natural and anthropogenic capitals to one centered on understanding the dynamic capacities that shape responses to change (Table 1; Figure 2).

We identify progress, with sustainable development practice having shifted from purely describing assets to acknowledging the importance of the capacities of a household, a community, or regions (e.g. urban areas) to persist, adapt or transform in response or anticipation of changes[24,26–32]. A large effort has been made to identify and strengthen a range of relevant capacities, particularly absorptive capacities (for persistence and recovery) and adaptive capacities (for responding to change, while maintaining essential functions and identity)[27,29,30]. Some increased attention has been paid to transformative capacities (for

breaking down existing systems or specific system dynamics and building alternatives), given the need to change the system dynamics causing the sustainable development challenges in the first place [27,31–36].

However, while research shows that it is specific capacities such as learning, reflexivity, navigating across scales, and responding to emergent processes or features that may be the most crucial for transformation[36–38], practice remains predominantly focused on building absorptive and adaptive capacities to respond to and recover from disasters and climate change related events (e.g. investments in livestock fodder reserves, early warning systems)[30,33]. A focus on capacities for transformation would challenge the existing risk-reduction approaches dominant in sustainable development, which often fail to address the complex causes of vulnerability and resilience-erosion, preferring to support adaptations to existing conditions[27,28,35].

Moreover, while there is a recognition of the need to focus on capacities in order to consider broad sets of complex dynamics (see [35]), we found the majority of the work reviewed still focuses on capitals (e.g. communal natural resources, income or human capital) rather than capacities, even though the word “capacity” is frequently used. Many reviews highlight that most practice remains largely aimed at understanding how to use existing, or invest in new capitals to strengthen the capacity to respond to disasters or to climate change impacts[27,29,39–41]. Capitals have been shown to be ineffective as proxies for capacities for multiple reasons, including that they: limit understanding, treat capacities as additive or substitutive (i.e. like assets), obscure dynamics among capacities and the ways that these interact, create redundancy, undermine or enhance one another, and rely on assumptions that the capitals that worked in the past will help to respond to future challenges[29,39,42,43]. A few exceptions were identified with some resilience initiatives beginning to explore dynamics and processes as capacities for transformative change

such as shifts in attitudes towards innovation[31], changes in cultural gender norms[44], agency and leadership[30] and these could inform future research and practice.

Ultimately, while the idea of focusing on capacity has been embraced in the discourse used surrounding resilience investments, we found the result has been a proliferation of indicators and metrics listing different capacities that often times simply reproduce capital-oriented metrics; with methods that struggle to differentiate between absorptive, adaptive and transformative capacities. This makes cross-comparisons, syntheses and learning across cases problematic[29,45]. Implementing this shift in practice is constrained by how most projects are designed and evaluated, where an overriding sense of instrumentality and a static approach to equating capacities with local-scale capitals and assets has stymied progress. Such challenges with linear and static design and evaluation approaches have been recognized as - at times - undermining resilience and project goals[26,28,42].

From objects to relations (shift 2). Despite broad acceptance of the interconnected nature of sustainable development challenges, practice still often resorts to breaking them down into separate components or objects which are then targeted by interventions[13]. This tendency to break systems into parts ignores the fact that complex SES have emergent behaviors and properties including resilience, which are not the same as the sum of the parts[17]. In fact, complex SES and their resilience are defined more by relationships than the parts themselves[21]. To apply SES resilience from this perspective, sustainable development needs to shift from focusing on distinct, independent objects to the dynamic relationships that shape resilience and sustainable development pathways[17,26] (Table 1; Figure 2).

Evidence indicates one aspect that has begun to shift includes the many studies and programs highlighting the importance of relationships, often with an emphasis on social relationships such as social networks and community relationships and their role in resilience[25,27,41,44,46,47].

However, when tracked through resilience programming, these relationships are mostly represented as measures of social capital which tend toward more object-oriented measures of relationships (e.g. numbers of relationships, household access to information), thus exemplifying how the concepts of resilience may be taken up in discourse, but practice lags behind. A few reviews highlight new qualitative approaches to social capital indicators (e.g. questionnaires focusing on strength and types of ties within networks, processes of social cohesion, mapping of social networks), which offer potential avenues to move away from these object-oriented approaches for capturing relationships (e.g. [38,48]). Despite the importance of ecological and social-ecological relationships in shaping resilience found in some reviews[37,40,49–51], they were not commonly focused on in practice, with most sustainable development interventions largely ignoring the dynamics of social-ecological or people-place interactions (e.g.[46,52]).

While there is an increasing recognition of the need for systems approaches that capture the multiple components and their interactions that shape resilience[31,32], in practice the social and ecological components are treated as objects that are separable, rather than as intertwined and therefore neither separate nor separable[17,26]. These approaches fail to recognize that no component or object can be correctly analyzed separate from the relationships that define it. Several reviews point to the need to move from property-focused analysis to relationship-focused analysis[53] and propose a focus on feedbacks and especially social-ecological feedbacks as an avenue for such a shift in sustainable development practice[40,43,53].

A move to relational approaches is evident in other areas of sustainable development beyond resilience, including human wellbeing[54], water security[55] and in sustainability science[56,57]. While currently less common in resilience programming, relational approaches are emerging and they are helping to foster new analyses and frameworks for action (e.g. [40,49,50]). In these instances the approaches are proving useful in understanding: how relationships enhance and undermine

resilience - including social-ecological relationships that are often neglected in practice[34,40]; how social-political processes are involved in creating vulnerability as a relational state[28,35]; the relational nature of information and its use in early warning and other observation systems[48–50]; and in introducing new methods to analyzing systemic interdependencies of resilience[37,53,58,59]. Most importantly such approaches appear to overcome problematic divisions between nature and culture[40,49,50], and shift the focus to the quality of relationships and the reconfiguration of relationships required for resilience and sustainable development[36,41,43,60].

Barriers to implementing this shift include many of the divides or silos between sectors, donor agencies, and project scales that perpetuate the need to break sustainable development into its parts rather than to focus on the behavior of systems as a whole over time[39,59]. An additional impediment to progress is that many of the knowledge systems that have long held more relational views on SES[49,50,58,61] are excluded from mainstream sustainable development research and practice, which is dominated by more reductionist and therefore object-oriented perspectives[56,57].

From closed to open systems (shift 3). The study of complex SES highlights that the boundaries of systems are fluid and porous, which means that defining system boundaries is not trivial and risks excluding factors or processes that could have important influences on a system's behavior[21]. This situation is made more complex in the hyperconnected globalized situation of the Anthropocene, where it is not only neighboring systems that can influence a system and its resilience, but far lying, regional and global systems which can affect and be affected by the system of interest[13]. This dynamic exchange implies that a shift is needed from treating boundaries as static to a recognition of boundaries as porous, dynamic, and artificial and in need of continuous review in collaboration with those involved and affected by that boundary (Table 1; Figure 2).

Some progress in making this shift is evident in the use of resilience in sustainable development practice through the use of two commonly used approaches: resilience assessments (e.g. [19,32]) and modelling (e.g. [53]), both of which require a system to be defined and thus, somehow "bounded". When done through participatory or co-production approaches, and complemented by other qualitative methods, these approaches can be useful for making boundary judgements transparent and legitimate to those that are involved[19,53]. However, many projects and initiatives have been found to pay inadequate attention to interconnections across scales with important consequences for equity and justice [28,35,62]. Several studies point to the critical role of broader social and political processes and networks that enable or constrain resilience and wellbeing outcomes, which remain unexplored and unaccounted for in sustainable development practice [28,29,35,43].

While there are methods available in resilience science that account for the impact of external factors and cross-scale dynamics[63] and methods able to trace the flows stemming in and out of the focal system to progressively redefine its boundaries[64], their uptake remains limited in practice. We found the dominant depictions of projects and funding were spatially bounded to a community or a study site that remained fixed and little emphasis was placed on factors and dynamics surrounding, and in relationship to, that defined geographic area[28,35]. In fact designs of such projects often force a static boundary because of their need to measure changes in the system (often as numbers of households) over the period of the project[60], which is often the case when resilience is narrowly depicted as recovery time for a household to "bounce back" after a shock (e.g. [24]). Calls remain ongoing for sustainable development investments to better grapple with the long-term, cross-scale social and political processes that affect whether specific interventions will be effective for general resilience and to consider the relationship with capacities, recognizing that capacities within a system will shape how effectively actors can identify and address cross-scale dynamics[28,34–36,43].

From outcomes to processes (shift 4). Sustainable development practice predominantly views success as making progress on a set of short-term and static outcomes such as targets of protected area extent or levels of household income[9]. Such a view cannot account for the continuously changing, non-linear, and relational nature of complex SES. Each change in a SES, be it endogenous or exogenously induced, will influence and be influenced by processes of change that will shape the system pathway in often unpredictable ways[21]. Viewing sustainable development as a dynamic process shifts the focus from only understanding what constitutes a desired outcome, to the process of sustainable development and how different development pathways emerge and are maintained or shifted (Table 1; Figure 2). It does not do away with outcomes, but moves from viewing outcomes as fixed endpoints to depicting them as being shaped by, and shaping, the processes of sustainable development[26].

This tension between outcome and process has been highlighted as important in resilience science, due to the risks that depicting resilience as an outcome raises, given that treating resilience as a single number or result can obscure important SES dynamics[65]. Some acknowledgement of the need to move away from focusing on outcomes alone exists in practice, moving toward approaches that are long-term, process-oriented, and founded on systems approaches[23,31,32]. However, the majority of sustainable development practice using resilience remains focused on a set of short-term outcomes determined as needed to respond to shocks and discrete events, with little acknowledgement of the dynamic and continuously unfolding nature of development[8,22,25,33,46,52,66] . As several reviews highlight, the focus on resilience, wellbeing and various capacities as narrowly defined outcomes, comes at a cost with insufficient time spent reflecting on project design, evaluation and impact metrics, and the relationships between outcomes and processes[27–29,36,41,53,60].

The little progress that has been made in adopting a more process-oriented view appears to occur when the focus shifts to: transformative change[27,31], frameworks for social change

processes[31,36,41], learning and experimentation[32,37,40] and emergence[19,36]. Recent scientific advances propose that rather than considering resilience as an outcome, it can be better understood as sets of capacities that filter and direct development pathways, shaping whether systems adapt or transform in response to change[26].

Resilience assessments have proved a popular avenue in practice for trying to build a more process-oriented understanding of how complex systems change, to highlight their dynamics and to determine what shapes the complex capacities of resilience and how resilience in turn shapes development pathways[19,32,65]. However, these often fall short through, for instance a reliance on analyses that separate out social and ecological objects, hampering shifts to relational and process-oriented views. We also found that in large scale evaluations of resilience investments, many resilience programs are constrained by funder requirements around impact measurement at the project and local levels of implementation[22,24,25,52], re-emphasizing outcomes as fixed end points, to the detriment of process-oriented approaches.

From generic interventions to context-sensitivity (shift 5). Much has been written about the problems with relying on generic interventions (or blueprints and best practices) in sustainable development and the need for it to better consider context[67]. From an SES perspective, context is dynamic and emerges from social-ecological relations at different spatial and temporal scales[21]. This implies that system behaviors relevant to sustainable development emerge from patterns of dynamic interactions that shape, and are shaped, by their context[17]. Applying this shift in practice requires an appreciation of the complex interplay between intervention and context (Table 1; Figure 2).

In sustainable development practice, context is often represented as a local-scale, unique or idiosyncratic place and time [25,27,30,33,41,66] excluding the possibility of generalizable interventions. However, some reviews make clear that context is not just local and static, but cross-scale,

dynamic and emergent, thereby depicting context not as purely idiosyncratic, but as a recognizable pattern of specific dynamic relationships[26,40,60]. This has helped to formulate a middle ground that considers both context-sensitivity and the interplay between contexts and interventions, rather than solely focusing on context-dependence.

Resilience science offers approaches such as social-ecological syndromes, archetypes, middle-range theories, or contextualized generalizations to identify local recurring contexts, recognizable patterns of social-ecological relations, mechanisms, and the contexts under which specific mechanisms are most likely to be effective[68–70] These approaches encourage the exploration of questions such as “what about context can be generalized for context-sensitive interventions?” and a move towards a process-oriented understanding of the types of interventions that might work in relationship with certain types of contexts. Few reviews found evidence of these approaches (but see [39,40,60]). Those that did find evidence of this shift make clear that an intervention (or even a shock) is not a discrete and independent event, but rather a process of transforming or reconfiguring relationships that shape and are shaped by context and in turn the intervention is affected by and evolves with the context [26,35,39,43].

By working to foster understanding of how the problem under consideration is created or perpetuated by relationships of a given context, the intervention is expected to have different effects based on the relationships one is trying to change. Further progress has been made possible by exploring the role of cross-scale dynamics[36], social-ecological relationships[26,40,49,50] and phases of transformative changes[43] as process-oriented interventions aiming to reconfigure specific relationships shaping contexts. The intervention from this perspective can only be understood and described in tandem (not in isolation of) the system structure, functions and processes it aims to disrupt.

The appeal of generic interventions is proving to be a challenging barrier to overcome in making this shift in practice. The urgency and scale of sustainable development challenges makes

interventions, especially technological ones that can “scale” both quickly, and without the costs associated with deep engagements to understand context-intervention interplay very appealing[39,60]. This is apparent in several resilience programs which call for “winning solutions” and even the SDGs focus on “accelerated actions”. However, without consideration of how the context and problem “scale” and interact, such interventions are unlikely to work as expected, which suggests an ongoing need to explore how problems scale, out, up and deep to form a stronger basis of contextual understanding[71,72].

From linear to complex causality (shift 6). Underlying much of sustainable development research and practice is the search for effective interventions to bring about a desired outcome. Beneath this search lies assumptions about why and how things work that often remain unexplored or hidden. Much of sustainable development practice is built on assumptions of linear cause-effect relationships, rather than acknowledging complex causality and its implications for understanding and affecting change in SES[21] (Table 1; Figure 2). Implementing a shift toward complex causation entails (i) dealing with multiple social-ecological causes whose interactions may involve multiple spatial and temporal scales, (ii) accounting for recursive causal pathways where an effect may feed back on its cause, and cause and effect are entangled, (iii) dealing with emergence and thus the novelty, unexpectedness and uncertainty of how processes evolve, and (iv) the co-constitution and co-evolution of phenomena through intertwined social and ecological processes[17].

Progress in practice is limited in making this shift, with dominant assumptions of linear cause-effect clearly present, such as linking post-disaster recovery and wellbeing with specific project interventions or food security after a drought with specific capacities in which investment has been made[22,46,52,66]. However, some aspects of complex causality are starting to be recognized within the monitoring, evaluation, and learning (MEL) communities typically responsible for

evaluating the impacts of sustainable development interventions[73]. Reviews highlight the need for more investment and time allocated to evaluate the complex non-linear interactions between programs and their outcomes[23,39,51,60].

Within the small sub-set of applications where progress has emerged, examples include the application of developmental evaluation[36], which is designed to support transformation as it unfolds; that is, when a predictable or linear impact is not possible to define at the outset. Additionally, complexity-informed theories of change and complex "resilience causal chains" have been used to inform project design and better account for complex problems and interventions[44,60,74]. Further, some new resilience assessment frameworks consider aspects of complex causality[19,27]. However, evidence also shows the difficulties and risks that arise when projects adopt these complexity-aware approaches to sustainable development, such as funding cuts that occur when a project does not follow a conventional logic model (e.g. [60]).

It is widely recognized that international development agencies' own linear logic frameworks and requirements for monitoring and evaluating impacts for resilience have created disincentives to consider complexity (e.g. [22,24,25,52]). Further, Eriksen *et al*. [28] show how an analysis of non-linear and emergent effects reveals why many projects that were expected to build adaptability and resilience actually end up worsening vulnerability and eroding resilience. Several reviews highlight the mismatch between the "causes" that are often focused on in more linear projects, and the social and political complexity or the relationships of interest and concern, a mismatch that risks further reinforcing marginalization and inequity [27,29,35].

The fact that development outcomes and processes are emergent and dynamic implies that causal models -even those which consider some limited aspects of complexity- and specific outcomes may not be able to be developed in advance of an intervention[73]. This poses challenges given that it means projects that aim to strengthen resilience need to become embedded and shaped by the co-evolutionary processes of development instead of trying to

steer a few variables according to *a priori* identified cause-effect relationships. This is a very different model of sustainable development and further makes pre- and post-comparisons for proving impact or success difficult[60].

New directions

Our review highlights emerging, albeit limited, innovative practices and areas of progress in using resilience science to reshape sustainable development for complex contexts. The advances that do exist help to demonstrate that it is possible to operationalize resilience science in sustainable development practice in order to engage and intervene in complex contexts in an innovative manner[10]. While complex dynamics cannot be controlled nor their outcomes predicted, we show that SES produce recognizable patterns and behaviors that can and have been understood and navigated. Applications of resilience science have helped to add important innovations, such as the move away from local - global tensions to focusing on cross-scale dynamics (shift 5). In so doing, the shifts help to find a way forward in navigating many of the existing tensions or dichotomies of sustainable development (e.g. top-down vs. bottom up; idiosyncratic vs. generalizable; structural vs. agency; social vs. ecological). By drawing on the complex systems foundations of SES resilience, the six shifts suggest opportunities and practical ways forward in the upcoming UN Decade of Action to navigate such tensions and the paradoxical discourses and practices that have become embedded in resilience and sustainable development initiatives and programs[26,32,40].

Worryingly, we found strong evidence of a substantial gap between what resilience science suggests the focus and approach should be when engaging in complex systems and how this is implemented in practice. This is particularly the case with large programs, their evaluations, and large reviews of empirical cases[22,24,25,27–29,46] Most of these highlight a continuing focus on capitals, objects, outcomes, and generic interventions, often at local and bounded scales, with a

prevalence of (often implicit) linear assumptions of causality. Across the six shifts it is clear that resilience science and sustainable development practice are not yet meeting in ways that are helpful to engage with the dynamic, social-ecological interdependencies of sustainable development.

We found that rather than simply requiring new methods or sources of data to overcome these barriers, deeper changes in philosophical, theoretical and methodological orientations are required[28,39,40,60]. To be able to bring resilience science and sustainable development closer together will require a shift towards novel, complexity-oriented paradigms to guide research and action for sustainability[56,57]. As paradigms shape how we study, choose methods, collect data and engage in research and practice, becoming more aware of the dominant and alternative paradigms in sustainable development is critical. The current dominant reductionist paradigm shaping much of the way resilience ends up being used in practice diverges from its scientific theory and was found to hamper progress in making shifts to more innovative approaches. While “operationalizing” a theory in practice will always require choices, applying it using a different paradigm creates divergence that dilutes and compromises resilience, both as a theory and its potential in practice. The result is programs and practices touted to be about resilience are then often found to be misleading, unethical, and actually eroding SES resilience[21,28,35,60]. Our review of the six shifts showed changes are needed, including, or especially, in the paradigms underpinning the approaches to resilience programming, with several studies pointing towards alternatives that adopt more process-relational and complexity-based perspectives in sustainable development[58,67,75].

As the world gears up for the “Decade of Action” left to achieve the UN’s 2030 Agenda for Sustainable Development[9], there is a need to recognize not only the urgency of the challenges, but also to better reflect their complexity by rethinking and reorienting sustainable development. Making these shifts in sustainable development practice is not simple but neither is it impossible

nor implausible given the examples of progress we identified. Moreover, it is clear from the review that progress made in one shift enables progress in others, with the shifts themselves being intertwined. Such an observation helps make the idea of reshaping sustainable development less overwhelming through the potential for positive feedbacks between progress in the shifts. It is not necessary to adopt all shifts before making progress, as using these shifts in whatever configuration is suitable will bring other shifts along in the process.

Taken together these shifts, and barriers to making the shifts, point to new directions for resilience science and sustainable development and the potential benefits of building closer links between these two areas of research and practice. Efforts to explore and advance these new directions will further require investments to build and mobilize capacities for researchers, practitioners and policy-makers to solve complex problems and engage in complex contexts outlined in these shifts[36,37]. Such capacities may need to be developed in certain areas and groups, but in others these capacities already exist but have been marginalized by dominant approaches to sustainable development and require efforts to halt that marginalization and enable them (e.g. [35,49,50,61,76]).

Contributions

All authors (BR, MLM, LJH, MS) contributed to the conception, design, and writing of the manuscript and its revisions. BR and MLM led the review, analysis, and revisions. All authors discussed and contributed to the final manuscript.

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Table 1: Six organizing principles for complex social-ecological systems from Presier *et al*.[21] Contrasting the six principles with current linear approaches to sustainable development reveal the need for six resultant shifts in the focus of study and choice of methods in sustainable development. Illustrative examples of progress are drawn from the reviewed literature, while examples of barriers to progress for each of the six shifts are also summarized.

Organizing principles for Complex Adaptive Systems (CAS)	**Shift number and label**	**Description of shift in research and practice**	**Example of progress**	**Barriers to progress in making the shift**
CAS have adaptive capacities	1: From capitals to capacities	From a focus on natural and anthropogenic capitals to an understanding of the dynamic capacities that shape responses to change.	Some progress challenging the notion that capitals differentiate responses to events. Resilience found to depend on the capacities at multiple scales for coordinated decision-making, collective action, innovation and experimentation [36,38]	A dominant instrumental focus to resilience programming and measurement that returns the emphasis to assets and capital.
CAS are constituted relationally	2: From objects to relations	From a focus on distinct, independent objects, to the dynamic relationships between social and ecological objects.	A relational approach to analyze ecological and social processes and interactions that shape resilience of family farms[40]	Compartmentalized nature of sustainable development forces a focus on objects, which together with a dominant reductionist approach to sustainable development prevent more relational approaches.
CAS are radically open	3: From closed to open systems	From determined and static boundaries to porous, dynamic and fluid boundaries.	Proposal of principles to help define and make boundary judgements[53]	Funding, design and impact evaluation of projects linked to inflexibility of spatially bounded communities or study sites.

Dynamic processes generate CAS behavior	4: From outcomes to processes	From a focus on outcomes as fixed endpoints to outcomes as shaped by and shaping the processes of sustainable development	A coevolutionary perspective of the interplay between social and ecological systems and resilience capacities in agro-ecological systems[26]	A dominant focus on sustainable development as targets as end points prevents or dilutes process based approaches.
CAS are contextually determined	5: From generic interventions to context-sensitivity	From generic interventions to the complex interplay between intervention and context.	Non-linear behavior as key for understanding a contextual response to an intervention[39]	The urgent search for generalizable and scalable interventions dilutes efforts and time required to be context-sensitive.
CAS have novel qualities that emerge through complex causality.	6: From linear to complex causality	From assumptions of linear cause-effect relationships towards complex causality	Highlighting the complexity of resilience causal chains[44] and example of a non-linear theory of change for development programs[60]	Linear theories of change or logic models that direct many development projects are often determined by the funder.

Figure captions

Figure 1: A graphical representation of the social-ecological systems (SES) school of resilience: a complex adaptive systems based perspective on the intertwined, multilevel and dynamic SES processes, interdependencies and relationships that shape resilience (Graphic by Jive Media Africa).

Figure 2: Six interconnected and intertwined shifts move sustainable development away from commonly used linear approaches towards innovative approaches able to account for complex SES dynamics. We review the contributions and constraints of SES resilience science and its use in sustainable development to make progress across these shifts. See text and Table 1 for more details on the shifts (Graphic by Jive Media Africa).