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Social-Ecological Systems
Insights for Navigating the
Dynamics of the Anthropocene

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Abstract

Social-ecological systems (SES) research offers new theory and evidence to transform sustainable development to better contend with the challenges of the Anthropocene. Four insights from contemporary SES literature on (a) intertwined SES, (b) cross-scale dynamics, (c) systemic tipping points, and (d) transformational change are explored. Based on these insights, shifts in sustainable development practice are suggested to recognize and govern the complex and codeveloping social and ecological aspects of development challenges. The potential susceptibility of SES to nonlinear systemic reconfigurations is highlighted, as well as the opportunities, agency, and capacities required to foster reconfigurative transformations for sustainable development. SES research proposes the need for diverse values and beliefs that are more in tune with the deep, dynamic connections between social and ecological systems to transform development practice and to support capacities to deal with shocks and surprises. From these perspectives, SES research offers new outlooks, practices, and novel opportunity spaces from which to address the challenges of the Anthropocene.

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INTRODUCTION: A NEW CONTEXT FOR SUSTAINABLE DEVELOPMENT

Ensuring all human beings enjoy prosperous and fulfilling lives in harmony with nature and planetary life support systems has long been at the heart of global discussions and treaties on sustainable development (1, 2). With mixed success over the past 50 years across interdependent dimensions of economic, social, and environmental progress, the challenge of sustainable development remains at the forefront of global agendas (3). Although the concept of sustainable development is far from new (e.g., 4), the context in which it now must be achieved is. Accruing evidence that the human imprint on the planet now shapes the world at global scales raises the challenge of sustainable development in a dynamic and uncertain Anthropocene (5, 6). The Anthropocene—the age of humans—has resulted in an interconnected global culture with cross-scale interactions connecting people and places in new ways, in turn resulting in novel and dynamic local, regional, and worldwide dependencies (7, 8). Escalating environmental changes interact and connect across scales with large social and economic changes, triggering feedback loops, abrupt change, turbulence, and increased exposure to new types of risk (9–11). The speed, connectivity, and scale of the Anthropocene increase the potential for more intense and frequent stresses, shocks, and resultant protracted crises, placing sustainable development in a fundamentally new context (e.g., 12–16).

Resilience in Dynamic Contexts

Resilience has emerged as a popular approach or concept to rethink and reshape development for dynamic and turbulent contexts. Resilience is a term that many disciplines, sectors, and policy arenas use (see reviews in 17–23). In some arenas, the term has been used to refer to the return rate to equilibrium upon a perturbation, i.e., bouncing back or recovery time after a disturbance (e.g., disaster resilience; 24), often with an implicit focus on trying to resist and control change. In other arenas, resilience is linked to adaptive capacity and the notion of coping with and adapting

to changes (e.g., climate resilience; 25). One of the longest standing “schools” of resilience is the social-ecological systems (SES) school, which emerged from ecology in the 1970s (22, 26–28). From the SES perspective, resilience is not limited to the capacity to absorb or adapt to change; it also includes the ability to transform with change. Transformability is the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable (29, 30).

A Contemporary Social-Ecological Systems Perspective on Resilience

The SES approach to resilience was founded on the theories of complex adaptive systems and their conceptual underpinnings of nonlinear dynamics, and uncertainty, as well as notions of multiple stability domains and adaptive management. As one of the longest standing and more dominant schools of resilience research (22), the SES approach continues to evolve (see review in 20; republished in 21). Maintaining its legacy of complex adaptive systems science, and its unique emphasis on the inseparable nature of people and the planet (27), it has built into its theory additional elements and concepts. Examples include the role of agency in social change (31), the importance of social-ecological innovations (32, 33), the function of social organizational forms such as networks in system dynamics (34–36), and the forms of governance linked to sustainable development in the Anthropocene (37, 38). Additionally, various coproduction and participatory approaches, as well as the role of collaborative learning within a range of scientific and policy processes have been empirically tested (39–42). The experiences of mobilizing and combining diverse knowledge systems (43–45) have been detailed. New models and frameworks drawn from SES research have been used to redefine issues related to poverty traps (46), power distribution and equity (47–50), and the role of culture in sustainable development (51–54).

On the basis of this evolving and growing interdisciplinary theoretical sophistication, contemporary SES resilience is now understood to represent “the ability of people, communities, societies, or cultures to live and develop with change and with ever-changing environments. It is about cultivating the capacity to continue to develop in the face of change, incremental and abrupt, expected and surprising” (20; republished in 21).

INSIGHTS FOR SUSTAINABLE DEVELOPMENT FROM SOCIAL-ECOLOGICAL SYSTEMS RESEARCH

It is apparent from its transdisciplinary evolution that the contemporary body of SES theories, concepts, and approaches (hereafter referred to as SES research) is fundamental to, but much wider than, the concept of resilience as a property or capacity of SES. This wider body of knowledge on complex SES and their dynamics appears well-matched with the current challenges faced as societies strive to develop, to address increasing disparities and limited choices, and to prevent further degradation of the planet, in the face of the complexity and turbulence of the Anthropocene. This review focuses on the body of knowledge of SES research, from which we distil and explore four main insights (**Figure 1**). They represent a set of unique transdisciplinary insights of relevance to sustainable development in the Anthropocene, complementary to, but different from, lessons learned in other areas of resilience and sustainability research (e.g., 19, 55). They include the intertwined nature of SES, the pervasiveness of cross-scale dynamics, the anticipation of systemic tipping points, and capacities and criteria for transformational change. These insights each suggest new approaches and shifts in current sustainability thinking and practice, which we explore below by presenting recent major theoretical contributions underpinning the insights, followed by some emergent implications for sustainable development in the Anthropocene.

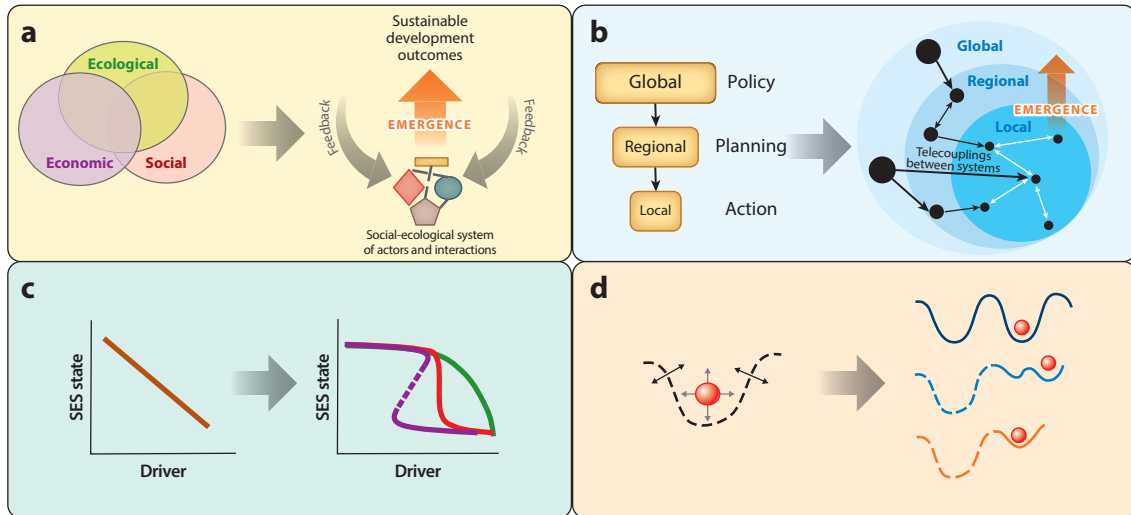


Figure 1

Schematic representation of the shifts in sustainable development thinking and practice, as suggested by our review of social-ecological systems (SES) research, (a) from interdependent pillars to inseparable complex social-ecological systems, (b) from local action to cross-scale dynamics, (c) from incremental change to systemic tipping points and shifts, and (d) from adapting to change to transforming for change.

Insight 1: From Interdependent Pillars to Inseparable Complex Social-Ecological Systems

The current three-pillared notion of sustainable development recognizes the role of ecosystems, economies, and societies in achieving development targets (3). It further acknowledges the interdependent nature of human and environment systems through the flow of materials, energy, and waste between these systems, and it places a large emphasis on avoiding or negotiating trade-offs between the pillars or systems (56). Concepts such as ecosystem services, natural capital, and planetary boundaries have served to cement the place of the environment and ecosystems in sustainable development policy (57–60). Despite this progress, SES research suggests that the pillared view on sustainable development is inadequate in its separation of social and ecological systems into sectors and policy targets with underlying assumptions of reducibility, linear trade-offs or synergies, and separability.

The delineation of social and ecological systems. While recognizing the role and importance of social (including economic) and ecological systems in development, SES research adopts a more integrated vision of these systems as not just overlapping and interdependent, but inseparable. This view is founded on the concept of the SES that Berkes & Folke (27) proposed as an integrated approach of humans-in-nature. They point out that in the social-ecological approach “the delineation between social and natural systems is artificial and arbitrary” (27), emphasizing the embedded nature of society within the biosphere and the long history of societies and ecosystems shaping and being shaped by each other. Acknowledging the inseparability of SES presents a different entry point for exploring the challenges of sustainable development, bringing to the fore theories of social-ecological emergence, coevolution, and diversity (e.g., 61–64), which cut across a large and often fragmented literature, as well as empirical studies of these strong relationships (e.g., 65, 66).

In sustainable development policy, there is a tendency to deconstruct and separate the social and ecological components relevant to sustainable development, to understand their properties and

trends, and from this to try and understand (or reconstruct) trade-offs, future trends, and responses (e.g., 56, 67). SES research highlights that the properties, behaviors, and trajectories of complex SES cannot be determined by the microlevel social or ecological entities or subsystems and their properties alone. In SES, agents or entities interact, and from such interactions macrolevel patterns with new properties emerge, which then feed back on the system and influence the microlevel interactions of the agents (e.g., 63, 68) (**Figure 1a**). This interplay between the adaptive responses of the entities and the emergent properties of the system implies that SES are more than the sum of the ecological or the social “parts.” It is only through a focus at the macrolevel of emergent phenomena that explanations of things such as resilience as a system property, tipping points, the evolution of norms, or adaptive capacity, which are crucial to sustainable development, are offered (63, 69, 70). Shifts to policy interventions, targets, and adaptive management, which acknowledge and are based on the system’s irreducible complex structure, are proposed for sustaining desirable system outcomes (e.g., 57, 71–73).

An emergent lens on system dynamics. A macroscopic focus on SES emergence has been useful to highlight the social-ecological coproduced nature of ecosystem services and human well-being (74–76). Such a focus helps to move beyond earlier conceptualizations of linear and separable biophysical supply and social demand for natural resources, ecosystem services, and ultimately human well-being to a more emergent, dynamic and process-based perspective on these (77). Examples include studies of cognitive function and mental health (78), extensions on poverty-trap approaches (46), microbial diversity and human health (79, 80), and multidimensional well-being (81, 82). Similarly, a macroscopic emergent perspective on sustainable development shifts the focus from simple, linear trade-offs between environment and development to theories and approaches for understanding causality in complex SES (83, 84). Rejecting the possibility of direct cause-effect analyses at the microscopic level, SES approaches reveal the role of feedbacks, power asymmetries, external factors, system structures and processes, as well as temporal and spatial scale dynamics that significantly affect development outcomes (e.g., 41, 83, 85–87).

The inseparable, embedded, and dynamic nature of SES also brings to the fore the codeveloping and coevolutionary nature of SES (e.g., 61, 88–91). This perspective emphasizes that people, economies, societies, and cultures shape, and are in turn shaped by, ecosystems. Although historically these patterns of codevelopment were often local and readily apparent, recent shifts in food production, urbanization, globalization, and trade have served to make these connections more widely dispersed over time and space (55, 86).

Social-ecological diversity and resilience. Social-ecological coevolution theories emphasize that diverse social and cultural contexts will shape, and be shaped by, diverse ecosystems in complex and continuous ways (88, 92). The resultant diversity is the focus of much SES research, which emphasizes the importance of diversity in actors, ecosystems, institutions, and social-ecological interactions as sources of resilience. These sources create and enhance the novelty, knowledge, behavior, and strategies required to respond to shocks or ongoing change (62, 63). The relationship between diversity and resilience is, however, not linear (62). Concepts such as response diversity, functional diversity, and redundancy are linked to tolerance of change, renewal and adaptation to change, as well as opening up pathways for transformation (93). Leslie & McCabe (94) highlight the role of response diversity in human actions and decisions to the resilience of SES and thus to sustainable development in the Anthropocene.

Implications for sustainable development. SES research suggests that many of the challenges of sustainable development are caused or reinforced by the lack of recognition of the deeply

intertwined nature of complex SES. Rapid urbanization, technological advances, the resultant decoupling from local environments and places, and the homogenization inherent in this process have not made SES less inseparable; they have, however, made the new couplings and dynamics more invisible, complex, cross-scale, and rapidly changing (95). The resultant feedbacks and their impacts on the codeveloping and intertwined futures of ecosystems and society are of great relevance to sustainable development in areas including global food systems and human health (96), urban planning and mental health (97), and persistent poverty (46). Moving beyond the notion of sustainable development as separable human development targets constrained by environmental or natural resource limits, to an inseparable SES perspective on sustainable development, offers a fresh perspective on sustainable development (**Figure 1a**). It further offers a novel and expanded opportunity space from which to address the challenges of the Anthropocene (33).

Beyond highlighting the risks of assumptions of separability and reductionism, SES research further points to new ways of recognizing and strengthening these connections from local to global scales in areas of practice from local-scale initiatives (98) to global collaborations (99). New approaches for measuring systems change, properties, and emergent behaviors (57, 74, 100) offer complementary alternatives to the current focus on sectoral policy targets. Furthermore, SES research offers innovative ways to conceptualize the codependence of social and ecological aspects of development challenges in areas such as poverty traps (46, 83), food systems (71), the management of crises and variance (101, 102), and stewardship and adaptive governance (103–106).

Insight 2: From Local to Cross-Scale Dynamics

Recognizing the intertwined nature of social and ecological systems, SES research also highlights the multi- and cross-scale nature of these intertwined SES connections and feedbacks across time and space (28, 107–109). While these cross-scale dynamics have always been part of planetary functioning, the Anthropocene further magnifies the importance of existing and new dynamics for development due to the novel levels, types, and complexity of connectivity created by globalization, the scale and spread of the human dimension across a range of ecosystems, and the speed at which social and ecological impacts are experienced (6, 110, 111).

Social-ecological connections and systemic risk. The Anthropocene context of novel and dynamic interconnections between sectors, scales, and regions presents new challenges for sustainable development, particularly through the emergence of globally networked risks (9), referred to as systemic risks (10). Interest in the properties of such systemic risks cuts across a large interdisciplinary literature, including the study of cascading ecological crises (103), nested vulnerabilities (13), networked threats (e.g., 112), femtorisks (113), and transboundary crises (114; see 11 for a review).

Although most of the systemic risk literature has focused on the social and technological domain rather than the social-ecological, there is an increased recognition in SES research that such risks may evolve from the interplay between humans and ecosystems at multiple scales (**Figure 1b**). The term telecoupling, as an example, elaborates the social and environmental flows that may create such transboundary connections (55), as a complement to previous advances in our understanding of biophysical transcontinental connections denoted as teleconnections (115). The cross-scale interconnection between the social and ecological can be illustrated through recent insights on the scale of moisture recycling introduced through the concept of precipitation sheds. Nearly 20% of annual average continental precipitation is the result of moisture recycling from terrestrial ecosystems, within and between continents, with several areas receiving almost half their annual rainfall this way (116). The concept of precipitation sheds implies that land-use decisions by one country or region can substantially influence rainfall patterns and related risks in other countries

or regions, with diverse impacts ranging from food production, urban drinking water supplies, or hydroelectricity production, as well as the potential to alter the available flows and water quality variables key to aquatic species and wildlife (116).

Social-ecological telecouplings linking scales and sectors. Social-ecological “telecouplings” may unfold across regional biomes (e.g., the ecological footprint of cities; 117), ecosystems (e.g., land-use changes and increased demand for freshwater associated with the expansion of aquaculture; 118), and societal sectors (e.g., financial shocks interacting with environmental change, such as the increasing financial risks associated with rapid climate change; 119). Recent global changes in the international corporate (120) and financial (121) systems, as well as increased global trade (122), can also create unprecedented teleconnections across biomes and regions. For example, a handful of global keystone actors, such as multinational companies in the seed or seafood business, can create waves of change across the globally intertwined SES (123). Several studies also elaborate the connections between changes in patterns of consumption and distal social-ecological consequences (15, 124). As a result, swift changes in norms, consumption patterns and policies, or even a lack of adaptability to changing circumstances may have larger-scale or distant social-ecological impacts as these propagate across global commodity and ownership chains (e.g., 86, 99, 125).

Implications for sustainable development. Sustainable development, which typically focuses on global and national policy and planning scales with local-scale implementation (55, 72), now has to grapple with a dynamic cross-scale context. In the Anthropocene, the local is no longer local, but, rather, is shaped by broader social-ecological dynamics and drivers (95, 126, 127). Furthermore, the global is not just global, but is also shaped and reshaped by the emergence from the local, with patterns and processes that may rapidly disperse as a consequence of scale, connectivity, and speed (**Figure 1b**). In this context, sustainable development as interventions at the local scale will not be sufficient, without recognition and governance of the processes, dynamics, and surprises arising from elsewhere. The ability to bring robust collaboration and learning between actors operating across scales and sectors through adaptive modes of governance is critical in this regard (106, 128). However, as these spatial connections increase, the ability to advance international norms and actions that reduce risks and that support capacities to deal with shocks and surprise is as important (11).

Insight 3: From Incremental Change to Systemic Tipping Points and Shifts

In moving to more integrated social-ecological and cross-scale visions of sustainable development, further recognition of the nonlinear nature of system dynamics is fundamental. Much of the thinking in relation to achieving sustainable development targets, such as reducing the rate of biodiversity loss or halving hunger, has implicitly assumed that responses to, and progress toward, such targets will proceed in a linear, incremental (and often infinite) way (129, 130). However, over the past three decades there has been growing evidence that ecosystems, social systems, and SES do not always respond in an incremental and predictable way to increasing or decreasing external pressures (131, 132) (**Figure 1c**). For instance, although slowly increasing pollution levels may initially result in little or no change in aquatic SES, beyond a certain critical threshold or tipping point, an additional increase in pollutant levels may suddenly trigger large, and often rapid, changes to freshwater systems and the human communities that depend on them. These changes are not simply nonlinear, but are associated with a marked shift in the feedback processes governing system dynamics. This shift in feedback processes leads to a fundamental reorganization in the structure and functioning of the SES, propelling it onto new states and development paths

(133, 134). The resultant large and persistent changes in system structure and function are referred to as regime shifts, critical transitions, or alternate stable states (69, 135).

Social-ecological systemic shifts. Although the risk of systemic shifts in different systems is largely unknown, such shifts have now been documented in a wide range of SES at a range of spatial and temporal scales, including coral reefs (136, 137), marine systems (138, 139), dryland systems (140–142), agroecosystems (143), and arctic systems (144, 145). Considering the large, ongoing, and directional change characteristic of the Anthropocene, these types of nonlinear changes may become the norm rather than the exception. Because these shifts are accompanied by a change in dominant feedback processes, they are often difficult, costly, or even impossible to reverse (146, 147). Where it is possible to reverse such shifts, it typically involves reducing external pressures substantially below the critical threshold at which the regime shift was originally triggered, a phenomenon known as hysteresis (131).

Recent syntheses suggest that many aquatic ecosystem services, including freshwater provision, fisheries, and water purification, are especially impacted by regime shifts, along with substantial impacts on biodiversity, climate regulation, and cultural ecosystem services (148–150). Such impacts on SES have marked consequences for key aspects of human well-being including livelihoods and economic activity, food and nutrition, and cultural values (145). Large-scale nonlinear shifts have also been highlighted in social dimensions and processes of SES, for example, in relation to shifts in social and political mobilization (151), system-wide shifts in social norms (152), orchestrated sociotechnical transitions (153), and shifts in pathways toward sustainability (154).

An emerging focus of SES research is engaged specifically with the intertwined social-ecological dynamics of regime shifts. Lade et al. (155) have shown theoretically that in certain circumstances the collapse of a common-pool resource can only be reproduced by accounting for the interaction between social and ecological processes—namely, the dynamics of the ecological resource and punishment in the social system. Accounting for only the social or only the ecological dynamics suggested that the system would not undergo a regime shift. Similar consequences of the interplay of social and ecological processes have been investigated in the dynamics of fish stocks and fisher welfare in the Baltic Sea (66).

Drivers of systemic shifts. Often, multiple drivers are involved in systemic shifts (132), including human-induced alterations of natural disturbances and loss of functional diversity (93, 135). Large-scale human impacts that characterize the Anthropocene have altered the magnitude, frequency, and duration of natural disturbances such as rainfall patterns, fires, storms, or droughts (e.g., 156), as well as landscape and seascape dynamics such as river regulation and fire and pest control, increasing the probability of many types of regime shifts (132).

Recent cross-system analyses have shown that the major proximate drivers of documented regime shifts in the context of the Anthropocene are climate change and drivers associated with agricultural activities such as land clearing and nutrient inputs (132). Furthermore, loss of diversity and simplification of production systems in favor of a handful of commercially valuable and traded species have reduced the capacity for absorbing or responding to such disturbance, thereby making SES more vulnerable to systemic change (e.g., 157–160).

The SES literature on governance (106, 128) has empirically clarified how systemic shifts to sustainable development emerge in SES, emphasizing the critical drivers of agency, organizations, networks, and institutions (31, 105, 161). Many of these activities focus on weakening the current dominant connections and feedbacks in the SES, while simultaneously building new connections through shadow networks and processes in order to foster systemic change (162). Convening

new constellations of actors and engaging in participatory development of management goals and visions are key in this process (98, 105, 163).

Systemic shifts across scales of space and time. It is increasingly clear that many SES shifts are embedded within larger cross-scale changes, suggesting a need for improved understanding of how global-scale political and economic changes cascade down to smaller-scale social-ecological shifts. For example, political and economic shifts in major fishing countries can directly impact fishing effort and the risk of fisheries collapse in successive, diverse localities around the world (126). To account for these potential global-scale effects of cumulative local and regional changes, recent studies have aimed at identifying potential cumulative changes that could shift Earth system dynamics out of a Holocene-type state (6, 164). Similarly, Barnosky et al. (165) have explored possible regime shifts in the Earth's biosphere and Steffen et al. (115) analyzed feedbacks in both natural and social systems that might foster a sustainable relationship between humans and the rest of the Earth system.

Taking a long-term historical perspective, Biggs et al. (166) explored how the domestication of fire led to widespread changes in terrestrial biomes, as well as the social dynamics of hunter-gatherer societies, in ways that enhanced the competitive niche of hominids over time. Christian (167) similarly suggests that several of the major shifts in the history of the Earth are associated with fundamental restructuring of the relationship between humans and ecosystems, including the invention of agriculture (168) and the Industrial Revolution (169). Shifting to more sustainable trajectories of development, rather than an incremental trend in development, will likely require a similar fundamental large-scale reconfiguration or shift in human-nature feedbacks across multiple scales (170).

Implications for sustainable development. Theory and increasing empirical evidence suggest that the potential for systemic reorganization may be the norm rather than the exception in complex SES (62), especially in the light of the more dynamic context of the Anthropocene. Sustainable development clearly cannot be achieved without accounting for the possibility of a wide range of social-ecological systemic shifts (**Figure 1c**). This is particularly so given the potential for cascading effects associated with these shifts (171). Rather than assuming that such events are rare exceptions that need only be accounted for in cases where they have been proven to exist, we need to assume that all SES are potentially susceptible to such changes, particularly in the context of the Anthropocene. In anticipating such shifts, sustainable development efforts can focus on limiting increases in drivers that may weaken key feedback processes maintaining the stability of desirable regimes, e.g., those that provide essential ecosystem services and underpin human well-being across societal groups (139, 148, 172).

However, this may not always be possible, especially in cases where knowledge about likely drivers of regime shifts is limited, the economic and political trade-offs of limiting potential drivers are large, or drivers derive from places distant from where the impacts may be felt (16, 127). In such cases, better tools will be needed for monitoring changes in the strength of the feedbacks that underlie the resilience of desired SES regimes. Such tools include generic indicators of increases in system variance and autocorrelation over time that reflect the weakening of dominant system feedbacks and associated loss of resilience (148, 172, 173). Challenges of data availability and time to react to such signals (174, 175) are areas that require further research to operationalize such indicators.

Insight 4: From Adapting to Change to Transforming for Change

Sustainable development has often focused on change: mainly, changing the conditions associated with poverty, while also changing the idea that development must always come at the cost of the

environment. However, changes undertaken in the name of sustainable development have often been incremental and only possible through a reliance on existing social and economic institutions (176), which have therefore largely persisted or adapted incrementally. Increasingly, however, it is recognized that calling for incremental adaptations to the social, political, and ecological conditions and shocks and stressors associated with the Anthropocene, its traps and tipping points, and its cross-scale realities may be insufficient (128, 177–179). Instead, interest is growing in sustainable development as transformational change.

Transformations to sustainability. SES research emphasizes that systems need change that allows structures and functions to persist and adapt, but also, at times, to transform (29, 30) (**Figure 1d**). Transformation has been defined as fundamentally altering, or “rewiring,” the SES, its structure, functions, feedbacks, and properties. This includes the way that authority and resources are structured and flow through systems; the norms, values, and beliefs that underpin those structures and processes; the functions and dynamics of ecosystems; and the ways that all of these are connected to one another across multiple scales (33, 170, 180, 181).

Reconfiguring SES onto sustainable development paths that acknowledge the former insights of social-ecological inseparability and complex dynamics is referred to in SES research as transformations to sustainability (154, 170). In achieving transformations to sustainability, change is required in the system dynamics that created the problems, for example, inequality, power asymmetries, or environmental degradation, in the first place. This happens not only through creating radically different paths for development, but also through breaking down the resilience of features of the current systems that constrain transformation (33, 182). The notion of breaking down the resilience of one development pathway while building an alternative distinguishes transformation from adaptation; the latter generally involves building resilience for some people or some subsystem of the existing pathway (**Figure 1d**).

Phases and scales in transformation. Despite emerging agreement across some disciplines, actors, and sectors about the growing importance of transformation, the reality is that many remain uncertain about how to make a transformational change happen deliberately. Lack of clarity also remains on how to collectively make decisions about new directions when there is so much uncertainty, surprise, and turbulence. SES research, with its complex dynamics foundations, has some insights to offer by drawing attention to, and providing guidance through, the complexity entailed in a transformation process. In particular, various scholars have described transformations as involving multiple phases, where progress through the phases is made in a nonlinear fashion (180, 183, 184). As with systemic shifts, transformations focus on social-ecological relations and feedbacks, as well as the nonlinear nature of these reconfigurations (see, e.g., 46, 185). In this sense, transformations can be seen as a type of systemic change or regime shift, as discussed above. Transformation as nonlinear, phased progress challenges the perception of linear incremental progressions from poverty to well-being, deforestation to reforestation, or fossil fuels to renewables. This insight highlights instead thresholds of change, where progress can involve the often invisible preparation for change, the navigation of change once past a threshold or tipping point, and finally a focus on building the resilience of the transformed system.

Moreover, the phases of transformation highlight the cross-scale nature of complex change processes and how focusing on ideas or initiatives that may generate transformative impacts at one scale may actually reinforce problematic patterns at another scale (186). SES models used to explore persistent poverty have begun to grapple with how to move away from actions that reproduce social-ecological traps at different scales (46).

Capacities for transformation. A growing acceptance has emerged in the literature that both adaptation and transformation are part of system resilience (181, 187). However, evidence shows that the capacities and processes for building each are distinct (188, 189), and adaptive capacities may even hinder transformative capacities (e.g., 190). This demands that sustainable development efforts progress beyond earlier assumptions of adaptation and transformation as responses on a continuum of temporal and spatial scales (e.g., 191). It also challenges previous development efforts that focused on adaptation and the implicit assumption that these capacities were more limited in developing countries than in developed, even though evidence indicates a more variegated distribution (177); the same is likely to hold true for transformative capacities.

Furthermore, implementing these ideas in practice will mean moving beyond a focus on capacities alone to highlight factors such as willingness to transform (192). The latter is an important factor in change processes taking into account both the resistance that emerges during change processes and the co-optation of transformative ideas or initiatives by powerful actors that can occur (193). This raises further questions in cases of unplanned transformations that emerge out of crises (e.g., 194) and how to make these equitable and sustainable.

The SES perspective on transformations highlights the critical need to reconfigure human-nature or people-planet connections when undertaking transformative development activities and the capacity needed to achieve this (33). To put these reconfigurations at the forefront of sustainable development efforts is a fundamentally different approach from separate siloed perspectives on economic development and environmental protection.

Implications for sustainable development. Transformations to sustainability will occur in turbulent contexts and not only will the resilience of existing systems and their legacies stall the possibilities for transformation (195), but also discourses of “transformation” may even be used to cover corrupt practices or business as usual (189). Recognizing that different phases occur in a transformation process and that different forms of strategic agency and capacity will be required in different phases (31), SES research also highlights the need to understand and engage with policies, governance arrangements, and the structures of networks involved in transformations. It furthermore highlights the need for these governance factors to be flexible enough to shift as appropriate during these different phases (196–198). Given the recognition that any transformation process should not reproduce the inequalities and ecological degradation that created the need for transformation in the first place, existing transformation efforts have focused on participatory, collective, and co-creative approaches (e.g., 41, 130).

The need for participatory, coproduced solutions is already common in sustainable development, but these have mostly focused on local scales. As is clear from the above discussion, transformations to sustainability in the Anthropocene will involve cross-scale dynamics as well as actors operating across those. Transforming across multiple scales will inevitably involve highly diverse perspectives about transformation and the need for confronting and making transparent the politics, power, contestation, and conflicts (199, 200). However, it also requires making clear the social-ecological nature of these transformations, rather than just the social or technical focus often adopted.

Transformations as innovative “seeds” or niche projects is a growing area of investment and interest in sustainable development; however, SES research makes clear the limits to the current predominantly technological focus in these investments. Furthermore, the SES perspective on transformations emphasizes the complex system dynamics involved—dynamics often ignored in current practice, for example, risk management. In moving from a conceptual focus on transformations, recent research about social-ecological innovations for transformation has provided insights for practice of the importance of local, niche experiments occurring “under the radar” that

later contribute to broader transformation processes (e.g., 161). Since then, significant effort has been invested in building an understanding about the range of successful cases that may be more likely to move us toward more sustainable and just forms of development (98). Recent research by Westley et al. (201) on the history of large-scale transformations indicates at least six criteria as important for identifying transformative potential of niche initiatives, or seeds. Measured against these criteria, it becomes clearer how to identify whether the ideas proposed hold the transformative potential described above, or whether they fit, rather, into the incrementalism of reform and adaptation approaches of the past.

SOCIAL-ECOLOGICAL SYSTEMS PERSPECTIVES ON SUSTAINABLE DEVELOPMENT IN THE ANTHROPOCENE

The Anthropocene clearly represents an intertwined world of people and nature different in many dimensions and functions from previous human experience. When viewed from an SES perspective, the Anthropocene can be said to have emerged as a complex adaptive system, where agents continuously interact at increasingly larger scales and out of those interactions larger-scale phenomena emerge that then feed back to the agents, resulting in macroscopic patterns and behaviors unseen before. Climate change, food price shocks, forced migration, pandemics, and other turbulent social-ecological dynamics are example outcomes of such feedbacks. The Anthropocene makes clear that the scale of the human dimension is such that the resilience of the Earth system as a whole is challenged, including suitable and desirable conditions for our own development. Under such conditions, sustainable development approaches and policies designed for the past will be insufficient and may reinforce the problematic aspects of the complex challenges currently faced on the planet. The challenge now for sustainable development is to acknowledge this new context in the design of policies and approaches fit for the context—and to do so in the setting of an already full, fragile, and turbulent planet.

Although resilience is a popular concept or approach for sustainable development to confront these challenges, focusing resilience efforts only at the household or community level, on recovery after disasters, or in preparation for climate change may work in the short term, but it will not help transform development into sustainable pathways in the context of the Anthropocene. SES research builds on these sectoral approaches to resilience, highlighting the shifts in thinking and practice outlined above, as well as new approaches more tailored to the complex context of contemporary sustainable development, which are more in tune with the deep and dynamic connections between social and ecological systems (e.g., 41, 62, 92, 100).

FROM INSIGHTS TO SUSTAINABLE DEVELOPMENT PRACTICE

SES research makes clear that moving concepts and theories from research into the practice of sustainable development should not be limited to practical and technological solutions only (202). Although these are the predominant focus of current practice, much of SES literature, building on the foundational work of Meadows (203), highlights the need to go beyond and deeper than the practical, mechanistic focus of current interventions. SES research highlights the value of development practices that acknowledge and target the complex system structures, processes, and values underlying most development challenges. Without practices connected to these underlying issues, practice at the more superficial or practical levels will be insufficient. Recently, Abson et al. (204) suggested three realms of transformational change at these deeper levels of intent: re-structure institutions, re-connect people and nature, and re-think knowledge production and use. These map well onto the above four SES insights, which add further details for these deep transformations to account for the speed, scale, connectivity, and uncertainty of the Anthropocene.

Explorations and examples of areas of transformative change for sustainability across sectors are highlighted in recent SES research (e.g., 200, 201).

Recognizing uncertain futures (e.g., 205), SES research proposes a focus on sustainable development as preparing for opportunity or creating conditions of opportunity for navigating toward sustainable futures (206). This does not mean that planning and design are not needed, but rather that plans and designs are flexible and adaptive to the complex dynamics involved. This form of planning for opportunity also focuses on creating options and diverse outcomes, while at the same time reducing the resilience of undesirable systems and development pathways. Such an approach focuses more on the transformative potential of initiatives than predicting the perfect path that can easily be controlled or managed ahead (170), guided by a need to avoid undesirable trajectories, especially those with known or suspected thresholds that challenge societal development and human well-being.

CONCLUSION: RESEARCH FRONTIERS IN KNOWLEDGE AND VALUE SYSTEMS

As research and practice begin to explore the complex social-ecological dynamics of sustainable development, signs of a broader portfolio of values are emerging that seems better suited to deal with the complexity and uncertainty inherent in the Anthropocene. SES research helps to understand how failures from conventional approaches and values emerge from ignoring or simplifying complex and dynamic social-ecological relationships (88). The significance of the social, institutional, and cultural contexts in social-ecological development is a frontier in SES research with an emerging rich literature (reviewed in, e.g., 20, 21). Perhaps an additional shift for sustainable development highlighted by the SES literature is the shift from value systems dominated by instruments and incentives to an appreciation of diverse values and beliefs, and the role of culture in guiding human actions and reactions (53, 54). New approaches, accounting for a broader set of knowledge and value systems, are emerging in SES research, closing the gap between science and society and appreciating diverse knowledges and competencies for dealing with complexity and change (e.g., 43, 207).

This set of insights into SES and their dynamics explored here offer some theories, approaches, and examples suggesting possible avenues to transform sustainable development practice for the context of the Anthropocene and its complex challenges. They are an initial (and small) set of insights contained in the vast and rapidly expanding domain of transdisciplinary sustainability science, highlighting the need for an agile collaboration of research and practice to distil, pilot, and adapt insights and implications for sustainable development in the Anthropocene.

SUMMARY POINTS

1. Sustainable development must now contend with the more dynamic, uncertain, and complex systemic context of the Anthropocene.
2. Research on and evidence from the study of social-ecological systems (SES), as complex adaptive systems, offer insights that outline necessary shifts in sustainability research and practice.
3. SES research emphasizes the risks of treating social and ecological systems as separable, instead highlighting the complex, intertwined and co-developing social-ecological nature of development challenges.

4. Studies of the existing and novel cross-scale dynamics of the Anthropocene, and the interplay between humans and ecosystems at multiple scales, highlight the potential for emergent systemic risks undermining sustainable development processes.
5. The increasing potential for nonlinear, systemic shifts in intertwined SES highlights the importance of drivers and feedback processes, as well as the need to build resilience to deal with unanticipated shifts.
6. From an SES perspective, resilience is not limited to the capacity to absorb or adapt to changes of the Anthropocene, but emphasizes the ability to evolve or transform with change, in support of sustainable futures.
7. Sustainable development will therefore depend on processes of transformational change onto diverse development paths, together with processes aimed at reducing the potential for—and resilience of—unsustainable and inequitable paths.
8. SES research recognizes that transformations to sustainable futures will require a focus on changes in system structures and processes, which will rely on diverse values, knowledges, and cultures in guiding those decisions.

FUTURE ISSUES

1. A major undertaking for sustainable development research and practice is to acknowledge, account for, and govern the new context of intertwined, cross-scale, and dynamic SES of the Anthropocene.
2. Recognizing the inseparability of social and ecological systems will require new interdisciplinary, cross-scale, and intersectoral sustainable development processes that recognize and reconnect societies with their often distant environments.
3. The novel, rapidly changing, and complex feedbacks of emergent systemic risks require new collaborations across scales, and new actions and norms at the global scale.
4. The increasing likelihood of tipping points and systemic reorganization of SES will require new understanding of how social and ecological processes interact to create unexpected shifts, their potential to cascade across scales or trigger planetary-scale tipping points, and how to build resilience to these shifts.
5. The potential for novel, unanticipated systemic shifts, where the drivers and feedbacks are unknown or poorly understood, highlights the need for monitoring tools that detect systemic changes that are indicative of weakening feedbacks and loss of resilience.
6. Current research and understanding of potentially transformative initiatives at local scales need to be complemented by research on large-scale transformations toward sustainability and how local sustainable development initiatives may play a role within much larger scale processes.
7. Transformations are often studied in hindsight, requiring new understanding and more refined criteria of which sustainable development approaches are most likely to lead to transformative changes.

8. Recognizing the system structures, processes, and values underpinning sustainability outcomes requires a significant reconfiguration and research effort into how sustainable development, resilience building, and other sustainability investments are monitored.

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