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PERSPECTIVE

Leverage points for sustainability transformation

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Abstract Despite substantial focus on sustainability issues in both science and politics, humanity remains on largely unsustainable development trajectories. Partly, this is due to the failure of sustainability science to engage with the root causes of unsustainability. Drawing on ideas by Donella Meadows, we argue that many sustainability interventions target highly tangible, but essentially weak, leverage points (i.e. using interventions that are easy, but have limited potential for transformational change). Thus, there is an urgent need to focus on less obvious but potentially far more powerful areas of intervention. We propose a research agenda inspired by systems thinking that focuses on transformational 'sustainability interventions', centred on three realms of leverage: reconnecting people to nature, restructuring institutions and rethinking how knowledge is created and used in pursuit of sustainability. The notion of leverage points has the potential to act as a boundary object for genuinely transformational sustainability science.

Keywords Human–environment systems · Institutional change · Knowledge creation and use · Social–ecological systems · Sustainability science · Transdisciplinarity

INTRODUCTION

Societies are increasingly operating outside safe planetary boundaries (e.g. Steffen et al. 2015), while many communities remain beset by poverty and inequality. Such situations persist despite substantial focus on sustainability issues in both science and politics (Fischer et al. 2007). Here, we argue that although sustainability science seeks to guide humanity "along more sustainable trajectories" (Kates et al. 2001, p. 641), much of what might be constituted as sustainability science fails to engage with the root causes of unsustainability, and is therefore unlikely to substantially alter our current development trajectories.

Addressing unsustainability requires societies to address interacting biophysical, social, economic, legal and ethical dimensions (Geels 2011). However, the dominant scientific discourses address sustainability problems from largely disciplinary perspectives. Different dimensions of sustainability are often researched separately with a focus on proximal problems and 'quick fixes' to unsustainability, rather than on the underpinning, ultimate drivers of current trajectories (Ehrenfeld 2004). Therefore, there is an urgent need to examine more deeply the root causes of unsustainability, and identify solution-oriented approaches to transformational change.

In this paper, we outline a research agenda seeking to identify and apply potentially transformational 'sustainability interventions'. We briefly review dominant discourses in sustainability science and critique the nature of the interventions that typically flow from these discourses. We then revisit Donella Meadows' concept of leverage points (Meadows 1999)—places in complex systems where a small shift may lead to fundamental changes in the system as a whole. Drawing on the ideas of Meadows, our core argument is that many sustainability interventions applied to date have addressed highly tangible, but essentially weak leverage points (i.e. interventions that are easy to make, but have limited potential for transformational change). We argue that there is a need to focus on perhaps less obvious, but potentially for more powerful areas of intervention. Specifically, we propose a research agenda centred around three realms of leverage: re-connecting people to nature, re-structuring institutions and re-thinking how knowledge is created and used in guiding humanity towards sustainability.

THE EMERGENCE OF SUSTAINABILITY SCIENCE

Sustainability science has emerged as a solution-oriented arena that transcends disciplinary boundaries and seeks to involve non-scientists in resolving the complex, multi-dimensional problems facing humanity (Miller et al. 2014). Despite increasing acceptance of this vision, in practice, much of the science that engages with sustainability issues remains rooted in traditional, disciplinary perspectives (Spangenberg 2011). Although disciplinary knowledge is undoubtedly valuable, it is likely that on its own it will be insufficient for facilitating the deep societal changes that would amount to a sustainability transformation (Fischer et al. 2007).

Disciplinary understandings of sustainability problems can feed into 'atomized' conceptualisations of, and solutions to, sustainability problems, where biophysical, social, economic and political facets of sustainability are addressed in isolation from each other, rather than as a set of tightly interacting components (e.g. Loos et al. 2014). Framing sustainability challenges in atomized ways promotes 'techno-fixes' to address what are often complex multi-dimensional problems (e.g. Câmpeanu and Fazey 2014), paying little attention to human actors and their social and political behaviour, or institutional dynamics. A common feature of such framings is that they often imply that sustainability problems can be resolved without consideration of the structures, values and goals that underpin complex problems at deeper levels. Many scientific endeavours assume some of the most problematic drivers of unsustainability are fixed system properties, or at least that such properties can be addressed in isolation using disciplinary approaches. For example, asking "How do we produce enough food, with minimal impacts on biodiversity, to meet changing diets?" is a reasonable question from a conservation biology perspective, in part because asking the potentially more important question "How do we change diets to minimise biodiversity impacts?" is considered outside the scope of that discipline.

In contrast to disciplinary approaches, there have been calls for integrated, system-oriented approaches to navigating social–ecological complexity (e.g. Fischer et al. 2015). Systems thinking transcends disciplinary boundaries by focusing on the dynamic interrelationships of different elements shaping complex sustainability issues. It takes a systemic view of sustainability issues rather than breaking them down into a series of discrete elements that can be addressed separately. Systems thinking has proved useful in many contexts, including economics (e.g. Arthur 1994), public administration (e.g. Kickert et al. 1999) and the social sciences (e.g. Ostrom 2009). Influential concepts in sustainability science that are closely related to, or stemming from, systems thinking include resilience thinking (e.g. Folke et al. 2010), transitions management (e.g. Pahl-Wostl 2007) and transformational sustainability research (Wiek and Lang 2016).

Systems thinking has led to "fundamental discoveries and sustainability actions that are not possible by using conventional disciplinary, reductionist, and compartmentalized approaches" (Liu et al. 2015, p. 963). For example, taking a systemic approach to understanding land use change has shown that agricultural intensification may actually exacerbate rather than forestall agricultural land expansion (Phelps et al. 2013). Similarly, Banson et al. (2015) revealed key interactions between the policy, social and environmental dimensions of the Ghanaian agricultural sector that could not be understood by looking at these dimensions separately. Systems thinking has been particularly important in understanding emergent properties that arise from the interactions between different components of a particular problem (Newell 2012). The value of system-oriented approaches for sustainability science is thus beyond doubt. However, with few notable exceptions (e.g. Carey and Crammond 2015; Hill et al. 2015), one of the most important facets of systems thinking has been largely overlooked to date: Where in a system should we intervene to change its overall behaviour?

In an inspiring essay, Donella Meadows (Meadows 1999) proposed a hierarchy of intervention points for leveraging change. She argued that the transformational capacity of a given intervention would depend on the characteristics of the system properties that a given intervention acts upon—with some interventions likely to cause transformational change, while others will only induce minor changes in outcomes. Given the ongoing failure of humanity to leave behind unsustainable development trajectories, the question naturally arises whether the most widely used interventions so far have perhaps targeted relatively ineffective leverage points. Here, we propose a re-orientation of sustainability science around the systems thinking notion of 'deep' leverage points (Box 1).

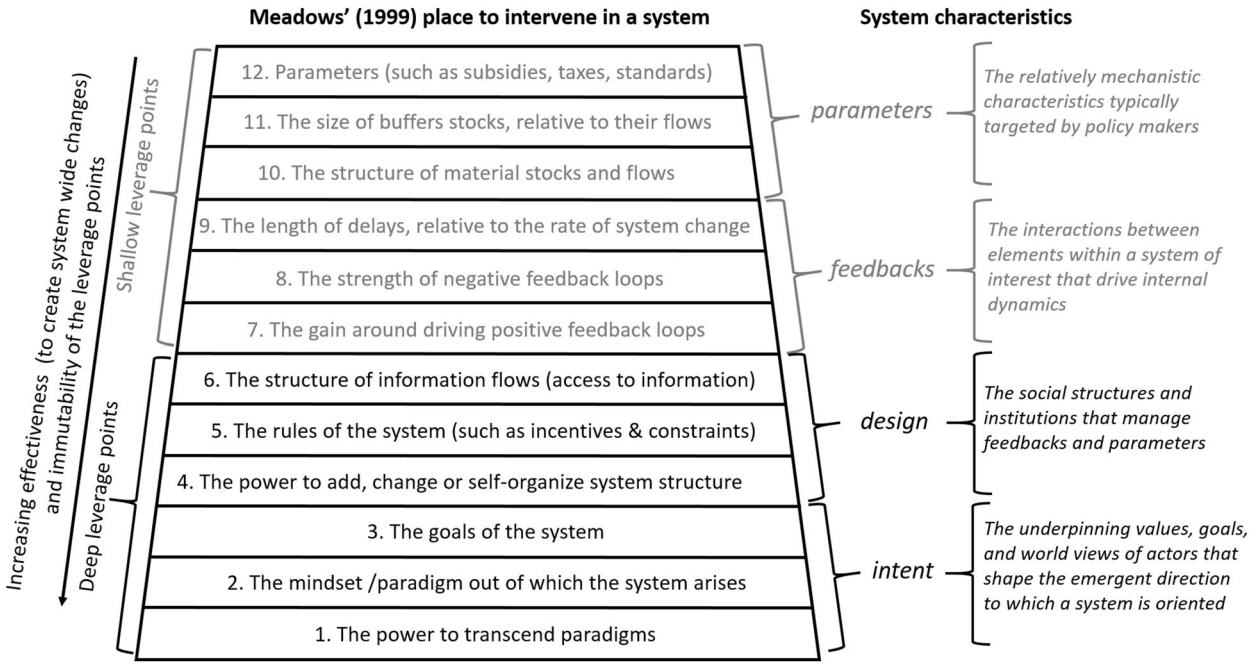
LEVERAGE POINTS

In considering how to influence the behaviour of a system Meadows identified twelve leverage points ranging from 'shallow'—places where interventions are relatively easy to implement yet bring about little change to the overall functioning of the system—to 'deep' leverage points that might be more difficult to alter but potentially result in transformational change. Meadows' leverage points can be aggregated into four broad types of system characteristics that interventions can target (from shallowest to deepest): *parameters*, *feedbacks*, *design* and *intent* (Box 2).

Box 1 Ontological and epistemological approaches to systems thinking

Systems thinking falls into two main categories regarding how the term 'system' is understood and used, which has important implications for a leverage points approach to sustainability. This ontological versus epistemological divide relates to whether systems are viewed as real-world phenomena that can be objectively studied [e.g. Liu et al. "our planet is a single system comprising complex interactions between humans and nature" (2015, p. 1258832-1], or as an epistemological approach to addressing particular issues of interest or concern (e.g. Ison 2010). Unlike Meadows, we take a more epistemological approach to the notion of systems. That is, *we view systems thinking as a lens through which sustainability issues can be addressed*. As such, a 'system' is bounded and defined by the subjective interests and pre-analytic assumptions of the researcher, with all the potential problems this entails. This epistemological approach means that particular importance must be placed on how, and why, the researcher chooses to delineate a system and what implications this has in the context of solution-oriented sustainability science. Following Ison (2008), we use the term 'system of interest' to acknowledge that systems are, in part, defined by the worldviews and concerns of researchers and other actors involved

Box 2 From twelve leverage points to four system characteristics



The four system characteristics represent a nested hierarchy of, tightly interacting, realms of leverage within which interventions in a given system of interest may be made. Deeper system characteristics constrain the types of interventions possible at shallower realms of leverage

Parameters are modifiable, mechanistic characteristics such as taxes, incentives and standards, or physical elements of a system, such as sizes of stocks or rates of material flows. *Feedbacks* are the interactions between elements within a system of interest that drive internal dynamics (e.g. dampening or reinforcing feedback loops) or provide information regarding desired outcomes (e.g. the effectiveness of a given incentive scheme). *Design* characteristics relate to the structure of information flows, rules, power and self-organisation. Finally, *intent* characteristics relate to the norms, values and goals embodied within the system of interest and the underpinning paradigms out of which they arise. We consider *intent* as the emergent direction to which a system of interest is oriented. *Intent* is therefore an emergent property arising from the multiple, potentially conflicting, sets of world views, goals and purposive behaviours within a given system of interest. For example, economic growth can be understood as the emergent *intent* of a socio-economic system if this is the dominant trajectory that the system

supports. Notably, such an emergent intent does not imply that all actors within the system of interest share this end as a normative goal, or that the system itself has a goal (Box 1).

Each of these four types of characteristics (*parameters, feedbacks, design and intent*) relate to different types of leverage point, at which specific interventions (levers) can be applied. The capacity of interventions to effect change is constrained by the hierarchy of the four system characteristics. We argue that, to date, sustainability research and policy have primarily addressed relatively shallow leverage points. Through their atomized focus, policy interventions (in their role as 'levers') have typically targeted shallow leverage points, failing to address issues of design and intent. This is apparent in the many policy instruments that focus on simply adjusting parameters, for example, by setting targets or providing financial incentives within existing structures, including carbon pricing and REDD+, green taxes, targets to increase the extent of protected areas and agri-environment schemes. We recognise that such 'shallow' interventions are important and can generate beneficial outcomes but, on their own, are unlikely to lead to transformational change.

Notably, policy interventions and dominant scientific discourses mutually reinforce one another, meaning that shallower interventions are favoured in both science and policy. For example, most high profile work on food security has focused on issues of food production (e.g. Foley et al. 2011). Such a focus emphasises material flows and buffer stocks, rather than deeper issues such as the rules, structures, values and goals that shape food systems. Because more is known about material interventions, it is easier to design interventions at these shallower levels. However, questions such as "is the global food system oriented to provide food security for all?" and "if not, how can its intent be changed?" have rarely been asked by scientists. Yet it is these questions that address the more fundamental challenges, and provide input to thinking about deeper leverage points.

A NEW RESEARCH AGENDA

The leverage points proposed by Meadows were, in her words, "a work in progress"—she aspired for them to be an invitation to others to think more broadly about systemic change. Here we outline our interpretation of key steps to refine and operationalize Meadows' vision into a concrete research agenda. These steps include (1) synthesis and integration of existing research on leverage points and their transformational role related to sustainability issues; (2) identifying concrete leverage points for sustainability transformation and (3) studying the interactions between shallow and deep leverage points.

SYNTHESIS AND INTEGRATION OF EXISTING RESEARCH ON LEVERAGE POINTS

There is a wealth of existing research from a broad range of fields to be drawn on and synthesised when addressing the notion of leverage points. For example, key ideas can be drawn from work on social–ecological transitions (e.g. Geels 2011), and from Ostrom's typologies of social–ecological systems (Ostrom 2009). In addition, multi-level governance research emphasises an institutional approach to understanding social–ecological systems (e.g. Piattoni 2010), and behavioural psychology sheds light on the behaviours of individual actors and organisations within systems of interest (e.g. Gergen 2012). Understandings of systemic change, identity and reorganisation are provided by resilience thinking (e.g. Berkes et al. 2002), and insights on the navigation or control of complex systems can come from cybersystemics (e.g. Ison 2012). Finally, transdisciplinary research provides methodologies for eliciting and integrating the knowledge, goals, values and norms of humans in both scientific and societal processes (e.g. Lang et al. 2012).

We believe that, within these and other frameworks, it would be fruitful to consider more actively whether given interventions go deep enough to really bring about the changes that are ultimately needed. As such, we see the notion of leverage points as a promising approach for transformational, solution-oriented sustainability science.

THREE REALMS OF DEEP LEVERAGE FOR SUSTAINABILITY TRANSFORMATION

While there are undoubtedly many ways in which transformational change can be levered, we highlight three realms of leverage that we believe to be of particular importance: (i) the role of institutions and institutional decline and failure in systemic change; (ii) people's connections to nature and their influences on sustainability outcomes and (iii) knowledge production and use in transformational processes. For ease of reference, we refer to these three realms of leverage as *re-structure, re-connect* and *re-think*. We note that we do not see a one to one relationship between these realms and the leverage points discussed. For example, changing how knowledge is produced might influence *feedback*, *design* and *intent* characteristics. Moreover, there are important issues, such as power dynamics (e.g. Fischer et al. 2015), that cut across the realms discussed here.

Re-structure: Change, stability and learning in institutions

Human societies organise themselves through institutions—the structures that make societal interaction predictable and guide human action towards collective goals. Formal institutions include written rules (laws, regulations) and agreements (plans, contracts) that are collectively binding. Informal institutions include customs, taboos or codes of conduct. Because institutions guide and constrain action, institutional change represents a crucial realm of leverage for sustainability transformations. Notably, institutions can embody fundamental societal paradigms ("constitutional choice" level—Kiser and Ostrom (1982)), mid-term rules ("collective choice" level) or short-term "operational choice" rules, and hence, institutional change can be associated with "deep" or more "shallow" leverage points. Because institutions tend to be self-reinforcing and resistant to change, harnessing institutional change for sustainability transformations can be difficult.

Identifying concrete levers related to institutional change requires an understanding of institutional dynamics. Existing research has focused mainly on institutional evolution (e.g. Thelen 2009), or on institutional innovations, that is, on developing new institutions that are better suited to foster sustainability (e.g. Pahl-Wostl 2007). In contrast, much less emphasis has been placed on processes of institutional failure and decline, and even less on potentially productive functions of such phenomena (Ostrom 2009). In a paradigm where the focus is strongly on creating new institutions for sustainability, a focus on institutional decline or failure may seem counterintuitive. However, Meadows (1999) argued that such counterintuitive approaches could be particularly important to effect change.

Against this background, we see four potential means to leverage structural change (Newig 2013). First, crises can trigger institutional adaptations towards sustainability. Building on works from economics (Schumpeter 1950) and social–ecological systems theory (Gunderson and Holling 2002), social systems typically respond to external or internal pressure through reorganisation, learning and adaptation. Both formal and informal institutions may reorganise, and indeed decline, in the face of changing environmental or societal conditions. A key lever therefore lies in ensuring institutions are designed to be open to the potentially transformational learning and adaptation opportunities invoked by crises (Eburn and Dovers 2015). One example of such built-in decline is the usage of 'sunset legislation', i.e. laws that demand revision or removal after a given time, periodically providing for windows of opportunity for institutional change.

Second, the purposeful destabilisation of unsustainable institutions may create windows of opportunity for change towards sustainability (Geels 2011). This is, however, by no means a causal necessity. While potentially a powerful lever, the intentional destabilisation or even dismantling of institutions (Bauer and Knill 2014) bears considerable danger and must be approached with great care and understanding of the institutions under consideration.

Third, the systematic analysis of institutional failure in different contexts may allow otherwise inaccessible insights into the functioning of institutions, and how to improve institutional functioning in the future. Such different contexts may include changes in the face of crises, purposeful destabilisation or indeed more fundamental disruptions including revolution and war. Hence, institutionalising such mechanisms of governance learning (Newig et al. 2016) is important for leveraging transformational change.

Fourth, existing (and well-functioning) institutions may decline or become lost. This may be due to 'catastrophes' such as wars or revolutions; or, new institutions causing almost invariable decline in old ones. Unregulated decline of existing structures can be problematic; hasty or uncontrolled institutional changes risk losing important institutional elements such as knowledge, networks or actor capacity (Newig 2013). Active management of decline would prevent such losses. In that sense, leveraging for sustainability also implies reflecting on issues of stability versus change.

Re-connect: Targeting interactions between people and nature

How people perceive, value and interact with the natural world fundamentally shapes the goals and paradigms underpinning many systems of interest. Although not always immediately apparent, the functioning of a system is influenced by the degree to which humanity's reliance on the natural world is acknowledged, and the extent to which a close relationship with nature is identified as essential to a 'good life'.

Scholars from several domains have identified a disconnection from nature at both individual and societal levels and have suggested that this may negatively influence sustainability (e.g. Nisbet et al. 2009). In exploring how a greater connection with nature might work as a lever, it would be useful to explore how material, experiential, psychological and philosophical connections to the natural world shape the values and paradigms that underpin human action.

Materially, all societies are connected to the environment through consumption of natural resources. As globalisation and industrialisation have expanded, societies

increasingly rely on distal ecosystems for provision of goods and services. While Hatfield-Dodds et al. (2015) argue that economic growth can be decoupled from environmental impacts, it is questionable whether decoupling can truly occur on a global scale, with evidence that economic development leads to a shift from local to global material consumption (Wiedmann et al. 2015). Scholars have called for a strengthening of the direct material links between people and nature in local ecosystems (e.g. Fischer et al. 2012). Such reconnections may shorten feedbacks, but perhaps more importantly, they may also influence the design of the system and facilitate other types of human–nature connections that can influence a system's emergent intent.

Experiential connection with nature is important for personal health and well-being (Keniger et al. 2013), and experiences of the natural world shape attitudes and behaviours towards the environment (Wells and Lekies 2006). Declines in nature-based experiences have been a source of concern for many scholars. Indeed, the 'extinction of experience' has been proposed as a possible causal factor underlying biodiversity decline (Miller 2005). Urbanisation has been cited as a major driver of experiential disconnection from nature, although careful planning and management of urban green infrastructure can assist in re-connecting urban dwellers to natural environments (Andersson et al. 2014).

A raft of psychometric tools has been developed to test personal relatedness with the natural world (Restall and Conrad 2015). These tools have revealed that a spectrum of human–nature connections exist. Of particular relevance is increasing evidence that underlying values towards nature influence environmental attitudes and behaviours (Schultz et al. 2005). However, pro-environmental values and attitudes alone do not necessarily lead to sustainable lifestyles. Psychological connection with nature needs to be coupled with institutional structures that make it easy for people to behave sustainably (Kaiser et al. 2010). Or—in systems language—a shift in the emergent *intent* in a given system of interest demands concurrent changes in its *design*.

Finally, different philosophical paradigms can be drawn on to conceptualise humanity's relationship to the natural world. For example, ecosystem services research can be considered to embody a production metaphor for human–nature relationships (i.e. nature provides goods and services for people to use). This can be contrasted with other metaphors that see humans as stewards of the natural world, as part of an intricate web of life, or as embedded within intertwined social, ecological and spiritual domains (Raymond et al. 2013). Connected to these different philosophical perspectives on human–nature relationships are moral and ethical obligations that govern appropriate human actions towards the environment. Contributions from the fields of environmental ethics and eco-theology help reveal the often implicit rules and goals that underlie the behaviour of individuals and indeed entire systems of interest. In the context of re-connecting people and nature, we see a need for research in three areas—(i) research on how disconnection relates to unsustainability outcomes, or how re-connecting people with nature can lead to system transformation; (ii) research to explore the relative transformational potential of different types of human–nature connections (e.g. material, experiential, psychological, philosophical) and (iii) research on how different types of human–nature connections interact—and can be influenced.

Re-think: How knowledge is produced and used

The way knowledge is created, shared and used in society crucially influences transformation processes (Berkes 2009), and has the potential to influence system *parameters*, *feedbacks*, *design* and *intent*. Much of human action is path dependent, building on the way things have been done previously and relying on established, often institutionalised, knowledge. Considering path dependencies in how we perceive and produce knowledge could be a key lever for sustainability transformation. It is broadly acknowledged that the way in which problems are framed and how knowledge is produced has significant implications for policy development and societal outcomes. Re-thinking knowledge for sustainability transformations requires an understanding of how knowledge flows through systems of interest, and how we identify the goals and expectations of sustainable transformations (*intent*) or select the methods and means that help us to get there (*design*).

In addition, questioning existing perceptions of legitimate knowledge in science and politics opens up the potential to identify (i) gaps in and strengths of the available knowledge base used to inform decision-making; (ii) assets and limitations of knowledge production processes and the settings in which knowledge is produced and used and (iii) socially constructed assumptions and unstated beliefs that may function as barriers to desired transformations towards sustainability. This aligns very well with the call for new forms of knowledge production and use—especially in the context of fundamental societal sustainability challenges (e.g. Spangenberg 2011).

Sustainability problems are often caused by the complex interplay of diverse social–ecological factors, and the knowledge needed for effectively governing these challenges has become progressively more dispersed and specialised (Ansell and Gash 2008). This often makes the knowledge required for understanding sustainability issues too complex to be managed by a single entity and leads to the need to integrate different types of

knowledge. For instance, developing solutions towards sustainable food systems often involve inputs ranging from agricultural, ecological, economic, engineering and public health research to the practical and experiential knowledge of farmers, wholesalers, food processing industry, retailers and consumers. Practitioners and civil society stakeholders who function in the midst of sustainability challenges are often more aware and familiar with the level of complexity than academic scholars, and hence can play a vital role in problem identification and solution development (Prell et al. 2007). However, finding transformational solutions and implementing them in concrete contexts will likely involve re-thinking the ways in which we approach the production, flows and use of these complex types and sources of knowledge. There are, among others, three key requirements of new forms of knowledge production for fostering sustainability transformations: (i) a problem- and solution-oriented research approach; (ii) mutual learning processes between science and society, and thus a re-thinking of the role of science in society (Lang et al. 2012), and (iii) the explicit inclusion of values, norms and context characteristics into the research process to produce "socially robust" knowledge (Scholz 2011). Producing and using knowledge in such a way has the potential to mitigate the often highlighted knowledge to action gap.

Recognising the importance of different types and sources of knowledge in collaborative research and learning processes is not new (e.g. Lang et al. 2012). In particular, the importance of integrating stakeholder perspectives into decision-making and associated challenges, such as power relations, conflicting interests, and epistemological differences, have been widely addressed (e.g. Armitage et al. 2008). Yet, many important aspects of knowledge production have received little attention, such as (i) assessing the ways in which knowledge is compiled and integrated; (ii) whose knowledge is legitimised and counts and to what extent; (iii) who decides what criteria are used to assess the available knowledge; (iv) which formats of knowledge production at the science–society interface are most adequate for specific contexts and most promising to really fostering transformational change in practice; (v) how knowledge produced in a specific context can be generalised or transferred to other contexts and (vi) how we identify what kind of knowledge is needed in any given situation.

INTERACTIONS AMONG LEVERAGE POINTS

In the context of studying deep leverage points (i.e. 'where' to intervene), it is necessary to consider the effectiveness of particular 'levers', that is, specific measures by which influence can be applied to a given leverage point. We note that while the analogy of levers and leverage points may imply simple mechanistic relations between a given lever (intervention) and systemic change, we are acutely aware that no such simple mechanistic relations exist. Different leverage points are not independent, and changes resulting from the application of a given lever may be complex and unexpected. Rather than following a 'social-engineering' approach, we therefore emphasise the importance of identifying potentially relevant interventions and their interdependencies in order to facilitate experimentation and learning.

As highlighted above, deeper system characteristics shape and constrain the types of interventions available at shallower leverage points. The paradigms, mind sets and values that determine *intent* are vital in shaping *design*. *Design*, in turn, determines the characteristics and strength of the *feedbacks* provided. Together, *intent*, *design* and *feedbacks* shape the material interventions that can be used to adjust behaviour. However, it is possible that *parameter* adjustments (for example, agri-environmental payments to farmers) or changes in *feedbacks* (for example, increased understanding of the impacts of climate change) may challenge or even shift the mind sets of actors—therefore ultimately altering the emergent *intent* of a given system of interest. An understanding of such potential interactions between deep and shallow leverage points represents a crucial gap in our current understanding of sustainability issues. As such we do not suggest that deep leverage points should be studied in isolation, but rather that an explicit focus on deeper leverage points may help uncover some of these systemic relations.

We argue that institutional change (*re-structure*), connections to nature (*re-connect*) and knowledge production and use (*re-think*) are particularly interesting realms of leverage to study because of the strong interactions between them. For example, formal and informal institutions shape and are shaped by human interactions with nature, as well as the knowledge that is generated about the context those institutions evolve within. Potentially, interventions within any of these realms of leverage have flow-on effects on the others. For example, institutional changes may facilitate the production and inclusion of different types of knowledge within a decision-making process. Investigating such interactions is important for understanding transformational change. In particular, more research is needed to understand: (i) how and to what extent deeper system characteristics (*design* and *intent*) shape and constrain shallower characteristics (*feedbacks* and *parameters*); (ii) the effectiveness of acting on a single leverage point (e.g. *intent*) compared to multiple leverage points in stimulating transformational system change; (iii) the role of potential 'cross realm levers' (e.g. interventions

that simultaneously address institutional reform, human–nature interactions and knowledge production) and (iv) the relation between theoretically informed understandings of transformational changes and the practical action undertaken to effect such changes.

CONCLUSIONS

Sustainability science is a solution-oriented research field, with the normative goal of aiding humanity in its transition towards sustainability. To do so, sustainability science needs to engage with the deep, or ultimate, causes of unsustainability and consider interventions that address the emergent *intent* and *design* of systems of interest, rather than only the adjustment of feedbacks and parameters. We propose that a research agenda centred on the concept of deep leverage points can provide a coherent framework for such engagement with the root causes of unsustainability. A leverage points framework to conceptualise transformation in social–ecological systems will enrich the multiple fields and disciplines that it needs to draw on. Most importantly, such a framework has tremendous potential to help reveal key, hitherto under-explored avenues to sustainability.

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