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Overcoming undesirable resilience in the global food system

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Non-technical summary. Our current global food system – from food production to consumption, including manufacture, packaging, transport, retail and associated businesses – is responsible for extensive negative social and environmental impacts which threaten the long-term well-being of society. This has led to increasing calls from science–policy organizations for major reform and transformation of the global food system. However, our knowledge regarding food system transformations is fragmented and this is hindering the development of co-ordinated solutions. Here, we collate recent research across several academic disciplines and sectors in order to better understand the mechanisms that 'lock-in' food systems in unsustainable states.

Technical summary. The current configuration of our global food system is undermining many of the UN Sustainable Development Goals (UN SDGs), leading to calls for major food system reform and transformation. Concurrently, other science–policy and business initiatives call for a food system more resilient to economic and environmental shocks, for example, by improving the economic resilience of current supply chains. Prioritization of short-term security to a subset of vested interests, however, can undermine the resilience of longer term beneficial outcomes for society. Here we advocate a more inclusive and farsighted approach focussing on the resilience of positive outcomes for the whole of society, that is, capturing the aim to promote resilient delivery of multiple UN SDGs. A significant challenge is to prioritize suites of interventions that can effectively transform the global food system to deliver these goals. Here, we use a transdisciplinary lens to identify 'lock-in' mechanisms that span four key areas – knowledge-based, economic/regulatory, sociocultural and biophysical constraints – which will help avoid ineffective siloed solutions to food system reform. Furthermore, we show how emergent system dynamics need to be considered using a more holistic approach. We highlight the importance of well-coordinated actions on multiple leverage points during windows of opportunity for food system transformation.

1. Navigating transformation, resilience and sustainability in the food system

In July 2017, the UN High-level Political Forum on Sustainable Development met to review progress towards the 2030 Agenda for Sustainable Development and reaffirmed the pledge by the 193 UN member states to end hunger, achieve food security, improve nutrition and promote sustainable agriculture, among other aims of the UN Sustainable Development Goals (UN SDGs). The participating member states emphasized that policy coherence and an enabling environment for sustainable development require engagement by all stakeholders including governments, public–private partnerships, the scientific community, the private sector, the donor community, non-governmental organizations, cooperatives, community groups, academic institutions and other relevant actors (United Nations Economic and Social Council, 2017). Given such a multiplicity of stakeholders, and the fact that complex interdependencies create major trade-offs between sustainable development goals (Waage *et al.*, 2015; European Environment Agency, 2016; IPES-Food, 2016; International Council for Science, 2017), a significant challenge is to prioritize suites of interventions that are most likely to be effective in transforming socio-ecological systems, such as the global food system, to better deliver the UN SDGs.

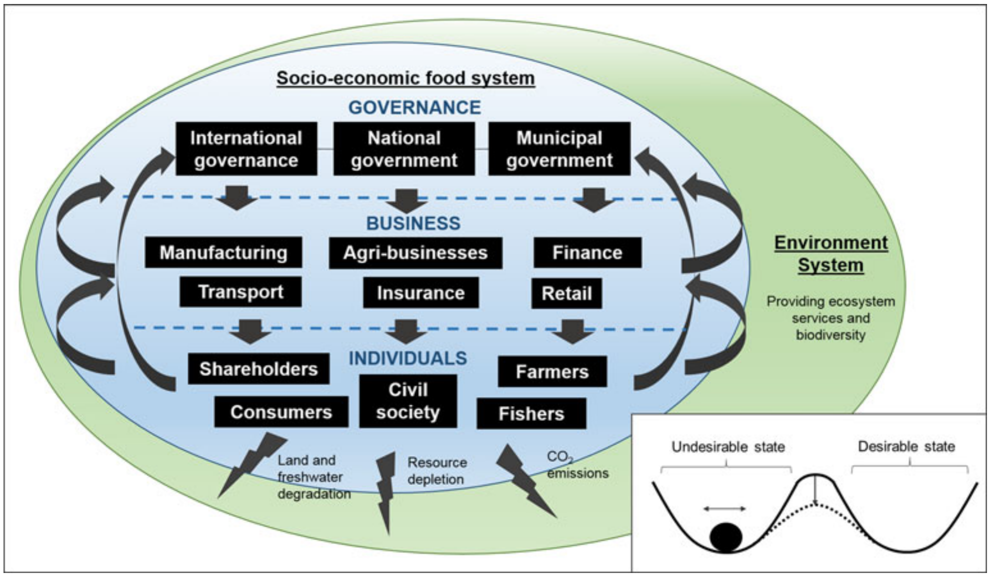

Fig. 1. Key actors in the food system linked through flows of goods and information (arrows). The current food system configuration is driving chronic social and environmental impacts which threaten its long-term sustainability. The inset panel shows a 'ball and cup' diagram from ecosystem science, characterizing how transformation of a system (the ball) to a more desirable state is more likely when the full range of 'lock-in' mechanisms are tackled in a coordinated way (vertical arrow; see Fig. 2 for examples of mechanisms).

Our global food system – defined as the network of activities and processes from production to consumption, including manufacture, packaging, transport, retail and associated businesses (Fig. 1) – is thought to be responsible for approximately 60% of global terrestrial biodiversity loss, 24% of greenhouse gas emissions, 33% of degraded soils and the overexploitation of 20% of aquifers (UNEP, 2016). Much of this environmental degradation is driven by high-input industrial agriculture and livestock rearing, with global supply chains largely controlled by a small number of multinational agribusiness and food retail companies (International Assessment of Agricultural Knowledge Science and Technology for Development, 2009). This industrialization of the food system has resulted in substantially higher productivity, with global productivity tripling between 1961 and 2011, providing cheaper more abundant food for many people (FAO, 2017). However, this food system is also inefficient, with around one-third of food lost or wasted (FAO, 2017) and persistent inequality in food distribution – 815 million people are still undernourished globally, 155 million children are stunted, and other forms of malnutrition are rising (FAO *et al.*, 2017). Additional social impacts include agrochemical exposure, local pollution from transport and processing, and increased zoonotic diseases and antibiotic resistance (Dangour *et al.*, 2017), as well as cultural erosion due to loss of traditional skills, knowledge, institutions and farming practices (IPES-Food, 2016).

Therefore, the current configuration of the global food system is directly undermining the attainment of many of the UN SDGs. This has led to increasing calls for major reform and transformation of the global food system (European Environment Agency, 2017; International Council for Science, 2017; United Nations Economic and Social Council, 2017). Concurrently, however, other science–policy and business initiatives call for a more resilient food system (MacLennan, 2014; Global Food Security Programme UK, 2015; Zeuli & Nijhuis, 2017). Resilience is defined as the resistance or rapid recovery of system interrelationships and functions after perturbation, which can also potentially involve aspects of internal adaptation and transformation in order to maintain function (Holling, 1973; Pimm, 1984; Carpenter *et al.*, 2001; Walker *et al.*, 2004; Schipanski *et al.*, 2016). However, resilient functioning for particular actors within the food system could promote the overall status quo and maintain the aforementioned negative aspects of the food system. How can these two apparently opposing perspectives of broad-scale system transformation and resilience be reconciled?

Many different disciplines investigate concepts of resilience, for example, engineering, geography, computer science, mathematics, psychology and ecology, and it has been a useful 'bridging concept' (Brand & Jax, 2007), although it is used nearly exclusively in a normative sense focussing on the beneficial aspects of maintaining function or structure in the face of shocks. However, many aspects of socio-ecological systems show resilience of outcomes which are undesirable for society as a whole (e.g. chronic poverty, invasive species, diseases, terrorist networks and greenhouse gas emissions from industry) (Unruh, 2000).

When talking about resilience, there is a need to be explicit regarding resilience 'of what?', 'to what?' and 'for whom?' (Carpenter *et al.*, 2001; Cutter, 2016), and, importantly, 'over what timeframe?' (Oliver, 2016). For example, global food retailers may seek resilient supply chains to maintain uninterrupted delivery of food products for their consumers in the face of extreme weather perturbations. To increase their economic resilience, one tactic is to secure production across multiple territories to defray risks; this has led to large-scale land acquisitions in developing countries which threaten the food security of local communities (European Environment Agency, 2015). Thus, targeting resilience in a narrow sectoral manner creates trade-offs with the resilience of positive outcomes for other actors in the system, or for society as a whole, including future generations.

In this article, we advocate a more holistic and long-term approach focussing on the resilience of a broad range of positive outcomes for the whole of society, that is, capturing the aim to promote the resilient delivery of multiple UN SDGs. The focus

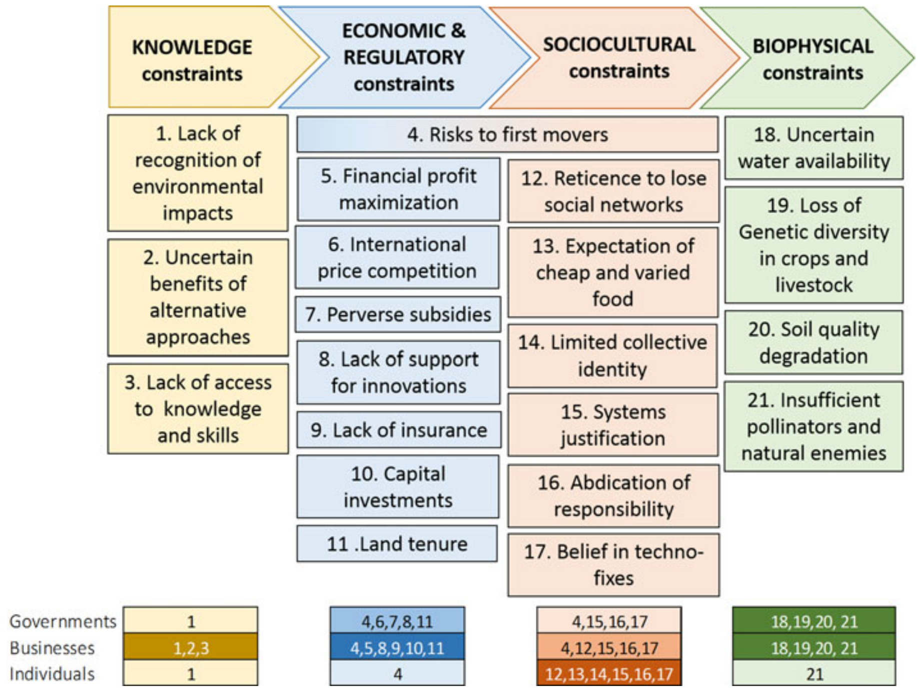

Fig. 2. Some of the mechanisms locking the food system into its current undesirable state. At the bottom are different actor types to which the different mechanisms mostly pertain (from the three levels in Fig. 1; colour shading indicates tally count of mechanisms, which are coded by numbers). See headed sections below for mechanism descriptions.

on a longer time frame (i.e. 2030 and beyond) is crucial, because whilst over the short term food security may be successfully achieved through redistribution of food using the same intensive production methods, over longer time scales food security will be threatened by these approaches. Under intensive food production, the loss and degradation of top soil, declines in pollinators and natural pest enemies, the development of pesticide and herbicide resistance, and the pollution of water and soil in the face of a changing climate all undermine the ability to sustain sufficient food production (Bullock *et al.*, 2017; FAO, 2017).

2. Unlocking undesirable resilience to achieve food system transformation

There have been optimistic approaches to achieving transformations in social–technical systems in sectors such as energy and transport (European Environment Agency, 2016). Under what is called the 'multi-level' perspective, social–technical systems are characterized as being structured and stabilized by factors such as knowledge, investments, policies, institutions, skills and cultural values (European Environment Agency, 2016; Geels, 2011). To disrupt this prevailing 'regime', new ideas, technologies, business models or cultural norms have to emerge, and positive ones (such as renewable energy technologies) may need protecting from immediate pressure from the regime (European Environment Agency, 2017). Certain authors even suggest actively searching for 'cracks' in the prevailing regime to sow disruption (Fourcade, 2012). Such approaches, which focus primarily on developing alternative approaches could remain largely theoretical unless we can tackle the strong feedback mechanisms that maintain a given system in its current undesirable state. For example, the rapid development of the global South and large-scale land acquisition by private interests may further drive the current industrial food model to even greater dominance (IPES-Food, 2016). Unless we can overcome such undesirable resilience, the food system may remain locked into its current state, slowly eroding its own sustainability until a perturbation or series of related perturbations cause sudden non-linear systemic collapses (Homer-Dixon *et al.*, 2015; Global Food Security Programme UK, 2017).

In the absence of genuinely disruptive innovations that may endogenously transform a system, we need to take a strategic transdisciplinary approach to unlock undesirable resilience. First, we need to envision an alternative trajectory for the system that secures multiple long-term benefits for society (IIASA, 2017), understanding how this influences incumbent power relationships on the one hand, and social goods on the other (in short, in a transformed system, who wins, who loses and over what time scales?). We use the UN SDGs to identify a set of long-term outcomes to which the food system needs to be re-aligned. Second, an interdisciplinary lens is needed to identify the various mechanisms that underpin undesirable resilience and prevent food system transformation. Finally, higher-level emergent system properties should be considered that help or hinder transformations. A broad set of disciplines can provide insights from the analytical sciences, such as complexity and ecosystem science, to the social sciences (analysis of power relationships, governance, institutions, economics, equity and gender) and the humanities (e.g. history of food systems).

Although research into system transformations is a rapidly expanding field, knowledge is still fragmented across disciplines (Feola, 2015). Much primary research on the mechanisms inhibiting system transformation, for example, are often discipline specific, with their own terminology (e.g. 'institutional inertia' (Rosenschöld *et al.*, 2014), 'wicked resilience' (Glaser *et al.*, 2018), 'unhelpful resilience' (Standish *et al.*, 2014), 'path dependency' (Barnes *et al.*, 2004), 'lock-in' (Barnes *et al.*, 2004), 'traps' (Haider *et al.*, 2018)). Previous syntheses of the specific mechanisms that maintain what we term 'undesirable resilience' in food systems have identified only a handful of mechanisms and have tended to exclude lessons from the environmental sciences (Robertson & Swinton, 2005; Scheffer & Westley, 2007; European

		'Lock-in' mechanisms pertaining to:-		
		INDIVIDUALS	BUSINESS	GOVERNMENT
	e.g. Fig. 2 mechanism code:	1-5, 10-21	1-5, 8-12, 15-21	1, 4, 6-8, 11, 15-21
Solutions instigated by:-	INDIVIDUALS	Knowledge-exchange on best practice; information provision to inform consumer choice; change social norms around consumer choices, food waste, recycling and farming/fishing practices; promote collective identity and social responsibility; follow best practice to restore pollinators and natural enemies; implement responsible use of water, soil and natural resources	Highlight good and poor business practice; use shareholder influence and invest in sustainable initiatives; exercise consumer choice for food that is sustainably produced, manufactured and transported	Communicate sustainability concerns; debunk infeasible techno-fixes; develop and engage with civil society movements and demands; vote on sustainability credentials
	BUSINESS	Improve information on sustainability of supply chains for foods; develop innovative insurance products and financing approaches; choice editing to promote sustainable food choices; invest and innovate sustainable products and services; facilitate new crop and livestock varieties for food producers;	Knowledge-exchange on best practice; demonstrate feasibility of positive change; develop innovative insurance products and financing approaches; debunk infeasible techno-fixes; innovative water management through public-private partnerships; develop innovations in sustainable practice	Provide reports on sustainable initiatives; co-develop innovative insurance products and financing approaches; innovative water management through public-private partnerships; facilitate new crop and livestock varieties and guidelines and regulation for sustainable food production
	GOVERNMENT	Education regarding sustainable practices; information and skill provision; stimulate and protect sustainable innovations; incentivise sustainable practices and regulate/tax others; reform land tenure governance; consult and act on social contract to protect future generations; change social norms around consumer choices, food waste, recycling and farming/fishing practices; debunk infeasible techno-fixes; improve incentives, regulation and enforcement on natural resource use	Information and skills provision; stimulate and protect sustainable innovations; incentivise sustainable practices and regulate/tax others; limit power of vested interests; debunk infeasible techno-fixes; incentivise practices which restore essential biodiversity; regulate and enforce sustainable natural resource use	Monitor and raise profile of social and environmental impacts; inter-governmental alignment on food system policy; debunk infeasible techno-fixes; take responsibility on social equity and intergenerational justice; implement biodiversity targets; quantify and reduce environmental impacts from imports; cooperate internationally on pests and disease

Fig. 3. Potential solutions implemented across hierarchical levels of the food system. The list is not exhaustive and multiple solutions must be implemented across all hierarchical levels in order to overcome the undesirable resilience of the current food system. Colour coding links to the type of mechanism in Fig. 2, that is, knowledge-based, economic/regulatory, sociocultural and biophysical constraints.

Environment Agency, 2016; IPES-Food, 2016; Kuokkanen *et al.*, 2017). Such fragmentation is hindering the development of co-ordinated solutions. The development of less siloed approaches, agreed to be essential for successful system transformations, requires better integration of understanding across academic disciplines (European Environment Agency, 2016; IPES-Food, 2016; International Council for Science, 2017). For example, we need to understand when, how and why biophysical mechanisms limit socio-ecological transformation and whether tackling these is a prerequisite for the development of effective social, political and economic interventions. A case in point is the extensive global land area degraded by soil erosion and desertification, such as the Loess Plateau in China, which requires extensive ecosystem restoration to facilitate sustainable food production and associated social benefits (Zhao *et al.*, 2013).

3. An interdisciplinary lens on food system 'lock-in' mechanisms

Below, we define an extensive list of mechanisms, including biophysical constraints, coupled with sociocultural, economic/regulatory and knowledge constraints, that underpin undesirable resilience in the global food system (Fig. 2 and sub-sections below; where '#' in parentheses refer to numbered mechanisms in the figure). These mechanisms were identified through an interdisciplinary workshop followed up with an exploration of relevant literature around the potential mechanisms identified. Many of these mechanisms are more likely to become apparent only once other constraining mechanisms are removed, yet over time they may become increasingly costly, or even impossible, to reverse. Although our list is not exhaustive, we propose that this interdisciplinary synthesis, which brings together ecological, cultural, social and economic factors, is a significant starting point. Most food systems transformation research frames this issue primarily as separate production, social or economic problems (Robertson & Swinton, 2005). Linked to these mechanisms we also provide a non-exhaustive list of possible solutions (Fig. 3), which need to be implemented contemporaneously across all the hierarchical scales in the food system – from individual to business to governance. This appreciation of cross-scale interactions for food system transformation leads to a more holistic approach akin to the 'panarchy' concept in socio-ecological studies (Allen *et al.*, 2014); yet, by focussing first on particular solutions identified using a reductionist approach, it is arguably more pragmatic and potentially easier to operationalize.

3.1. Knowledge constraints

For some food system actors there may be limited understanding of the wider scale, longer term negative environmental impacts of current approaches (e.g. the impacts of food waste and dietary choices) and therefore no incentive to adopt alternatives [#1] (Ingram, 2008). There may be some appreciation of the unsustainability of current approaches, but uncertainty and lack of consensus prevail regarding the costs and benefits of adopting alternative approaches (due to lack of reliable information and forecasting tools, or plurality of values, among other factors) [#2] (Vermeulen *et al.*, 2012). Another constraint is that certain actors (e.g. farmers or retailers) might want to adopt a new strategy that enhances food system sustainability, but they lack access to the necessary knowledge or skills [#3]. For example, many farmers have lost the traditional knowledge needed to farm more sustainably, or lack information on how to innovate or adapt current best practice to changing environmental conditions (Altieri *et al.*, 2015). Thus, there is a clear role for policy to stimulate innovations and opportunities in practice across the food system and to support more effective and targeted knowledge exchange and training in alternative approaches. Moreover, recent research shows how homogeneous representations of women farmers and the technical focus of policy interventions pose risks to further marginalize knowledge of the most vulnerable and exacerbate existing inequalities within agriculture under climate change (Friedman *et al.*, 2018).

3.2. Economic/regulatory constraints

Being a first mover (e.g. a retailer deciding to stock only sustainably produced food) can have higher direct costs and carry greater risks [#4]. Incentive structures and regulatory frameworks need reform because the rational economic choice for actors is often to maintain unsustainable practices [#5] (Civil Society Statement on the Reform of European Agricultural Policies, 2017). Also, powerful vested interests who benefit financially from the current situation may hinder system reform (IPES-Food, 2016). Improved inter-governmental alignment on food system policy is urgently needed because macroeconomic decisions can shape and constrain sustainable approaches. International price competition has prompted national governments to encourage large-scale specialization in food production to reap the benefits of comparative advantage (MacDonald *et al.*, 2015; European Environment Agency, 2016). Governments have been reticent to regulate for internalization of environmental costs into prices to avoid unpopular price rises and a reduction in competitiveness [#6]. Reform of financial incentives (direct subsidies, tariffs or quotas) is also needed because these often promote food production at the expense of the environment and sustainability to gain competitiveness [#7]. Other economic obstacles to food system transitions include limited support of new practices [#8], lack of innovative insurance products (e.g. to buffer the uncertain yields of farming [#9]), and the 'sunk' capital cost that actors such as farmers, manufacturers and retailers have invested in conventional approaches [#10] (IPES-Food, 2016). Financial and regulatory reform is needed to stimulate necessary risk taking to overcome these constraints and support innovation. Finally, review of land tenure and governance structures may be needed, given that unclear or reduced continuity of land ownership and increasing contract/tenant farming creates greater incentives for farmers to ignore sustainability [#11] (Gebremedhin & Swinton, 2003).

3.3. Sociocultural constraints

In the face of economic costs or risks to first movers, policy innovations may be needed to ensure that a critical mass of actors adopt an alternative approach in tandem; for example, through incentivizing collective responses [#4] (Feola & Binder, 2010). A related issue at an individual level is the potential loss of social networks providing both personal and financial support that are at risk from a shift to alternative approaches [#12] (Amel *et al.*, 2017). Policy focussed on influencing consumer demand is also critical. Many consumers now expect a wide variety of cheap food to be constantly available, leading food retailers to source products accordingly, with less regard for environmental impacts [#13]. The limited demand for, and supply of, sustainably sourced food may stem from knowledge deficits. However, in some cases consumers, producers and retailers may recognize, yet disregard, environmental impacts on the basis that they themselves do not bear the direct costs. In this case, collective identity, which would incline individuals to favour choices that provide benefit to wider society, including future generations, is negligible, precluding shifts towards sustainability [#14] (Zylstra *et al.*, 2014; Amel *et al.*, 2017). In other cases, people may indeed care deeply about wider societal inequality but suffer cognitive bias causing them to accept the current status quo (cf. 'systems justification' (Jost *et al.*, 2004)) [#15]. Alternatively, consumers assume that government oversight ensures food system sustainability, whilst governments assume that consumers act rationally on the basis of their value sets and adequate information, so that market choices should deliver the best for society [#16]. Reframing the social contract between governments and citizens is needed to prevent this simultaneous abdication of responsibility. Finally, many actors throughout the food system believe that society will be able to innovate its way out of future environmental problems through technological 'fixes' to compensate for compromised regulating services (e.g. geoengineering solutions to climate change, new genetically engineered crop strains and robotic pollinators) [#17] (Corner *et al.*, 2013). Support for technological innovation is essential, but this does not obviate the need for policy to stimulate action to mitigate future environmental damage (European Environment Agency, 2015).

3.4. Biophysical constraints

Certain ecological factors are likely to be obstacles to alleviating food system lock-ins. Water availability may increasingly be a constraint in areas that have come to depend upon irrigation; reversion to rain-fed agriculture might compromise yield levels, predictability or quality, especially under climate change [#18] (Elliott *et al.*, 2014). In such cases, facilitation of innovative water management – for example, multiscale governance through public–private partnerships – may become necessary (Chaffin *et al.*, 2016). Reliance on few crop and livestock varieties demanding high chemical, water and nutritional inputs, and the loss of genetic diversity in other varieties, may become a limiting factor in shifting to less intensive farming practices [#19]. Years of intensive farming can often lead to soil degradation (e.g. compaction; erosion; depletion of nutrients, organic matter and key functional biodiversity), so that relinquishing techniques relying heavily on chemical inputs is difficult [#20] (Feola & Binder, 2010). Extensive loss of natural areas in farmed landscapes may mean that, among other species, key pollinator species and natural enemies of agricultural pests are lost, and hence that low-pesticide farming is no longer viable (Hammond Wagner *et al.*, 2016). Therefore, fast-tracking implementation of targets, such as those of the Convention for Biological Diversity on habitat restoration, may be necessary to enable the viability of less intensive food system approaches [#21]. Improved international collaboration on invasive alien pests and diseases, exacerbated by globalized trade and climate change (Chapman *et al.*, 2017), may also be needed to ensure that natural biological control can be effective in preventing yield losses.

4. Consideration of whole-system dynamics

After identifying a more desirable state for the global food system that balances multiple UN SDGs and subsequently ascertaining the mechanisms that constrain such a transformation (Fig. 2), it is important to consider the emergent dynamics of the system. More holistic, analytical approaches to investigating lock-ins in socio-economic systems are developing (Lade *et al.*, 2017; Ngonghala *et al.*, 2017), even though the field is still in its infancy. However, there is a long history of research into the opposite phenomenon of positive narratives of resilience, generally defined as the ability of a system to resist or recover from perturbations and maintain function (Holling, 1973; Pimm, 1984; Oliver *et al.*, 2015), from which lessons can be learned. Below, we draw out lessons relevant to understanding undesirable resilience in the global food system.

4.1. Exploiting windows of opportunity for food system transformation

Substantial research, in particular with regards to shifts in ecosystems between semi-stable states has documented how system transformations are most likely to occur during periods when external perturbations are substantial (Folke *et al.*, 2004). Reported shifts in ecosystems are usually considered as being from a desirable to a less desirable state (e.g. with lower provision of ecosystem services), but ecosystems can equally be locked-in to less undesirable states (Standish *et al.*, 2014). Transient periods of unusual environmental conditions can be quantified to predict when a shift to a new ecosystem state is likely to occur (Balke *et al.*, 2014). Much effort has been spent ascertaining whether there might be 'early warning' indicators of impending ecosystem shifts (Scheffer *et al.*, 2009; Dai *et al.*, 2012; Global Food Security Programme UK, 2017), although with limited success in some real-world systems (Biggs *et al.*, 2009; Dakos *et al.*, 2015). For socio-ecological systems, and food systems in particular, we might question whether there are similar transient 'windows of opportunity' to reconfigure systems to more desirable, sustainable states. Recognizing these conditions *a priori* may be challenging, but doing so would provide a stimulus to galvanize coordinated efforts to act on some of the mechanisms described in Fig. 2 to facilitate successful system transformation. Windows of opportunity may arise at different hierarchical levels in food systems: individual citizens, business or governments (Fig. 1). For example, for the European food system, opportunities for system change may be opening at the level of individual citizens, where there is growing demand for food system reform – as called for by over 150 European organizations in a Civil Society Statement on the Reform of the European Agricultural Policies (Civil Society Statement on the Reform of European Agricultural Policies, 2017). At the level of businesses, there is increasing potential for working in partnership with government and civil society to shape the food environment and consumer preferences, especially around promoting healthy diets, for example, through 'choice editing' by retailers (European Environment Agency, 2017). At the level of governance, a window is arising through simultaneous major policy renewals (e.g. in 2020 renewal of the EU's Common Agricultural Policy and Common Fisheries Policy and Cohesion Policy). For the UK, exit from the EU, including the proposed major new changes to trade agreements, offers an opportunity to redesign food and environmental regulation in order to improve long-term sustainability. However, it of course also harbours substantial risks for food system transformations that could actually have worse net long-term outcomes for society (Schipanski *et al.*, 2016).

4.2. The importance of co-ordinated action on multiple leverage points

There are multiple mechanisms maintaining lock-ins to undesirable outcomes in the food system (Fig. 2), and thus multiple entry points for levers to unlock such undesirable resilience (e.g. instigating behavioural change amongst shareholders, consumers and producers; facilitation of business innovation; government regulation or incentive schemes; Fig. 3) (Ölander & Thøgersen, 2014; Everard *et al.*, 2016). The lack of a genuinely interdisciplinary approach to appraising lock-in mechanisms to date has led to siloed approaches to solutions for food systems transformation. An additional problem this fragmented approach engenders – as well as completely neglecting certain important mechanisms – is that interventions aiming to transform the system tend to be poorly coordinated and unlikely to be effective. It is rarely acknowledged that ineffective solutions may actually enhance undesirable resilience. Using an ecosystems example, attempts to control certain toxic pasture weeds (e.g. globally invasive ragwort species) through conventional management practices can actually increase weed spread (Leiss, 2011). Similar properties may occur in socio-ecological systems, such as the global food system. For example, persistent communication regarding negative environmental and social impacts may cause actors who have vested interests in the current food system configuration to develop strategies to resist or influence change for their own interests (e.g. denigration of 'expert knowledge' and propagation of 'alternative facts') (Lang & Heasman, 2015). Another example is where resource efficiency gains in food production lead to cheaper product prices, which stimulate increased consumption or increased waste (the Jevons paradox or 'rebound effect'), thus subverting any environmental gains (European Environment Agency, 2015). In light of these unexpected consequences, careful planning of co-ordinated cross-sectoral interventions is likely to be necessary to achieve food system transformation.

5. 'Locking-in' positive system states to achieve resilience of beneficial outcomes

Following transformation of a system, or subsets of that system, to deliver beneficial outcomes for society, we may want to 'lock-in' these benefits so that they are resilient over the longer term (i.e. in systems science language, creating 'virtuous circles' rather than 'vicious cycles') (Nyborg *et al.*, 2016). A reformed food system delivering across multiple UN SDG outcomes needs to be resilient to the forces that might undermine this new system configuration. High levels of inter-connectivity in food systems can create a systemic risk to a reformed system by undermining sustainability efforts through price undercutting (Benton, in press), whereby cheaper but less sustainable products (due to externalization of health and environmental costs) outcompete sustainably produced products and spread through the food system. This is analogous to highly-competitive invasive species spreading rapidly through globalized trade routes (Chapman *et al.*, 2017). To reduce this risk of the system reverting to an undesirable state, promoting modularity in the food system (i.e. relatively isolated sub-systems with differentiated approaches to sustainability) may be helpful (Gilarranz *et al.*, 2017). In ecological systems, diversity enhances the stability of beneficial ecosystem functions through increased likelihood of at least one strategy (e.g. genotype or species) performing well in a given set of circumstances (Oliver *et al.*, 2015). Similar 'portfolio effects' operate in financial investment systems (Abson *et al.*, 2013). In food systems, local networks could achieve systemic diversity through the adoption of different governance mechanisms, institutional organization or food production methods (Hodbod *et al.*, 2016; Bullock *et al.*, 2017).

With regards to the scale (regional, national, sub-national) at which such modules could most effectively operate, the 'city-region' scale has been suggested as promising with regards to the potential for shorter supply chains with lower environmental impacts (FAO, 2016; IPES-Food, 2016; International Food Policy Research Institute, 2017), and a number of policy initiatives are developing focussed at this scale (e.g. the Milan Urban Food Policy Pact signed by cities globally, and the New Urban Agenda adopted by the UN (United Nations, 2016)). However, consideration is needed on how to share good practice across these initiatives without reducing their diversity, and also on how to ensure that local networks are not undercut by cheaper, less sustainable products from the global market. This may become a particular problem as chronic environmental and social issues escalate (with impacts particularly concentrated in cities) (International Food Policy Research Institute, 2017) in combination with rapid urbanization, making sustainably produced food an unaffordable luxury.

6. Conclusion

Although there seem to be contradictions amongst concurrent calls for greater resilience in the food system versus wholesale system transformation, these may be resolved by taking a more comprehensive, longer term approach to beneficial outcomes – that is, ensuring maintenance of multiple UN SDGs for the benefits of wider society now and in future generations. Resilience in UN SDG delivery up to 2030 and beyond requires transformation of our global food system (European Environment Agency, 2017; International Council for Science, 2017; United Nations Economic and Social Council, 2017). We have highlighted new insights using a transdisciplinary lens, where one can begin to identify lock-in mechanisms that span four key areas: knowledge-based, economic/regulatory, sociocultural and biophysical constraints, to avoid ineffective, siloed solutions to food system reform. Furthermore, in our work we show emergent system dynamics also need to be considered using a more holistic approach; for example, helping us to recognize the importance of well-coordinated action on multiple leverage points during windows of opportunity for food system transformation. The crucial need to foster a much broader interdisciplinary dialogue is equally applicable to undesirable resilience in many socio-ecological systems; for example, greenhouse gas emissions, poverty traps, invasive species, diseases and terrorist networks. Building on the bridging concept of resilience, but with a new focus on overcoming resilience of undesirable outcomes, will allow more rapid progress in transforming systems to states that deliver multiple long-term beneficial outcomes to society. For the global food system, this involves designing system transformation to overcome short-term gains and vested interests in order to deliver multiple UN SDGs for current and future generations.

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References

Abson, D. J., Fraser, E. D., & Benton, T. G. (2013). Landscape diversity and the resilience of agricultural returns: a portfolio analysis of land-use patterns and economic returns from lowland agriculture. *Agriculture & Food Security*, *2*(1), 2. doi: 10.1186/2048-7010-2-2

Allen, C. R., Angeler, D. G., Garmestani, A. S., Gunderson, L. H., & Holling, C. S. (2014). Panarchy: theory and application. *Ecosystems*, *17*(4), 578–589. doi: 10.1007/s10021-013-9744-2

Altieri, M. A., Nicholls, C. I., Henao, A., & Lana, M. A. (2015). Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development*, *35*(3), 869–890. doi: 10.1007/s13593-015-0285-2

Amel, E., Manning, C., Scott, B., & Koger, S. (2017). Beyond the roots of human inaction: fostering collective effort toward ecosystem conservation. *Science*, *356*(6335), 275–279. doi: 10.1126/science.aal1931

Balke, T., Herman, P. M. J., & Bouma, T. J. (2014). Critical transitions in disturbance-driven ecosystems: identifying windows of opportunity for recovery. *Journal of Ecology*, *102*(3), 700–708. doi: 10.1111/1365-2745.12241

Barnes, W., Gartland, M., & Stack, M. (2004). Old habits die hard: path dependency and behavioral lock-in. *Journal of Economic Issues*, *38*(2), 371–377. doi: 10.1080/00213624.2004.11506696

Benton, T. G. (in press). Nine meals from anarchy: the fragility of food systems in a globalised world. In *Disrupted Balance – Society at Risk* (ed. J. Vasbinder). Singapore: ParaLimes.

Biggs, R., Carpenter, S. R., & Brock, W. A. (2009). Turning back from the brink: detecting an impending regime shift in time to avert it. *Proceedings of the National Academy of Sciences*, *106*(3), 826–831. doi: 10.1073/pnas.0811729106

Brand, F. S., & Jax, K. (2007). Focusing the meaning(s) of resilience: resilience as a descriptive concept and a boundary object. *Ecology and Society*, *12*, 23.

Bullock, J. M., Dhanjal-Adams, K. L., Milne, A., Oliver, T. H., Todman, L. C., Whitmore, A. P., & Pywell, R. F. (2017). Resilience and food security: rethinking an ecological concept. *Journal of Ecology*, *105*, 880–884.

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From metaphor to measurement: resilience of what to what? *Ecosystems*, *4*(8), 765–781. doi: 10.1007/s10021-001-0045-9

Chaffin, B. C., Garmestani, A. S., Gosnell, H., & Craig, R. K. (2016). Institutional networks and adaptive water governance in the Klamath River Basin, USA. *Environmental Science & Policy*, *57*(Supplement C), 112–121. doi: https://doi.org/10.1016/j.envsci.2015.11.008

Chapman, D., Purse, B. V., Roy, H. E., & Bullock, J. M. (2017). Global trade networks determine the distribution of invasive non-native species. *Global Ecology and Biogeography*, *26*(8), 907–917. doi: 10.1111/geb.12599

Civil Society Statement on the Reform of European Agricultural Policies (2017). Civil Society Statement on the Reform of European Agricultural Policies Good Food, Good Farming – Now! Retrieved from http://www.ifoam-eu.org/sites/default/files/ifoam_eu_ngos_policy_cap_reform_european_agricultural_policies_cso_statement_20170306.pdf

Corner, A., Parkhill, K., Pidgeon, N., & Vaughan, N. E. (2013). Messing with nature? Exploring public perceptions of geoengineering in the UK. *Global Environmental Change*, *23*(5), 938–947. doi: https://doi.org/10.1016/j.gloenvcha.2013.06.002

Cutter, S. L. (2016). Resilience to what? Resilience for whom? *The Geographical Journal*, *182*(2), 110–113. doi: 10.1111/geoj.12174

Dai, L., Vorselen, D., Korolev, K. S., & Gore, J. (2012). Generic indicators for loss of resilience before a tipping point leading to population collapse. *Science*, *336*(6085), 1175–1177. doi: 10.1126/science.1219805

Dakos, V., Carpenter, S. R., van Nes, E. H., & Scheffer, M. (2015). Resilience indicators: prospects and limitations for early warnings of regime shifts. *Philosophical Transactions of the Royal Society B*, *370*(1659), 20130263. doi: 10.1098/rstb.2013.0263

Dangour, A. D., Mace, G., & Shankar, B. (2017). Food systems, nutrition, health and the environment. *The Lancet Planetary Health*, *1*(1), e8–e9. doi: 10.1016/S2542-5196(17)30004-9

Elliott, J., Deryng, D., Müller, C., Frieler, K., Konzmann, M., Gerten, D., Glotter, M., Flörke, M., Wada, Y., Best, N., Eisner, S., Fekete, B. M., Folberth, C., Foster, I., Gosling, S. N., Haddeland, I., Khabarov, N., Ludwig, F., Masaki, Y., Olin, S., Rosenzweig, C., Ruane, A. C., Satoh, Y., Schmid, E., Stacke, T., Tang, Q., & Wisser, D. (2014). Constraints and potentials of future irrigation water availability on agricultural production under climate change. *Proceedings of the National Academy of Sciences*, *111*(9), 3239–3244. doi: 10.1073/pnas.1222474110

European Environment Agency (2015). European Environment – State and Outlook 2015: Synthesis Report. Copenhagen: European Environment Agency. Retrieved from https://www.eea.europa.eu/soer

European Environment Agency (2016). Sustainability Transitions: Now for the Long Term. Eionet Report, No 1/2016. Retrieved from https://www.eea.europa.eu/publications/sustainability-transitions-now-for-the

European Environment Agency (2017). Food in a Green Light – a Systems Approach to Sustainable Food. EEA Report, No 16/2017. Retrieved from https://www.eea.europa.eu/publications/food-in-a-green-light

Everard, M., Reed, M. S., & Kenter, J. O. (2016). The ripple effect: institutionalising pro-environmental values to shift societal norms and behaviours. *Ecosystem Services*, *21*, 230–240. doi: http://dx.doi.org/10.1016/j.ecoser.2016.08.001

FAO (2016). Food for the Cities Programme – Building Sustainable and Resilient City Region Food Systems. Retrieved from http://www.fao.org/3/a-i5502e.pdf

FAO (2017). The Future of Food and Agriculture – Trends and Challenges. Rome: FAO. Retrieved from http://www.fao.org/publications/fofa/en/

FAO, IFAD, UNICEF, WFP, & WHO. (2017). The State of Food Security and Nutrition in the World 2017. Building Resilience for Peace and Food Security. Rome: FAO. Retrieved from http://www.fao.org/state-of-food-security-nutrition

Feola, G. (2015). Societal transformation in response to global environmental change: a review of emerging concepts. *Ambio*, *44*(5), 376–390. doi: 10.1007/s13280-014-0582-z

Feola, G., & Binder, C. R. (2010). Identifying and investigating pesticide application types to promote a more sustainable pesticide use. The case of smallholders in Boyacá, Colombia. *Crop Protection*, *29*(6), 612–622. doi: https://doi.org/10.1016/j.cropro.2010.01.008

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., & Holling, C. S. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics*, *35*(1), 557–581. doi: 10.1146/annurev.ecolsys.35.021103.105711

Fourcade, M. (2012). On Erik Olin Wright, envisioning real utopias, London and New York, NY, Verso, 2010. *Socio-Economic Review*, *10*(2), 369–402. doi: 10.1093/ser/mwr032

Friedman, R., Hirons, M., & Boyd, E. (2018). Weathering change: a typology of Ghanaian women cocoa farmer perspectives on climate change and vulnerability. *Climate Change and Development*. doi: 10.1080/17565529.2018.1442806

Gebremedhin, B., & Swinton, S. M. (2003). Investment in soil conservation in northern Ethiopia: the role of land tenure security and public programs. *Agricultural Economics*, *29*(1), 69–84. doi: https://doi.org/10.1016/S0169-5150(03)00022-7

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: responses to seven criticisms. *Environmental Innovation and Societal Transitions*, *1*(1), 24–40. doi: https://doi.org/10.1016/j.eist.2011.02.002

Gilarranz, L. J., Rayfield, B., Liñán-Cembrano, G., Bascompte, J., & Gonzalez, A. (2017). Effects of network modularity on the spread of perturbation impact in experimental metapopulations. *Science*, *357*(6347), 199–201. doi: 10.1126/science.aal4122

Glaser, M., Plass-Johnson, J. G., Ferse, S. C. A., Neil, M., Satari, D. Y., Teichberg, M., & Reuter, H. (2018). Breaking resilience for a sustainable future: thoughts for the Anthropocene. *Frontiers in Marine Science*, *5*(34). doi: 10.3389/fmars.2018.00034

Global Food Security Programme UK (2015). Extreme weather and resilience of the global food system (2015). Final Project Report from the UK–US Taskforce on Extreme Weather and Global Food System Resilience, The Global Food Security programme, UK. Retrived from https://www.foodsecurity.ac.uk/publications/

Global Food Security Programme UK (2017). Environmental Tipping Points and Food System Dynamics: Main Report (2017). The Global Food Security programme, UK. Retrived from https://www.foodsecurity.ac.uk/publications/

Haider, L. J., Boonstra, W. J., Peterson, G. D., & Schlüter, M. (2018). Traps and sustainable development in rural areas: a review. *World Development*, *101*, 311–321. doi: https://doi.org/10.1016/j.worlddev.2017.05.038

Hammond Wagner, C., Cox, M., & Bazo Robles, J. L. (2016). Pesticide lock-in in small scale Peruvian agriculture. *Ecological Economics*, *129*(Supplement C), 72–81. doi: https://doi.org/10.1016/j.ecolecon.2016.05.013

Hodbod, J., Barreteau, O., Allen, C., & Magda, D. (2016). Managing adaptively for multifunctionality in agricultural systems. *Journal of Environmental Management*, *183*, 379–388. doi: https://doi.org/10.1016/j.jenvman.2016.05.064

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, *4*, 1–23.

Homer-Dixon, T., Walker, B., Biggs, R., Crepin, A.-S., Folke, C., Lambin, E. F., Peterson, G. D., Rockström, J., Scheffer, M., Steffen, W., & Troell, M. (2015). Synchronous failure: the emerging causal architecture of global crisis. *Ecology and Society*, *20*, 6.

IIASA (2017). TWI2050 The World in 2050 – a Global Research Initiative in Support of a Successful Implementation of the United Nations 2030 Agenda. Retrieved from http://twi.wp.iiasa.ac.at/wp-content/uploads/sites/13/2016/07/TWI2050-trifold-flyer.pdf

Ingram, J. (2008). Are farmers in England equipped to meet the knowledge challenge of sustainable soil management? An analysis of farmer and advisor views. *Journal of Environmental Management*, *86*(1), 214–228. doi: https://doi.org/10.1016/j.jenvman.2006.12.036

International Assessment of Agricultural Knowledge Science and Technology for Development (2009). Agriculture at a Crossroads. Synthesis Report – a Synthesis of the Global and Sub-Global IAASTD Reports. Retrieved from https://archive.org/details/fp_Agriculture_at_a_Crossroads_Synthesis_Report_English

International Council for Science (2017). A Guide to SDG Interactions: from Science to Implementation (ed. D.J. Griggs, M. Nilsson, A. Stevance, D. McCollum). International Council for Science. Retrieved from https://www.icsu.org/cms/2017/05/SDGs-Guide-to-Interactions.pdf

International Food Policy Research Institute (2017). Global Food Policy Report. Washington, DC: International Food Policy Research Institute. Retrieved from http://www.ifpri.org/publication/2017-global-food-policy-report

IPES-Food (2016). International Panel of Experts on Sustainable Food Systems (IPES-Food). Report 02: From Uniformity to Diversity. Retrieved from http://www.ipes-food.org/images/Reports/UniformityToDiversity_FullReport.pdf

Jost, J. T., Banaji, M. R., & Nosek, B. A. (2004). A decade of system justification theory: accumulated evidence of conscious and unconscious bolstering of the status quo. *Political Psychology*, *25*(6), 881–919. doi: 10.1111/j.1467-9221.2004.00402.x

Kuokkanen, A., Mikkilä, M., Kuisma, M., Kahiluoto, H., & Linnanen, L. (2017). The need for policy to address the food system lock-in: a case study of the Finnish context. *Journal of Cleaner Production*, *140*(Part 2), 933–944. doi: https://doi.org/10.1016/j.jclepro.2016.06.171

Lade, S. J., Haider, L. J., Engström, G., & Schlüter, M. (2017). Resilience offers escape from trapped thinking on poverty alleviation. *Science Advances*, *3*(5), 1–11. doi: 10.1126/sciadv.1603043

Lang, T., & Heasman, M. (2015). *Food Wars: The Global Battle for Mouths, Minds and Markets*. London: Routledge.

Leiss, K. A. (2011). Management practices for control of ragwort species. *Phytochemistry Reviews*, *10*(1), 153–163. doi: 10.1007/s11101-010-9173-1

MacDonald, G. K., Brauman, K. A., Sun, S., Carlson, K. M., Cassidy, E. S., Gerber, J. S., & West, P. C. (2015). Rethinking agricultural trade relationships in an era of globalization. *BioScience* *65*(3), 275–289.

MacLennan, D. W. (2014). Hope for Our Planet: How a Resilient Global Food System Can Feed a Growing World. Duisenberg Lecture, Cargill President and Chief Executive Officer. Retrieved from https://www.cargill.com/story/hope-for-our-planet-how-a-resilient-global-food-system-can-feed

Ngonghala, C. N., De Leo, G. A., Pascual, M. M., Keenan, D. C., Dobson, A. P., & Bonds, M. H. (2017). General ecological models for human subsistence, health and poverty. *Nature Ecology & Evolution*, *1*(8), 1153–1159. doi: 10.1038/s41559-017-0221-8

Nyborg, K., Anderies, J. M., Dannenberg, A., Lindahl, T., Schill, C., Schlüter, M., Adger, W. N., Arrow, K. J., Barrett, S., Carpenter, S., Chapin 3rd, F. S., Crépin, A. S., Daily, G., Ehrlich, P., Folke, C., Jager, W., Kautsky, N., Levin, S. A., Madsen, O. J., Polasky, S., Scheffer, M., Walker, B., Weber, E. U., Wilen, J., Xepapadeas, A., & de Zeeuw, A. (2016). Social norms as solutions. *Science*, *354*(6308), 42–43. doi: 10.1126/science.aaf8317

Ölander, F., & Thøgersen, J. (2014). Informing versus nudging in environmental policy. *Journal of Consumer Policy*, *37*(3), 341–356. doi: 10.1007/s10603-014-9256-2

Oliver, T. H. (2016). How much biodiversity loss is too much? *Science*, *353*, 220–221. doi: 10.1126/science.aag1712

Oliver, T. H., Heard, M. S., Isaac, N. J. B., Roy, D. B., Procter, D. A., Eigenbrod, F., Freckleton, R., Hector, A., Orme, C. D. L., Petchey, O. L., Proença, V., Raffaelli, D., Suttle, K. B., Mace, G. M., Martín-López, B., Woodcock, B. A., & Bullock, J. M. (2015). Biodiversity and the resilience of ecosystem services. *Trends in Ecology & Evolution*, *30*, 673–684.

Pimm, S. L. (1984). The complexity and stability of ecosystems. *Nature*, *307*, 321–326.

Robertson, G. P., & Swinton, S. M. (2005). Reconciling agricultural productivity and environmental integrity: a grand challenge for agriculture. *Frontiers in Ecology and the Environment*, *3*, 38–46.

Rosenschöld, J. M. A., Rozema, J. G., & Frye-Levine, L. A. (2014). Institutional inertia and climate change: a review of the new institutionalist literature. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(5), 639–648. doi: doi:10.1002/wcc.292

Scheffer, M., Bascompte, J., Brock, W. A., Brovkin, V., Carpenter, S. R., Dakos, V., Held, H., van Nes, E. H., Rietkerk, M., & Sugihara, G. (2009). Early-warning signals for critical transitions. *Nature*, *461*(7260), 53–59. doi: 10.1038/nature08227

Scheffer, M., & Westley, F. R. (2007). The evolutionary basis of rigidity: locks in cells, minds, and society. *Ecology and Society*, *12*, 36.

Schipanski, M. E., MacDonald, G. K., Rosenzweig, S., Chappell, M. J., Bennett, E. M., Kerr, R. B., Blesh, J., Crews, T., Drinkwater, L., Lundgren, J. G. & Schnarr, C. (2016). Realizing resilient food systems. *BioScience*, *66*(7), 600–610. doi: 10.1093/biosci/biw052

Standish, R. J., Hobbs, R. J., Mayfield, M. M., Bestelmeyer, B. T., Suding, K. N., Battaglia, L. L., Eviner, V., Hawkes, C. V., Temperton, V. M., Cramer, V. A., Harris, J. A., Funk, J. L. & Thomas, P. A. (2014). Resilience in ecology: abstraction, distraction, or where the action is? *Biological Conservation*, *177*, 43–51. doi: http://dx.doi.org/10.1016/j.biocon.2014.06.008

UNEP (2016). Food Systems and Natural Resources. A Report of the Working Group on Food Systems of the International Resource Panel. Westhoek, H., Ingram J., Van Berkum, S., Özay, L., & Hajer M. Retrieved from http://www.resourcepanel.org/reports/food-systems-and-natural-resources

United Nations (2016). HABITAT III – NEW URBAN AGENDA. Draft outcome document for adoption in Quito, October 2016. Retrieved from http://habitat3.org/wp-content/uploads/Habitat-III-New-Urban-Agenda-10-September-2016.pdf

United Nations Economic and Social Council (2017). Ministerial declaration of the 2017 high-level political forum on sustainable development, convened under the auspices of the Economic and Social Council, on the theme Eradicating poverty and promoting prosperity in a changing world. E/HLS/2017/1. Retrieved from https://sustainabledevelopment.un.org/hlpf/2017

Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy*, *28*(12), 817–830. doi: https://doi.org/10.1016/S0301-4215(00)00070-7

Vermeulen, S. J., Campbell, B. M., & Ingram, J. S. I. (2012). Climate change and food systems. *Annual Review of Environment and Resources*, *37*(1), 195–222. doi: 10.1146/annurev-environ-020411-130608

Waage, J., Yap, C., Bell, S., Levy, C., Mace, G., Pegram, T., Unterhalter, E., Dasandi, N., Hudson, D., Kock, R., Mayhew, S., Marx, C., & Poole, N. (2015). Governing the UN Sustainable Development Goals: interactions, infrastructures, and institutions. *The Lancet Global Health*, *3*(5), e251–e252. doi: 10.1016/S2214-109X(15)70112-9

Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, *9*(2), 5.

Zeuli, K., & Nijhuis, A. (2017). The resilience of America's urban food systems: evidence from five cities. Report supported by Rockeller Foundation and ICIC. Retrieved from http://icic.org/wp-content/uploads/2017/01/Rockefeller_ResilientFoodSystems_FINAL_post.pdf?x96880

Zhao, G., Mu, X., Wen, Z., Wang, F., & Gao, P. (2013). Soil erosion, conservation, and eco-environment changes in the Loess plateau of China. *Land Degradation & Development*, *24*(5), 499–510. doi: 10.1002/ldr.2246

Zylstra, M. J., Knight, A. T., Esler, K. J., & Le Grange, L. L. L. (2014). Connectedness as a core conservation concern: an interdisciplinary review of theory and a call for practice. *Springer Science Reviews*, *2*(1), 119–143. doi: 10.1007/s40362-014-0021-3