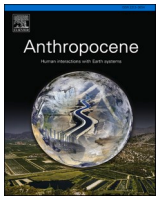
Anthropocene 43 (2023) 100396

Contents lists available at ScienceDirect

Anthropocene

journal homepage: www.elsevier.com/locate/ancene



Invited State of Science

Intersecting security, equity, and sustainability for transformation in the Anthropocene

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ARTICLE INFO

Keywords:
Complex adaptive systems
Vulnerability
Justice
Sustainable development
Sustainability transitions
Sustainability pathways

ABSTRACT

Transformative rather than incremental adaptation will be necessary to keep pace with rapidly changing social-ecological systems characteristic of the Anthropocene. Alongside mounting urgency for transformative adaptation, there is also growing recognition that it is no longer possible to achieve sustainable transformation without also addressing security and equity concerns. Thus, dimensions of security, equity, and sustainability (SES) are increasingly intersected in transformation research and practice. However, interpretations of SES dimensions and their intersections vary widely across disciplines, policy sectors, and problem domains, and knowledge of SES intersections is fragmented. To navigate this vast body of knowledge, a conceptual framework is presented that: 1) integrates a set of guiding critical questions for defining and assessing different framings for each SES dimension; 2) identifies modes of theorizing SES intersections; and 3) relates the previous two elements to leverage points targeted, either theoretically or in practice, for transformative change. Nine prominent integrated concepts and associated case studies were identified that explicitly addressed intersections among all SES dimensions. Integrated concepts addressed a diversity of leverage points, but only two mixed epistemological and methodological approaches sufficiently to provide explanatory insight into SES intersections while also supporting science-based change-making. Potential risks of ambiguity around SES framings and needs for addressing SES intersections in future transformation research are highlighted. Optimistically, transformation scholarship has moved beyond simply stating the importance of SES dimensions to focusing on the causal interactions among SES dimensions, which is leading to compelling new blends of explanatory and action-oriented paradigms to pursue transformation.

1. Introduction

Issues of security, equity, and sustainability (SES) are currently at top of mind for many researchers, policy- and decision-makers, and the public. Such salience reflects this particular moment in the Anthropocene in which *transformative* rather than incremental change is needed. Deep inequities have come to the fore with increased attention to growing wealth gaps within and between countries (Geels, 2013; Mijs, 2021; Zucman, 2019), and galvanizing moments of social injustice persistently reframing mainstream discourses of a broad range of topics (Biermann, 2020; Dunivin et al., 2022). The existential threat of climate change has growing salience with increasingly expensive and deadly natural disasters (Ebi et al., 2021; Painter, 2020; Tol, 2011), and terms like "climate crisis" have been used to mobilize local to international action to mitigate climate impacts (Ojala et al., 2021; Sanderson and O'Neill, 2020). Similarly, mounting evidence of broad biodiversity losses has raised calls for urgent and unprecedented action (Díaz et al., 2019; Dinerstein et al., 2019), while also drawing attention to formidable tradeoffs with food production to meet growing demands (Ellis and Mehrabi, 2019). The precariousness of global supply chains was exposed by the COVID-19 pandemic (Sarkis, 2021; Xu et al., 2020), which saw nearly two decades of poverty and hunger reduction reversed in a single year (FAO, 2021). Apparent convergence among these various trends, intellectual threads, and social movements has prompted the integration of SES issues in diverse ways (e.g., Glover and Hernandez, 2016; Leach et al., 2018; Spratt, 2017). However, interpretations of SES intersections vary widely across disciplines, policy sectors, and problem domains, and knowledge of how SES dimensions interact and potentially drive transformative change is fragmented. The ultimate goal of this review is to synthesize knowledge about the implications of multiple definitions and framings for each SES dimension, how they are conceived of as intersecting, and to what extent integrative approaches to SES have transformative potential by targeting deep leverage points for systemic change.

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https://doi.org/10.1016/j.ancene.2023.100396
Received 28 December 2022; Received in revised form 24 April 2023; Accepted 20 June 2023
Available online 26 June 2023

Recognition of the interconnected nature of current global challenges is growing and considered a defining characteristic of social-ecological systems in the Anthropocene (Bai et al., 2016; Bonneuil et al., 2017; Brondizio et al., 2016). In response, many high-profile, international policy frameworks have set ambitious goals that span SES dimensions. The United Nations 2030 Sustainable Development Goals (SDGs) were particularly comprehensive across SES dimensions, including aspects of peace (SDG 16) and food and water security (SDGs 2, 6), equality (SDGs 1,5, 10), and environmental sustainability (SDGs 12–15) (United Nations, 2015). A growing literature has analyzed tradeoffs, complementarities, and governance challenges among interacting SDGs (e.g., Nilsson et al., 2016; Fuso Nerini et al., 2017; Kanter et al., 2018; Brondizio, 2017; Bowen et al., 2017; Barbier and Burgess, 2019; Pham-Truffert et al., 2020; Filho et al., 2023), and the dangers of pursuing one or a narrow set of goal(s) in isolation are well documented. For example, international efforts to protect and conserve biodiversity have too often pursued exclusionary approaches through 'green grabs' that ignore social impacts, such as land dispossession and livelihood disruptions (e.g., Beauchamp et al., 2018; Ojeda, 2012). Technological innovations in agri-food systems may be intended to improve the environmental sustainability of production, but can also exacerbate existing inequalities among producers (Barrett et al., 2020; Hackfort, 2021; Herrero et al., 2021) or promote agricultural expansion through a 'rebound effect' that leads to landscape homogenization and loss of agro-biodiversity (Paul et al., 2019). Because many of the SDGs target unsustainable trends rooted in systemic problems, the increased focus on interactions among SDGs is a positive development (Pradhan et al., 2021).

Fundamental transformations in the design and intent of social systems are needed to meet the SDGs and navigate the inevitable tradeoffs that will arise (Blythe et al., 2018; Green and Healy, 2022). Calls for transformative change are increasingly high-profile and mainstream. In addition to the central motivation of the SGDs to "transform our world" (United Nations, 2015), the Intergovernmental Panel on Climate Change's fifth assessment report concluded the necessity of "large-scale transformations" for stabilizing greenhouse gas emissions (Clarke et al., 2014). Transformation has been interpreted in sustainability science broadly as the fundamental restructuring of social, economic, and political systems to address root causes of unsustainability (Blythe et al., 2018; Reyers et al., 2018). Moreover, since transformation challenges existing structures, it involves shifts in power and is likely messy, fraught, contested, and/or unprecedented (Eriksen et al., 2015; Westley and McGowan, 2017; Zagaria et al., 2021). The concept of sustainability transformations has been interpreted in a variety of ways, such as socio-technical transitions (Geels, 2019), social-ecological transformations (Olsson et al., 2014; Tjornbo et al., 2013), sustainability pathways (Clarke et al., 2014; Scoones et al., 2020), and transformative adaptation (Eriksen et al., 2015; Pelling et al., 2015), depending on disciplinary origin or theoretical orientation. Foundational to all of these conceptualizations of transformation is the need to address interconnected, causal interactions among inequality, insecurity, and environmentally unsustainable behaviors (Blythe et al., 2018; Green and Healy, 2022; Smith et al., 2014).

Despite acknowledgement of the need for societal transformation, and maturing scholarship tackling SDG interactions, systematic knowledge addressing the interlinkages among all three SES dimensions is still lacking and deeply problematic in an age of hyper-connectivity and complexity (Leach et al., 2018). A recent synthesis review (Leach et al., 2018) demonstrated ten interaction dynamics through which (in)equity and (un)sustainability are co-produced and co-evolve. Generally, "though feedbacks, economic, social and spatial inequities can push those at the bottom and already poor into unsustainable practices that further reduce equity and sustainability" (Leach et al., 2018: 7). In contrast, knowledge of how the security dimension dynamically interactions with equity and sustainability is much less developed and represents a critical knowledge gap. Given the contested nature of transformation, a future in which increasing conflict and associated security threats seems likely and recent trends are not encouraging. Violent conflicts have reached their highest level globally since 1946 with one quarter of the global population living in conflict-affected countries (United Nations, 2022). The absolute number of refugees was the highest on record in 2021 (Filho et al., 2023), and over 100 million were forcibly displaced worldwide just in the first half of 2022 (United Nations, 2022). Moreover, transnational illicit supply networks, trading in 'goods' ranging from arms, drugs, wildlife, to people, generate an estimated US$1.6 to $2.2 trillion annually (Nellemann et al., 2016) and are associated with widespread social and environmental harms that undermine sustainability (McSweeney et al., 2014; UNEP, 2018; Gore et al., 2019; Magliocca et al., 2022). Such security threats are pervasive in contexts of inequitable opportunity, access, and/or power that create populations vulnerable to exploitation by more powerful actors, which in turn perpetuates insecurity and inequity (Luckham, 2015). Instability from persistent security threats makes it unlikely that SGDs to conserve biodiversity, mitigate GHG emissions, and sequester carbon can be met (United Nations, 2022).

The overall objective of this review is to understand how SES issues have been brought to the forefront of scientific, policy, and public discourses as related, if not interdependent, considerations in pursuit of transformation. Prerequisite to this is a comprehensive review of how each SES dimension has been (re)defined, and which other SES dimensions have been mobilized in those definitions, to frame transformation research, practice, and their interactions. To guide the review and synthesis of such vast intellectual domains, a conceptual framework is first presented that integrates insights into conceptualization and implementation approaches from sustainability science (Schlüter et al., 2022) with a descriptive model of leverage points for systemic change (Abson et al., 2017; Meadows, 1999). The next section reviews nine concepts that integrate across all three SES dimensions and illustrates their application with selected case studies. The conceptual framework is then applied to assess the potential for transformation by linking each integrative concept's approach to conceptualizing and implementing sustainability transformations with the specific leverage points targeted. The review concludes with a discussion of how SES dimensions are (or are not) being deeply integrated in transformation scholarship, and whether there are gaps that open the possibility of crossing over to the 'dark side of transformation' (Blythe et al., 2018).

2. Conceptual framework

Scholarship of each SES dimension and their interactions draws from a diversity of disciplinary and practitioner perspectives and motivations. Such diversity is a strength, providing distinct but collectively comprehensive treatments of each SES dimension and their interactions, and potentially bringing complementary theories, data, and methodologies to bear on the multifaceted challenges of transformation (Clark and Harley, 2020). However, such diversity also challenges comparisons and integration of ideas across the intellectual domains from which particular perspectives on SES dimensions have emerged. When there are multiple possible definitions for a single SES dimension, which vary by disciplinary orientation and research program, systematically unpacking the ways in which those dimensions might interact is a daunting task (e.g., see the discussion of the 'triple bottom line' of sustainability in Section 4.3). The framework presented here provides a model for understanding 1) how each SES dimension and its interactions are defined; 2) how the epistemologies of integrative SES ideas influence their conceptualization and implementation; and subsequently 3) which leverage points for systemic change are targeted.

Approaches to transformation scholarship have generally been problem- and action-oriented, and the lack of a shared theoretical foundation, for example in social-ecological systems or systems engineering, in part explains why such a diversity of framings and concepts have emerged (Blythe et al., 2018; Eriksen et al., 2015). It is helpful,

then, to have a set of guiding questions for evaluating and comparing the ways that SES dimensions are defined and conceptualized as interacting. Borrowing from critical security studies (Luckham, 2015; McDonald, 2021; Peoples and Vaughan-Williams, 2020), a useful interrogative approach to assess each SES dimension is to ask 'of what', 'for whom', 'by whom', and 'by what means'? Asking 'of what' clarifies the referent objective of the SES dimension as the entity (e.g., individual, community, ecosystem, or sector) of interest (Peoples and Vaughan-Williams, 2020). Questions of 'for whom' and 'by whom' bring into focus the political nature of transformation and the possibility that biased or imprecise framings of SES dimensions can be mobilized to prevent transformation (Barrett et al., 2022; Blythe et al., 2018). The question of 'by what means' focuses inquiry on the ways each SES dimension are pursued or provisioned. The latter three questions provide clarity about the mechanisms through which each SES dimension is addressed and how interactions among SES dimensions are envisioned to lead to transformation. For example, sustainability can be conceptualized as social, ecological, or intergenerational considerations; for individual, community, ecological, or global systems; and be pursued through individual behaviors, disruptive technologies, or international agreements.

Given the diversity of knowledge domains that contribute to transformation scholarship, there are also diverse ways to conceptualize (or 'theorizing' more broadly) intersections among SES dimensions. Based on insights from sustainability science, Schlüter et al. (2022) provide a guide for thinking about theories as assemblages of different elements that can serve a variety of purposes and originate from disciplinary to transdisciplinary settings. A theory's *purpose* can be explanatory and used for framing a research process, identifying causal factors or mechanisms, predicting system behavior, synthesizing knowledge, and/or analyzing observed system changes. A theory may alternatively or additionally emerge from and inform action, and can be used for informing interventions, providing principles for generating systemic change, and/or guiding knowledge co-production (Schlüter et al., 2022: 3). The *positionality* of theorizing can occur external to or embedded within the system of interest. External theorization is consistent with conventional and expert-driven research approaches, whereas embedded theorization is more common in participatory and action-oriented research and practice (Schlüter et al., 2022: 4). Different combinations of theorizing purposes and positionalities can produce different modes of theorizing: basic or applied research, related to external theorization, or embedded research or science-based change--making related to embedded theorization. Thus, the mode of theorization influences the definitions and framings of SES dimensions and choice of elements that animate SES intersections. Specific applications of research or practice that intersect SES dimensions may move between these different modes in conceptualization and implementation phases and/or adopt a hybridized approach. Ultimately, the ways in which transformation scholarship connects SES definitions to the conceptualization and implementation of their intersections, whether for the purposes of explanation or action, shapes how interventions target social-ecological systems and whether transformation might be realized (Dorninger et al., 2020).

Despite the diverse modes of theorizing SES interactions present in transformation scholarship, theory and implementation of sustainability interventions remain disconnected with no consistent approach for diagnosing barriers to or catalyzing systemic change. Recently, the long-overlooked perspective of 'leverage points' (Meadows, 1999) has gained traction in transformation scholarship and sustainability science as means for intervening in root causes of unsustainable practices. Leverage points are places in complex systems where relatively small changes can lead to potentially transformative systemic changes (Abson et al., 2017). Leverage points differ in their potential effectiveness to create change, and range from relatively shallow, weak, but highly tangible (e.g., system parameters and feedbacks) to deep, strong, but more elusive (e.g., system design and intent) (Abson et al., 2017; Meadows, 1999) (Fig. 1). Generally, there is a lack of knowledge about and ability to identify 'leverage points' for transformative change in social-ecological systems, which constitutes a basic science need if we are to close the 'sustainability gap' between current sustainability targets, like the SDGs, and the ability of interventions to produce transformative change (Fischer et al., 2007).

Most sustainability interventions focus on shallow leverage points (e.g., changing subsidy levels, tax incentives) that have limited potential for transformational change, while interventions at deeper leverage points addressing underpinning values, worldviews, and paradigms are rarer (Abson et al., 2017; Dorninger et al., 2020). For example, a classic Pigovian carbon tax on the externalities of CO_2 emissions represents a relatively shallow leverage point that targets 'parameters' of an unsustainable activity, i.e., making it more costly to emit. Alternatively, a social cost of carbon (Tol, 2011) approach attempts to target deeper leverage points in addition to the shallower parameter leverage point by changing the intent of the tax to more fully account – both tangibly and culturally – for the interconnected impacts of climate change. Of course, a social cost of carbon approach is likely insufficient alone to prompt sustainability transformations, but the contrast with a conventional tax illustrates how shallow and deep leverage points can interact to be more impactful. Despite the simplistic metaphor of levers, leverage points are in fact interdependent and can interact in complex and unexpected ways. Limited understanding of these interactions is a crucial knowledge gap (Abson et al., 2017; Dorninger et al., 2020). Applying the leverage points perspective to SES intersections is a productive entry point for contributing to the knowledge base of how and in what configurations leverage points interact.

To summarize, the conceptual framework relies on critically defining SES dimensions, understanding the purpose and positionality (i.e., mode) of theorizing their intersections, and interpreting how intersecting SES considerations may produce transformation through the leverage points perspective. Integrating a set of critical, guiding questions supports more precise definition of SES dimensions. In doing so, potential interactions among SES dimensions become apparent, and the specific interactions can be better understood by unpacking the modes of theorization used to understand them. Finally, overlaying the modes of theorization for explaining, and/or putting into action interventions that target, interactions among SES dimensions with the leverage points perspective elucidates the mechanisms through which SES intersections are envisioned to lead to transformation.

3. Methods

Given the breadth of applications and history of scholarship around each of the SES dimensions individually, a systematic review of all their possible intersections is not feasible. Moreover, there are numerous systematic reviews for various aspects of security (Connolly-Boutin and Smit, 2015; Gibbs et al., 2012; Jolly and Ray, 2007; Leese and Wittendorp, 2018; Luckham, 2015; Paravantis et al., 2019; Peoples and Vaughan-Williams, 2020), equity (Agyeman et al., 2016; Friel et al., 2011; Leach et al., 2018; Sovacool et al., 2022; Spratt, 2017; Williams et al., 2022), and sustainability (Agrawal et al., 2022; Barbier and Burgess, 2017; Clark, 2007; Clark and Harley, 2020; Irwin et al., 2016, 2017; Randall, 2020; Reyers et al., 2022). Thus, this review adopts the methodology of 'state-of-the-art' and 'umbrella' reviews (Grant and Booth, 2009). A state-of-the-art review specifically focuses on more contemporary research, in contrast to combined retrospective and current approaches of conventional literature reviews, with the goals of assessing the current state of knowledge, offer new perspectives on an issue, and/or highlights areas of need for future research. A state-of-the-art review provides the reader with the broad feel for the quantity and main characteristics of a knowledge area with having to review multiple articles describing specific developments (Grant and Booth, 2009: 101). Umbrella reviews are particularly useful when there are multiple knowledge areas for which systematic reviews exist

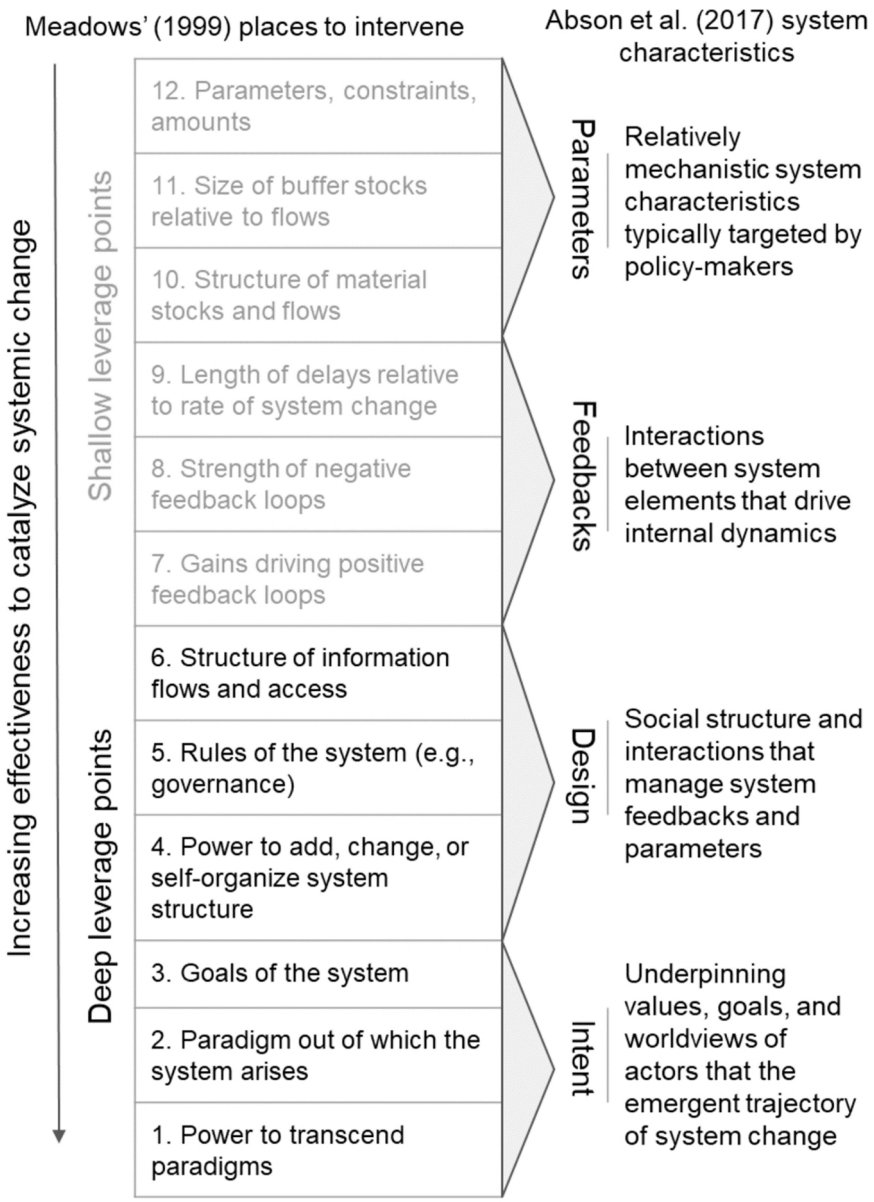

Fig. 1. Adaptation of leverage point frameworks from Meadows (1999) and Abson et al. (2017).

contributing to a shared research question, and from which evidence can be compiled into one accessible and synthetic document (Grant and Booth, 2009). This review adopts a combination of these approaches given the breadth of the topic and rapid development of transformation research.

First, relevant systematic reviews, conceptual frameworks, or other synthesis works were identified using Scopus with a set of targeted search terms.[1] Title, abstract, and keywords were screened to determine if at least two SES dimensions were considered in the synthesis in the context of transformations of social-ecological systems and/or the Anthropocene. Synthesis works also had to define and analyze SES dimensions in depth (e.g., feature of the analysis or narrative framing) and not just cite them as important for the framing the broader applicability of the work. Full texts of the synthesis works meeting these inclusion criteria were reviewed to additionally refine the collection. Highly cited works were chosen until the number of conceptual linkages among SES dimensions encountered saturated and the same seminal works were repeatedly cited. Forward and backward citation searches were performed in Google Scholar to identify any other highly cited works contributing to SES scholarship. Concepts that integrated all three SES dimensions, or 'integrative concepts', were identified from the set of seminal works. Forward and backward citation searches were repeated in Google Scholar for each seminal work containing an integrative concept with an additional filter term "case stud* " to identify empirical applications of each concept.

The conceptual framework presented in Section 2 was applied to each integrative concept and their associated case studies (Fig. 2). First, the guiding questions – 'of what', 'for whom', 'by whom', and 'by what means' – were applied to bound and synthesize definitions for each SES dimension and extract information about specific applications of the integrated concepts. The mode of theorization was determined by distinguishing between conceptualization and implementation phases. For each phase, the purpose and positionality of the knowledge generation process underlying the integrated concepts were identified. It was

[1] Search query producing 207 results: '(*security AND (*equit* OR *equalit* OR inclusive*) AND *sustainab*) AND ((soci* AND ecolog*) OR (soci* AND environ*) OR (human AND environ*)) AND system AND (review OR synthesis or framework)' from 2000 to 2022.

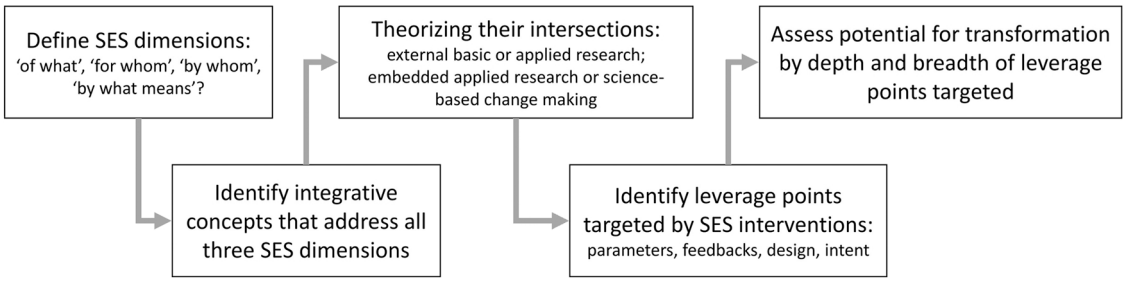

Fig. 2. Conceptual framework for defining and linking SES dimensions and assessing the potential of integrative concepts to produce transformative change by targeting interventions at various leverage points.

typically easier to first define the explanatory or action-oriented purpose of the research. The former tended to assemble theoretical elements guided by existing knowledge gaps, whereas the latter was more driven by the demands of specific problems. The positionality was then evident based on the sources of knowledge from which the theoretical elements were drawn. For example, embedded theorization often resulted from 'grounded theory' and participatory approaches, whereas basic research theorization drew from deductive analyses and previously synthesized knowledge. Finally, integrative concepts were coded for the leverage points they addressed based on descriptions of how SES dimensions interact, barriers to or opportunities for intervention, and/or examples of their interventions informed by the integrative concept.

4. Results

Findings from the review are organized into three parts. The first section offers definitions for each of the SES dimensions by taking stock of and synthesizing the plethora of knowledge and application domains contributing to one or more SES dimensions in the context of sustainability transformations. It was not possible nor desirable to review all available definitions for concepts as broad as sustainability, for example, rather the review focused on finding definitions for each SES dimension in relation to at least one of the other SES dimensions. A more detailed treatment of defining each dimension than what is provided below is available in the Supplemental Information. Next, a focused review of notable concepts that integrated all three SES dimensions (i.e., 'integrative concepts') is presented along with case studies that illustrate the integrative concepts in practice. Finally, an analysis is presented of how each integrative concept conceptualizes SES intersections and implements those conceptualizations to target specific leverage points. This enabled a comparative assessment of each integrative concepts' potential for transformative change.

4.1. Defining security

Among the myriad of framings of 'security' in the Anthropocene, climate change as a 'national security' threat is among the most prominent. More than 70% of national security documents released by governments around the world have recognized climate change as a threat in national security planning (McDonald, 2018; Scott, 2015). However, the definition of 'security' in the context of climate change and broader environmental sustainability concerns is far from clear and continually reproduced from different theoretical, practical, and political perspectives (McDonald, 2018; Simpson, 2007). The connections between security and equity are equally blurry but have been invoked increasingly with the broadening of security studies. To understand the various interpretations and applications of the concept of 'security', it is first necessary to define security for whom, what threatens security, which actors are capable of providing security, and how that security is provided (McDonald, 2021; Peoples and Vaughan-Williams, 2020).

Traditional security studies emerged from the Cold War era conceptualizing security from the 'supplier' perspective, which views security through the lens of the state (Luckham and Kirk, 2013). This 'realist' school of traditional security studies conceived of the state and associated military threats to the state as the referent object of security (Peoples and Vaughan-Williams, 2020). A direct result of this framing is that 'securitizing' any threat immediately links that threat to 'high politics' that justifies an exceptional response, such as suspending normal governance procedures, redirecting resources, and mobilizing political will to address existential threats (McDonald, 2018, 2021; Peoples and Vaughan-Williams, 2020). The post-Cold War era saw a broadening of the referent objects of and threats to security through an alternative 'end-user' perspective to consider broader issues of human, economic, and environmental security (Luckham, 2015; McDonald, 2021; Peoples and Vaughan-Williams, 2020). Human security has been defined as freedoms from a conflictual environment (Jolly and Ray, 2007), want (i.e., resource access or availability), fear, and hazard impacts (Bogardi et al., 2012), and the freedom of future generations to inhabit a healthy environment. Economic development is then seen as a way to address human (in)security by attending to sources of risk from violence (or threats of violence), economic disruptions (i.e., 'dislocations'), and social or environmental unsustainability (Jolly and Ray, 2007; Luckham, 2015; United Nations, 2004; World Bank, 2011). Contemporary definitions of food security also arose from this broadening of security concepts (Barrett et al., 2022). Rising demand from population growth, climate change, inefficient production methods, inefficient calorie allocation, food waste, changing diets associated with rising wealth, and uneven access and distribution are all seen as threats to food security (Cassidy et al., 2013; Foley et al., 2005; Godfray et al., 2010; Tilman et al., 2011). Notably, mainstream concepts of food security focus on production of and access to food (e.g., Godfray et al., 2010), while generally avoiding the question of which actors provide food security. The 'end-user' perspective engages broader meanings of security from diverse perspectives, such as political ecology and economy, agricultural economics, and international development, and begins to blur the lines between security and equity and sustainability dimensions.

However, securitization of development, human well-being, and natural resource topics has been criticized as too all encompassing, construing everything as a possible risk to security (Paris, 2001), and endangering military involvement in issues that are best tackled through non-military means (Knudsen, 2001). Securitizations of climate change and environmental sustainability are thus problematic for the analytical framing of 'supplier' or 'end-user' of security. It is often unclear the ways in which climate change threatens security and whose security is threatened (McDonald, 2021). As McDonald (2018) argues, the ways in which climate change has been articulated as a security issue reflect the means and actors presumed best to address it. Many have cited climate change as a 'threat multiplier' and trigger for conflict that threatens national security and international stability (e.g., Abrahams, 2019; Barnett and Adger, 2007; Busby, 2008). Others emphasize the threat to lives and livelihoods of vulnerable populations exposed to climate-related impacts (e.g., Barnett, 2001). The former framing clearly situates the state as a primary actor to address the threat of climate

change and maintain territorial sovereignty and integrity, while the latter focuses on climate change mitigation measures, implemented through either top-down or bottom-up means, to support the welfare and resilience of affected communities (McDonald, 2018). However, many critics of such framings of climate security, or environmental security more generally, note that such threats exceed the scale and authority of any single state to address (Fairhead, 2001; McDonald, 2021). Such debate reinforces the view of critical security studies that security threats and identified insecurities are constructed by and emerge from social and political processes (Aradau et al., 2015; Peoples and Vaughan-Williams, 2020). Thus, different conceptualizations of climate security can lead to vastly different courses of action, which emphasizes the need to precisely define the referent objects, threats, agents, and means of security (McDonald, 2018, 2020).

4.2. Defining equity

While security or sustainability issues are often the entry points into SES considerations for public, policy, and scientific discourses, equity is increasingly considered a key dimension (Clark and Harley, 2020; Williams et al., 2022). Understanding equity and its intersections with security and sustainability requires consideration of closely related concepts of justice and fairness. A foundational definition of justice was provided by Rawls (1971) as what is morally right and the 'first virtue' of social institutions (Rawls, 1971). Further ethics-based articulations of justice in the context of social-ecological systems include human responsibility toward nature and the rights of future generations to nature (e.g., Luck et al., 2012; Sikor et al., 2014). Fairness is often materially defined as the means and capabilities for a worthwhile life (Sen, 2008), and normatively defined as necessary to be a 'good society' and without which a desirable Anthropocene is unattainable (Leach et al., 2018). Similar nuances exist around the use of 'inequality' versus 'inequity' (see Fraser, 2009; Leach et al., 2018; McDermott et al., 2013; Sikor et al., 2014). While both concepts of 'equality' and 'equity' incorporate elements of justice and fairness relevant to security and sustainability concerns, equity is adopted here because it emphasizes institutional fairness in a way that is consistent with the leverage points framework for transforming system intent and design (Abson et al., 2017) applied in the analysis later in this review.

Relying on the framework presented by Williams et al. (2021), equity is understood through four elements: dimensions of justice, subjects of equity, fairness principles, and reflexivity. Dimensions of justice are further defined as recognitional, procedural, and distributional. Recognitional justice is often context-dependent and understood within the unique cultural beliefs, practices, and institutions of a specific society (Fraser, 2009; Sikor et al., 2014; Williams et al., 2021). Procedural justice involves people's ability to influence and be included in decision-making processes through the exertion of power and agency (or lack thereof) (McDermott et al., 2013). Distributional justice is concerned with how equitably resources, access, and/or burdens are allocated within or between societies (Rawls, 2001). Equity scholars have pointed out that these three dimensions are interconnected (Leach et al., 2018) as, for example, recognitional marginalization can lead to procedural exclusion, which often produces inequitable distributional outcomes.

Each of these dimensions of justice are articulated relative to the subject of equity in the forms of 'what' and 'for whom'. Equity of 'what' can take multiple forms (International Social Science Council (ISSC), Institute for Development Studies (IDS), & United Nations Educational Scientic Cultural Organization (UNESCO), 2016) including: economic considerations of assets, capital, living standards, and employment opportunities (Irwin et al., 2016; Randall, 2020; Zucman, 2019); social status, rights, and opportunities for education, health, and justice (International Social Science Council (ISSC), Institute for Development Studies (IDS), & United Nations Educational Scientic Cultural Organization (UNESCO), 2016); political inclusion (Gaventa and Martorano, 2016); environmental endowments and entitlements (Leach et al., 2018); and access and contribution to knowledge (Agyeman et al., 2002). Equity 'for whom' is typically defined based on various forms of socio-cultural identity (e.g., religion, gender, ethnicity), and considers how disparities between those socio-culturally defined identities are distributed and experienced (Crenshaw, 1991; Leach et al., 2018).

Fairness principles constitute ethical and normative criteria for assessing equity and its goals. Distinct from equality, which would consider an equal distribution of outcomes to be fair, equity-based fairness adopts a needs-based orientation that favors the underserved or disadvantaged in society (Rawls, 2001). Such equity criteria and goals are well reflected in the recent United States Executive Order 13985[2] with its intent to advance racial equity and support for underserved communities through reform of government agencies. Reflexivity considers how the preceding three elements are defined and by whom by acknowledging that the definition of equity in unavoidably subjective and situated. Recognitional justice demands reflection on how the socio-cultural identities of those defining equity, its criteria, and its goals influences those definitions (Williams et al., 2022). Similar to how different discourses of security can lead to different courses of action (McDonald, 2018, 2020), how equity is defined by policymakers or researchers reflects their own socio-cultural systems in which they are embedded (i.e., positionality; Roegman, 2018) and can lead to alternative explanations of the causes of inequity and potential leverage points for addressing it.

4.3. Defining sustainability

While the history and depth of the security and equity scholarship is substantial, the sheer breadth and diversity of uses of sustainability terminology and concepts are vast. Acknowledging more expansive definitions of sustainability that bridge social, economic, and environmental domains, such as the 'triple bottom line' (Elkington, 1998), the focus here will be on environmental sustainability. Indeed, 'triple bottom line' thinking is arguably a precursor to contemporary discourses of SES intersections. However, rather than consider all SES dimensions under the umbrella of sustainability, it is productive to unpack each dimension to be explicit about how they interact and integrate more diverse disciplinary perspectives than those that have traditionally contributed to the sustainability domain (e.g., security studies). Thus, an environmental sustainability perspective is adopted here to focus on transformation in response to climate change and to leave room for explicit treatment of security and equity dimensions.

In the context of sustainability science, the goals of sustainability have been articulated as "inclusive well-being through the stewardship of natural and anthropogenic resources" (Clark and Harley, 2020: 341). Distinct concepts of 'weak' and 'strong' sustainability are prominent in the field of resource economics and acknowledge the multilevel and globalized nature social-ecological systems (Irwin et al., 2016). The paradigm of 'weak' sustainability relies on the foundational assumption that forms of natural, human, and reproducible capitals are fully substitutable, and the replacement of natural capital by human or reproducible capital of equal value does not deplete the total value of wealth available for future generations (Barbier and Burgess, 2017, 2019; Irwin et al., 2016). As described by Irwin et al. (2016), 'weak' sustainability may be achieved regionally, e.g., through trade to address food insecurity, but inattentiveness to the broader socio-ecological systems within which each location is embedded can unintentionally destabilize physical, natural resource, and/or economic security elsewhere (Irwin et al., 2016). 'Strong' sustainability, in contrast, asserts that there exist essential or critical natural capitals (e.g., unique environments,

[2] Available at: https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government/.

biodiversity, and life-support functions) that are not substitutable, and thus require maintenance and preservation for future generations (Barbier and Burgess, 2017, 2019; Irwin et al., 2016). 'Strong' sustainability faces issues of what non-material goods to place values on, and how to estimate their value in a future of deep uncertainty in climate and economic conditions. Ultimately, these divergent framings of sustainability depend on assumptions of the substitutability of natural and reproducible capital, and tends to break along disciplinary lines of economists and natural scientists.

Interested readers are directed to in-depth reviews of sustainability science from Clark and Harley (2020), Miller et al. (2014), National Academies of Science Engineering Mathematics (2021), Schlüter et al. (2022), and West et al. (2020).

4.4. Integrative concepts

The definitions presented above attempt to draw boundaries between the SES dimensions, but in practice their meanings are often overlapping. Certain concepts inherently blend multiple SES dimensions. However, as described above, the lack of nuance and specificity in defining SES dimensions often leads to preferential and/or incomplete treatment of one or more SES dimensions over the others. Applying the guiding questions presented as part of the conceptual framework (Section 2) focused the review on nine 'integrative concepts' that emerged as recurring ideas that explicitly addressed and linked each SES dimension. Illustrative case studies implementing each of the integrative concepts were also identified and summarized in Table 1.

4.4.1. Environmental Livelihood Security

The first integrative concept identified was 'Environmental Livelihood Security' (ELS; Biggs et al., 2015). Citing a lack of consideration for livelihoods in water-energy-food (WEF) nexus research, the authors proposed a framework integrating the established sustainable livelihoods approach (SLA; Scoones, 1998) with WEF nexus concepts of resource interdependencies related to security. SLA considers a portfolio of capital assets (natural, physical, social, financial, political, human) assembled in various combinations to purse a livelihood strategy. Biggs et al. (2015) intersected SLA considerations of (in)equitable access to capitals due to elements of power and governance with nexus conceptualizations of environmental and human security related to reliable, affordable, and equitable supplies of WEF resources. The ELS approach considered interactions among processes that transform WEF resources and constitute livelihood strategies with environmental pressures on natural resource supplies (e.g., from climate change), and how those pressures on and benefits from resource demands vary in their social distribution.

An illustrative application of the ELS framework investigated the climate-security-resource-livelihoods nexus in Northern Nigeria and Lake Chad (Wakdok et al., 2021). The case study focused on human, livelihood, and WEF insecurities stemming from long-standing competition for land and water resources among farmers and migrating herdsmen, which have been exacerbated by climate change-driven resource scarcity. Notably, Lake Chad, which supports water resource provision, fisheries, and numerous other ecosystem services, is now 10% of its former size (Wakdok and Bleischwitz, 2021: 2). Additionally, institutional failures, such as "allowing for ungoverned spaces, rent seeking and intrusion" (p. 3) have created inequities in resource access, which have combined with climate change-driven land and water scarcity to cause conflicts among herders and farmers. The authors described a history of grazing policy interventions, such as the attempted establishment of grazing reserves and routes, which addressed only shallow leverage points (e.g., size of buffer stocks, structure of materials stocks and flows), did not account for inequities and diversity among the region's rural livelihood strategies, and were thus met with social and political resistance. The authors then used the ELS lens to consider several proposed development scenarios to recharge the dwindling water resources in Lake Chad and support associated livelihoods. The most ambitious scenario involved the construction of an international waterway to directly address environmental sustainability by recharging water resources and restore ecosystem services (e.g. sequester carbon through afforestation). Notably, this scenario expanded the goals of intervention (LP 3) beyond water resources to construction of renewable energy infrastructure and improved mobility (LP 10), which would additionally address livelihood and energy security and improve inequitable access to bolstered natural resources (LPs 8, 11) and economic opportunities (Wakdok and Bleischwitz, 2021: 11–12).

4.4.2. Inclusive wealth

The second integrative concept was 'Inclusive Wealth', which received early, high-profile attention in the United Nations Environment Programme's Inclusive Wealth Report (UNU-IHDP & UNEP, 2012). At the core of the Inclusive Wealth concept is a broadening of the definition of human well-being beyond economic growth to include social and ecological factors and the well-being of future generations. This definition builds on concepts laid out in the Millennium Assessment (Reid et al., 2005) linking ecosystem services (supporting, regulating, provisioning, and cultural) and human well-being (security, basic material for good life, health, good social relations, freedom of choice and action), and has become integral to the definitions and targets of contemporary UN Sustainable Development Goals (e.g., Menton et al., 2020; Morton et al., 2017). With foundations in welfare economics, the Inclusive Wealth concept shifts the focus from 'needs' to the discounted value of consumption flows as the targets for sustainable development (UNU-IHDP and UNEP, 2012). Consumption flows depend on a nation's wealth defined as the social worth of a suite of capitals: reproducible capital; human capital; knowledge; natural capital; population; institutions; and time. Importantly, the key to accounting for current or future externalities is shadow prices, or the market-traded price of a good (if market-traded) plus the value of externalities (e.g., damages) (UNU-IHDP and UNEP, 2012: 24). This invokes concepts of human security related to sufficient consumption and 'strong' sustainability and inter-generational equity in its consideration of future generations and potential externalities to nature-based assets that might disrupt consumption flows (Irwin et al., 2016).

Banerjee et al. (2020) used a modeling approach to conduct an Inclusive Wealth analysis of Rwanda's Green Growth strategies. The authors developed an application of the Integrated Economic-Environmental Modeling (IEEM) Platform with the Integrated Valuation of Ecosystem Services Tradeoffs (InVest) model to analyze changes in standard economic indicators, such as gross domestic product and employment, as well as social wealth and ecosystem services among alternative green growth strategies related to fuel, timber, and food security. Inclusive Wealth concepts informed the design of the IEEM-ESM and analysis of model outputs. Specifically, the IEEM-ESM generated metrics of sustainable income growth through genuine savings, natural capital stocks, and ecosystem services supply, which highlighted tradeoffs and synergies that "would have gone undetected through the conventional application of stand-alone economic, LULC change, or ecosystem service modeling and analysis" (p. 18). Alternative public policies were considered that differentially promoted increases in forest plantations, efficient cookstove use, irrigation, and fertilizer. Resonating with the ELS approach described above, the spatially explicit nature of the IEEM-ESM enabled an analysis of the uneven distribution of changes in ecosystems services and their contributions to human well-being across Rwanda. For example, the model analysis identified public policies that increased food security through intensified fertilizer application while also mitigating the negative effects on water quality through increased nutrient uptake from forest plantation expansion. This case study illustrated how the Inclusive Wealth concept can target several shallower leverage points, such as the size of buffer stocks (LP 11; i.e., capitals) relative to their flows through parameter adjustments (LP 12; i.e., shadow prices) and attention to system lags (LP 9; i.e.,

Table 1
Selection of illustrative case studies implementing each of the integrative concepts and the leverage points they addressed. Each case study was evaluated using the four guiding questions with respect to how each SES dimension was defined and considered.

Case Study	Dimension	Of What?	For Whom?	By Whom?	How?	Leverage Points
Environmental Livelihood Security						
Wakdok & Bleischwitz (2021)	Security	Human security from conflicts; food, energy, water resources security	Migrating herdsman, farmers; Lake Chad ecosystems	Lake Chad Commission countries, multi-lateral lending agencies, international financial institutions.	*Past policies*: Restrictive grazing policies; creation of grazing reserves and routes *Transformative scenario*: Construction of an international waterway to recharge water resources, restore ecosystem services, and support livelihoods	11, 10, 8, 3
	Equity	Distributional equity of benefits from water resources				
	Sustain.	Herder and farmer livelihoods; grazing lands and fisheries				
Inclusive Wealth						
Banerjee et al. (2020)	Security	Timber, fuel, and food supplies	Society as proxied by macroeconomic productivity	National government of Rwanda	Alternative Green Growth strategies that differentially promote increases in forest plantations, efficient cookstove use, irrigation, and fertilizer	12, 11, 9, 3
	Equity	Distributional	Current and future generations			
	Sustain.	Genuine savings rates, natural capital stocks, and ecosystem services	Current and future generations			
Ecological Security						
Kim (2020)	Security	Human, environmental, and national	Vulnerable ecosystems, livelihoods of local communities, national security from military threats	Local and international activists, governments, judicial systems, domestic and foreign military	Mobilization of domestic and international activists through nonhuman ecological symbols to contest the construction of military bases in South Korea and Japan that would impact vulnerable ecosystems	5, 3, 2
	Equity	Distributional and representational	Equal rights to protection of vulnerable ecosystems and nonhuman beings			
	Sustain.	Ecological	Vulnerable ecosystems			
One Health						
Leach et al. (2017)	Security	Human (health) security	Socially vulnerable populations, ecosystem services	Local and national public health and natural resources management agencies	Identification of synergies and trade-offs of ecosystem management that benefit livelihoods while also mitigating zoonotic disease risks	11, 5, 4, 2
	Equity	Distributional				
	Sustain.	Ecosystem stability and change				
Poverty/Social-Ecological Traps						
Mikulcak et al. (2015)	Security	Human, economic, and environmental	Rural communities, ecosystems, and cultural heritage	National government, international development organizations	Strengthening state institutions to implement policy interventions that support cultural and eco-tourism entrepreneurship and human capital in rural communities, which can create reinforcing feedbacks in built and financial capital while conserving natural and cultural capitals	12, 11, 10, 8, 6
	Equity	Distributional and procedural				
	Sustain.	Social, economic, and environmental				
Civic Ecology						
Sanecka et al. (2020)	Security	Food and environmental	Local communities	Green space stewards within local communities	A shared vision of green spaces as creating a stronger sense of community, shared sense of place, and enhancing connection with nature can support community self-organization, inclusive decision-making, and accelerate social innovations.	10, 7, 4, 2
	Equity	Representational and procedural				
	Sustain.	Social and environmental				
Community-Based Forest Management						
Liu and Ravenscroft (2016)	Security	Livelihood and environmental	Forests managed under common property rights	Local communities	Decentralized decision-making and governance of common property forest resources can empower common self-governance and more effective natural resource management.	10, 5, 4
	Equity	Distributional, representational, and procedural				
	Sustain.	Social, economic, and environmental				
Inequity & Transformation Analysis						
Bennett et al. (2019)	Security	Livelihood and environmental	Marine fisheries and various stakeholder groups dependent on the fisheries	Canadian government, stakeholder groups	Policy interventions that improve fisheries management to reduce catch levels and allow for stock rebuilding through inclusive and participatory governance that explicitly considers distributional, representational, and procedural justice	10, 6, 4, 2, 1
	Equity	Distributional, representational, and procedural				
	Sustain.	Marine fisheries and dependent coastal community and fisher livelihoods				
Socio-Technical Innovation Bundles						
McDonald et al. (2022)	Security	Food, livelihood, and climate	Farmers in coupled rice-wheat cropping systems in	Government and agricultural Extension	Techno-managerial innovations to establish earlier wheat sowing dates are	10, 7, 6, 3

(*continued on next page*)

Table 1 (*continued*)

Case Study	Dimension	Of What?	For Whom?	By Whom?	How?	Leverage Points
	Equity Sustain.	Distributional Food production	the Eastern Ganges Plain of India		coupled with social innovations in the forms of better knowledge provision and removal of market and social barriers to farmer access	

discount rates), in combination with the deeper leverage point of changing the goals of the system (LP 3) by redefining and accounting for dimensions of wealth beyond macroeconomic growth.

4.4.3. Ecological security

The third integrative concept identified was 'Ecological Security' (McDonald, 2018, 2021), which has intellectual roots in critical security studies. Ecological Security is a reaction to anthropocentric ideas about security, particularly in climate security discourses, and emphasizes a broader consideration of the "rights and needs of the most vulnerable across time, space, and species: impoverished populations in developing states; future generations; and other living beings" (McDonald, 2021: 8–9). Ecological security rests on: 1) recognizing harms to a wide range of beings with respect to long-term resilience; 2) ethics based on interconnectedness among species; and 3) realizing the distinction between 'human' and 'nature' is meaningless in the Anthropocene. Security is thus inextricably linked to equity (intergenerational and inter-species) and sustainability (defined as ecological resilience). Ecological Security is particularly attentive to deep leverage points related to the rules and goals of the system and the paradigm from which it arises. The concept clearly articulates the reference object and means of security because they have implications for who defines the threats, prioritizes the response, and assigns the responsibility and means to respond (McDonald, 2021). More broadly, Ecological Security offers an alternative, ethics-based paradigm to conceptualizing security threats from climate change, and expands consideration of security to interconnected ecosystems and species beyond the current anthropocentric view.

The concept of Ecological Security has been applied in diverse contexts. Kim (2021) described how the Ecological Security concept was used in two social movements resisting the construction of military bases in Jeju, South Korea and Okinawa, Japan. Both social movements organized around nonhuman symbols, and in doing so mobilized broader concepts of equity and sustainability in defense of ecological and human security over national security (LP 3). The construction of a domestic military base in Jeju, deemed necessary to boost national security, threatened (and eventually destroyed) a unique volcanic rock formation known as Gureombi. The proposed (and still contested) construction of a United States (US) military base in Okinawa has been depicted by the Japanese government as an urgent task for the US-Japan alliance, but would adversely impact important habitat for the endangered marine mammal called the dugong (Kim, 2021: 263). The Ecological Security discourses around these two social movements considered both vulnerable human and nonhuman beings as equally deserving objects of security (LP 2; Kim, 2021: 259). In both cases, debates centered on value tradeoffs presented between environmental sustainability and inequitable impacts from base construction versus national security interests and additional employment for local, human populations. Both nonhuman entities had significant ecological and cultural value, and were used as symbols to extend equity considerations and transcend local concerns of "not in my backyard" (NIMBY) resistance (LP 5). In fact, an international activist network bypassed the Japanese government and brought the movement into an ongoing US court case of *Dugong* vs. *Rumsfeld* (the acting Secretary of Defense at the project's start), illustrating the mobilization of SES intersections in litigation and policy-making. Although the mobilization of Ecological Security framings met with mixed success in stopping construction, "they still brought about verbal commitments and visible, if limited, changes in the behavior of movement foes" (Kim, 2021: 274).

4.4.4. One health

The fourth integrative concept identified was 'One Health'. One Health has recently gained prominence in scholarly discourse, for example through the 2015 establishment of the journal *One Health*, and increasingly in high-level policy and international governance documents (Gallagher et al., 2021). The One Health concept asserts that "the health of humans, animals, and the environment are inextricably linked" (Garcia et al., 2020: 1), and the One Health approach "consists of multidisciplinary teams working together to solve complex problems to improve health, society, and safeguard natural resources" (Garcia et al., 2020: 2). In a scoping review of One Health policies, principles and methodologies, Gallagher et al. (2021) described One Health as a "framework for addressing 'wicked problems' in which issues commonly revolved around specific population vulnerabilities and social inequities and tended to have diverse, competing stakeholders. Disputes between involved parties were often socially, economically and/or politically charged. They were typically dynamic issues fraught with scientific uncertainty and unintended consequences were a noted concern" (p. 2). Specifically, Gallagher et al. (2021) were interested in One Health applications that linked to the more holistic concepts of health promotion and harm reduction. These are understood, respectively, as socio-ecological dimensions of reciprocal care between society and nature, and actions that individuals and communities can take to make a situation safer and healthier by addressing social, personal, and other harms (Gallagher et al., 2021: 2). The authors' review found that only 7% of the articles reviewed employed the more systemic concepts of health promotion and harm reduction and those examples appeared within the last eight years. Security and sustainability concerns were addressed through the social and ecological determinants of health to prevent the emergence of risk factors for entire populations. Health promotion addressed equity through the empowerment of individuals and communities to increase control over and improve their health, cope and adapt to changes, and build resilience.

Leach et al. (2018) conducted a comparative analysis of local zoonotic disease-ecosystem-livelihood dynamics in Kenya, Zambia, Zimbabwe, Sierra Leone, and Ghana. A One Health approach was used to analyze potential synergies and trade-offs associated with human health security interventions that impact ecosystem sustainability and local livelihoods. Key to understanding these complex dynamics was the use of embedded research methodologies, such as narrative interviews and focus groups, ethnographic observations, and participatory mapping (LP 4, 5). This approach shifted the paradigm (LP 2) away from conventional interventions, such as culling bats in Ghana as a strategy for mitigating henipaviruses, which may reduce disease risks in the short-term but risk losing ecosystems services, such as pollination and bushmeat, that can destabilize ecosystems on which local livelihoods depend (LP 11; Leach et al., 2017). Both short-term (e.g., above normal seasonal precipitation, sudden onset drought) and long-term (e.g., transition from woodlands to cultivated landscapes, increases in irrigated extent) landscape changes were linked to changes in ecosystem sustainability and disease vector dynamics that (increased) decreased disease vulnerability of local communities through increasing livelihood (in)security. Regardless of the trajectory of diseases risks, all cases illustrated socially differentiated disease risks resulting from social relations that create and/or reinforce inequity. Gendered or marginalized

livelihoods, such as (respectively) female gardeners' exposure to Lassa fever or squatters' and hunters' use of tsetse-inhabited woodland patches, provided examples of how livelihoods bring people into contact with disease vectors (Leach et al., 2017: 16).

4.4.5. Poverty/Social-ecological traps

The fifth integrative concept identified was that of 'traps' generally and Social-Ecological or Poverty Traps more specifically, which represent persistent and undesirable livelihood, well-being, and/or ecological states (Barrett and Swallow, 2006; Cumming, 2018; Radosavljevic et al., 2021). When interacting factors that create traps are considered at multiple system levels (e.g., micro, meso, and/or macro), the term 'fractal poverty traps' is used to capture the existence of multiple dynamic equilibria that are self-reinforcing through feedback effects (Barrett and Swallow, 2006; Radosavljevic et al., 2021). For example, at "aggregate scales of communities and regions, the terms on which individuals can buy or sell goods and services—terms that are effectively exogenous at the individual or household scale—begin to turn in part on how communities of households organize themselves … as well as local contracting conventions, physical security, and road and marketing infrastructure all have pronounced effects on market conditions" (Barrett and Swallow, 2006: 10). Poverty traps are often defined by interactions among savings rates, return on labor, and barriers to entry to new activities. Many development interventions have been criticized for acting at this level through micro-finance and/or supporting agricultural inputs, which do not address the interactions among multi-scale factors the create persistent traps (Barrett et al., 2016). Moreover, existing inequities in capital assets, access, and well-being can create and/or exacerbate traps and determine who can break free and who cannot. "Successful individuals able to access more resources and use them become more successful, leading to rising social inequity and injustice at the group level" (Cumming, 2018: 6). From human, livelihood, and environmental security perspectives, poverty traps are more likely in 'less favored lands', which create insecurities through lower and more erratic rainfall and poorer soil. In turn, these locations receive less government investments in and support for infrastructure and services, which creates conditions of relative deprivation that reinforce low productivity livelihoods and limited access and often lead to degradation of supporting natural resources (Barrett and Swallow, 2006: 8).

Given the substantial empirical support for the Poverty Traps concept from the Global South, a case study from Romania was chosen to illustrate the generality of the concept. Noting that conventional rural development models do not explain why development stagnates in certain regions, Mikulcak et al. (2015) combined concepts from poverty traps and sustainable livelihoods to analyze the barriers creating and maintaining a low-welfare equilibrium state (i.e., trap) in Central Romania. The region was characterized by high rates of rural poverty, outmigration and low infrastructural development, while also possessing high biodiversity and farmland stocks. Efforts to develop social and economic stocks through rural economy liberalization to the wider EU commodity market could have improved rural living standards but risked depleting cultural and natural capitals. Barriers to development out of the trapped state were found to be interacting and mutually reinforcing. "For instance, low wages seemed to foster a low work ethic; and the fear of additional costs such as for water or electricity hampered infrastructural development [LP 12]. In other words, low financial capital appeared to be one major cause for low built capital [LP 8]. Insufficient built capital, in turn, was considered a barrier to the development of rural enterprises such as tourism, and thus to potential income opportunities [LP 10, 11]" (Mikulcak et al., 2015: 254). Furthermore, a 'democratic deficit', in the forms of limited information about financing opportunities among rural communities, weak administrative capacity, and corruption, was cited as creating and reinforcing poverty trap conditions (LP 6). The authors concluded that conventional development interventions targeting relatively shallow leverage points, such as 'big push' micro-financing and/or agricultural subsidies, were unlikely to succeeded, and instead interventions that targeted reinforcing feedbacks connecting multiple types of capital would be most effective (Mikulcak et al., 2015: 256).

4.4.6. Civic ecology

The sixth integrative concept was 'Civic Ecology' (Krasny and Tidball, 2012), which is an umbrella term for intentional, local environmental stewardship initiatives focused on enhancing green infrastructure and community well-being in urban or other human-dominated ecosystems (Tidball and Krasny, 2007). Civic Ecology as an interdisciplinary field of study is "concerned with individual, community, and environmental outcomes of community-based environmental stewardship practices, and the interactions of such practices with people and other organisms, communities, governance institutions, and the ecosystems in which these practices take place" (Krasny and Tidball, 2012: 268). Urban community gardens and citizen science biodiversity monitoring projects are common Civic Ecology practices that emphasize local knowledge and social learning. These activities can build local human, social, natural, financial, and physical capital that become integrated into positive feedback loops (LP 7) that address distributional and procedural inequities and material insecurities through, respectively, community empowerment and emancipation (LP 4) and increasing biodiversity and/or food production (LP 10) in underserved and/or disadvantaged places (Oswald Spring et al., 2014). In these contexts, civic ecology can foster the community mobilization and self-organization needed to address larger social structural issues like creation of more green spaces, increasing investments for financial security, and reduction of crime and violence (Oswald Spring et al., 2014).

A Civic Ecology case study by Sanecka et al. (2020) examined the motivations of urban dwellers in Warsaw, Poland, for become green space stewards through interviews and a grounded theory approach. Previous studies have found a range of factors explaining engagement in green space stewardship, including environmentalist values, supplementary food and/or income, health benefits, education and knowledge transmission, reducing environmental footprints, empowerment and strengthening communities, and upkeep of ecosystem services (Sanecka et al., 2020: 3). The author found that the main motivator in their study context was possessing a shared paradigm of green spaces as creating a stronger sense of community, shared sense of place, and enhancing connection with nature (LP 2). The stewardship initiatives they studied throughout Warsaw led to "creating, renewing, and strengthening local urban communities …. [The authors] found a shared green vision for re-designing what the "urban" could be like as the prime motivator for transformation" (Sanecka et al., 2020: 12–13). Notably, the authors identify the 'place-making' motivation as key to supporting communities' with ability to self-organize and self-governance (LP 4). This case study illustrated the applicability of Civic Ecology as a structuring concept for intervention to target design and intent leverage points in practice, which other integrative concepts mostly address only theoretically but not often in practice.

4.4.7. Community-based forest management

The seventh integrative concept identified was Community-Based Forest Management (CBFM) (Gilmour, 2016; Harbi et al., 2020). CBFM has been around for more than 40 years but was popularized through Ostrom's (1990) work on governing the commons, which situated local communities, when granted sufficient property rights, as the best stewards to self-organize and manage forests sustainably (Gilmour, 2016). Empirical research into CBFM has been led by International Forestry Resources and Institutions (IFRI) exploring the factors leading to forest sustainability and successful governance from more than 350 communities and 9000 forest plots globally (Wollenberg et al., 2007). Conceptually, CBFM has been the leading model for decentralized forest management in response to community demands for greater distributional, representational, and procedural equity, and increased recognition by decision-makers that communities may be best positioned to

manage forest resources sustainably (Gilmour, 2016). There are diverse CBFM schemes ranging from fully public lands to increasing devolution of property rights to full private lands (Gilmour, 2016), but common goals of CBFM across schemes are to empower forest communities, slow or halt forest conversion, and reduce environmental conflict (Harbi et al., 2020).

CBFM was investigated as a means for effective collective action by Liu and Ravenscroft (2016). The authors investigated the impact of China's collective forestry property rights reform (CFPRR) on creating new cultural understanding and acceptance of CBFM. The case study was seen as a counterpoint to precedents of community-based management being undermined when common property rights are exposed to large-scale or commodity markets. Previous top-down approaches to forest management in the study context failed because policymakers were unable to obtain detailed information on local issues or efficiently implement and monitor management plans without community involvement (LP 10). This information gap led to unintended outcomes, such as privileged elites capturing benefits from common property for themselves. Moreover, decentralizing decision-making authority to the local community empowered them to monitor and resolve conflicts themselves, leading to more efficient and effective management (LP 4, 5). The authors found "evidence of pro-environmental behaviors with respect to the ecological forests, and pro-community behaviors with respect to fire prevention, logging practices and boundary disputes. … The Hongtian case suggests … that in a supportive environment, common pool resources can release people from poverty rather than consigning them to it" (Liu and Ravenscroft, 2016: 408).

4.4.8. Inequity and transformation analysis

The eighth integrative concept identified was 'Inequity and Transformation Analysis' (ITA) (Tschakert et al., 2013). Grounded in vulnerability scholarship, but noting the recent neglect of structural inequities in that scholarship, Tschakert et al. (2013) integrated material and institutional vulnerability assessment approaches to create a more dynamic paradigm for vulnerability research oriented towards transformations. An ITA approach leads to "analyses that explicitly address structural drivers of vulnerability and their relational construction arising from inequality, marginalization, poverty and constraining social–ecological dynamics while opening doors for transformative change" (Tschakert et al., 2013: 341). ITA critiques contemporary vulnerability assessments for their overemphasis on quantifying vulnerability through indicators and maps of poverty, which portray these populations as inherently vulnerable and mask the dynamic processes and structural inequities that produce vulnerability (Tschakert et al., 2013: 343). The ITA approach attempts to shift the vulnerability paradigm (LP 2) toward the "the role of systemic, structural and relational drivers of social–ecological vulnerability – the relational aspects of inequality and marginalization – in an attempt to broaden the assessment horizon from 'the vulnerable' to include those who are in positions of power. This entails a closer look at *why* people are vulnerable and *what* mechanisms create and sustain their vulnerability" (Tschakert et al., 2013: 344). Structural inequities in material stocks and flows (LP 10) and access to decision-making processes (LP 6) are identified as sources of vulnerability to climate change and barriers to transformative adaptation. Participatory approaches and anticipatory learning are seen as key to building adaptive capacity through problem-solving, community ownership of solutions, priority setting, and accountability of decision-making and trade-offs.

Although not explicitly applying ITA, a case study by Trung Thanh et al. (2021) implement its concepts by moving beyond 'snapshots' of livelihoods to livelihood trajectories among fishing and aquaculture households in Tam Giang Lagoon (TGL) in Vietnam. The study examines aquaculture adoption as a potentially transformative adaptation of coastal communities in response to climate change. In this context (and the authors also argue more generally), livelihood trajectories are key to understanding how current vulnerabilities have emerged, for whom, and capacity for action and decision-making to improve future vulnerabilities (Nelson et al., 2014; Trung Thanh et al., 2021). The authors found that overall TGL households' livelihoods were trending towards increasing vulnerability, but three distinct livelihood trajectories were detected: accumulating, fluctuating, and marginalizing. Households adopting aquaculture increased their capital assets and enhanced their resilience to variable fishery and macroeconomic conditions. However, the loss of habitat from aquaculture expansion adversely affected fishing households locked into a 'social-ecological trap' of increasing vulnerability. These fishers have become reliant on "destructive (and by now mostly illegal) fishing gear, acutely aware that it destroyed ecological habitats, thereby reducing fish reproduction and consequently compromising their own livelihood base" (Trung Thanh et al., 2021: 10). The authors noted that conventional vulnerability assessments that consider only community-level vulnerability would be insensitive to the differential livelihood trajectories and risk fishery management policies that could perpetuate or exacerbate inequities. Consistent with the ITA concept, the authors concluded that "more inclusive decision-making processes [LP 1, 4] open essential spaces for designing and implementing fishery management policies and abandon misguided "one-size--fits-all" approaches that merely further the interests of the most affluent constituencies, even in contexts of persistent poverty and growing inequality" (Trung Thanh et al., 2021: 15).

4.4.9. Socio-technical innovation bundles

Finally, the ninth integrative concept was 'Socio-Technical Innovation Bundles" (Barrett, Benton, Cooper et al., 2020). Technical innovations are considered as any technology, information source, or management practice that can disruptively advance agricultural production methods, while social innovations are institutional transformation accelerators, such as adaptation pathways, public acceptance, responsibility, policies, monitoring, markets, finance, and trust (Barrett, Benton, Cooper et al., 2020; Barrett, Benton, Fanzo et al., 2020; Barrett et al., 2022). Innovation bundles are needed because single technologies inevitably involve tradeoffs among climate, environment, health, employment, equity, productivity, or resilience design objectives (Barrett, Benton, Cooper et al., 2020: 974). As stated at the outset of this review, this is a core challenge of transformation: "the creative destruction of technological change inevitably generates both winners and losers, both positive and negative spillovers across desirable objectives, and thus, opposition to innovations' emergence and scaling" (Barrett, Benton, Fanzo et al., 2020: i). Technical advances must be coupled with social and policy changes, because innovations will inevitably have unintended impacts on non-target outcomes and groups. Moreover, sufficient technical knowledge is not a barrier to transformational change, but rather more influential are sociopolitical barriers of insufficient leadership, political will, and willingness to find cooperative solutions rather than winner-take-all outcomes. Attentiveness to these social dynamics is critical for transformation at scale to be possible. Socio-technical innovation bundles are intended to bring about transformational change by locally contextualizing innovations (e.g., addressing marginalization and power imbalances) and supporting scaling through social innovations that reinforce and drive change.

An example of socio-technical innovation bundling was provided by McDonald and colleagues' (2022) study of coupled rice-wheat cropping systems in the Eastern Ganges Plain region of India. In the case study context, delayed monsoon onset has pushed back rice planting and consequently compressed the window for favorable planting conditions for following dry season wheat. The authors combined field and household survey data, time series remote sensing analysis, and dynamic crop models to investigate the influence of techno-managerial innovations, including sowing dates, new cultivars, irrigation use, and availability of capital, labor, and seeds, on wheat yield gaps. Multiple alternative or combined pathways for adjusting the cropping calendar of the rice-wheat system were proposed. These ranged from expanding rural electrification to support early irrigation needs to establish rice

crops before the arrival of the monsoon (LP 7); better forecasting of monsoon onset (LP 6); provision of appropriately aged seedlings for transplant through social and small business enterprises (LP 10); alternative rice sowing practices that harvest with sufficient time to establish wheat earlier (LP 10); switching rice cultivars to those that mature sooner (LP 10); and changing tilling and harvesting practices. The authors found a 69% increase in the attainable wheat yield gap through adjustment of wheat sowing dates in relation to rice harvest. Importantly, the authors conclude that these techno-managerial innovations alone will be insufficient, and must be combined with removal of institutional barriers, better knowledge provisioning, and enabling changes to markets and social structure (LP 3; McDonald et al., 2022: 548).

5. Synthesis

The potential to produce transformative change depends on how well the underlying causes of unsustainability – insecurity and inequity – are integrated (Green and Healy, 2022; Smith et al., 2014) and which leverage points are targeted by integrated interventions (Dorninger et al., 2020). Fig. 3 maps each integrative concept to its approach to conceptualizing and implementing sustainability transformations and the specific leverage points that were targeted. Leverage point (LP) 12 represents the shallowest while LP 1 is the deepest. The most frequently targeted shallow and deep leverage points where 'structure of material stocks and flows' (LP 10) six times followed by 'size of buffer stocks relative to flows' (LP 11), 'power to add, change, or self-organize system structure' (LP 4), and 'goals of the system' each targeted four times. This configuration of leverage points reflected the strong emphasis on addressing inequity as the root cause of human and environmental insecurity and environmental unsustainability. Surprisingly little attention was given to leverage points of 'strengthening of positive' (LP 7) or 'weakening of negative' feedbacks (LP 8). There were no particular patterns in either the modes of theorization or particular SES dimensions addressed that explained this lack of attention.

Most integrated concepts followed one of two pathways: 1) conceptualized from outside of the system through basic research approaches and transitioned to applied research approaches for implementation; or 2) conceptualized from inside of the system through embedded research approaches and transitioned to science-based change-making for implementation. Integrative concepts following the first pathway targeted relatively more shallow than deep leverage points, which likely reflected the applied nature and external positionality of the research process. This was consistent with the associated case studies' attention to top-down interventions or provisioning related services to address SES concerns by states or other extra-local entities, which tend to focus on more tangible and accessible leverage points like taxes, incentives, and flows of physical inputs. The integrated concepts in the second pathway skewed more towards the deeper leverage points related to system design and intent. This was explained by conceptualization and implementation from embedded perspectives emphasizing participatory methods and empowerment of local communities. These integrated concepts also featured inequity as a key mechanism driving SES interactions, and thus focused relatively more on deep leverage points related to changing existing social and political structures that have produced marginalization populations.

The remaining integrated concepts of 'Inequality and Vulnerability Analysis' and 'Socio-Technical Innovation Bundles' followed a third pathway that crossed over from theorizing from the outside, through either basic or applied research, to theorizing from the inside for implementation. Although these two concepts came from different disciplinary traditions (i.e., hazards and economic development, respectively) they targeted many of the same leverage points. Each addressed Parameters, Design, and Intent leverage points, but Socio-Technical Innovation Bundles also focused on the gains from positive feedbacks as the key to scaling-up innovations and leading to transformation. Both concepts were notable for their convergence of interdisciplinary and transdisciplinary approaches.

Review of the selected case studies (Table 1) demonstrated that integrated concepts that included a mix and wide range of shallow and deep leverage points appeared both more actionable and likely to produce transformative change. Integrated concepts that were skewed more toward shallow leverage points (e.g., Poverty Traps) suggested more actionable interventions, such as agricultural input subsidies, microfinance schemes, or social safety net programs (e.g., Mikulcak et al., 2015), but their case studies noted significant barriers – often related to institutional issues or power asymmetries – to transformative change. Conversely, integrated concepts that were skewed toward deep leverage points (e.g., Ecological Security) identified foundational values and worldviews (e.g., holistic ethics and equity for nonhuman species; Kim,

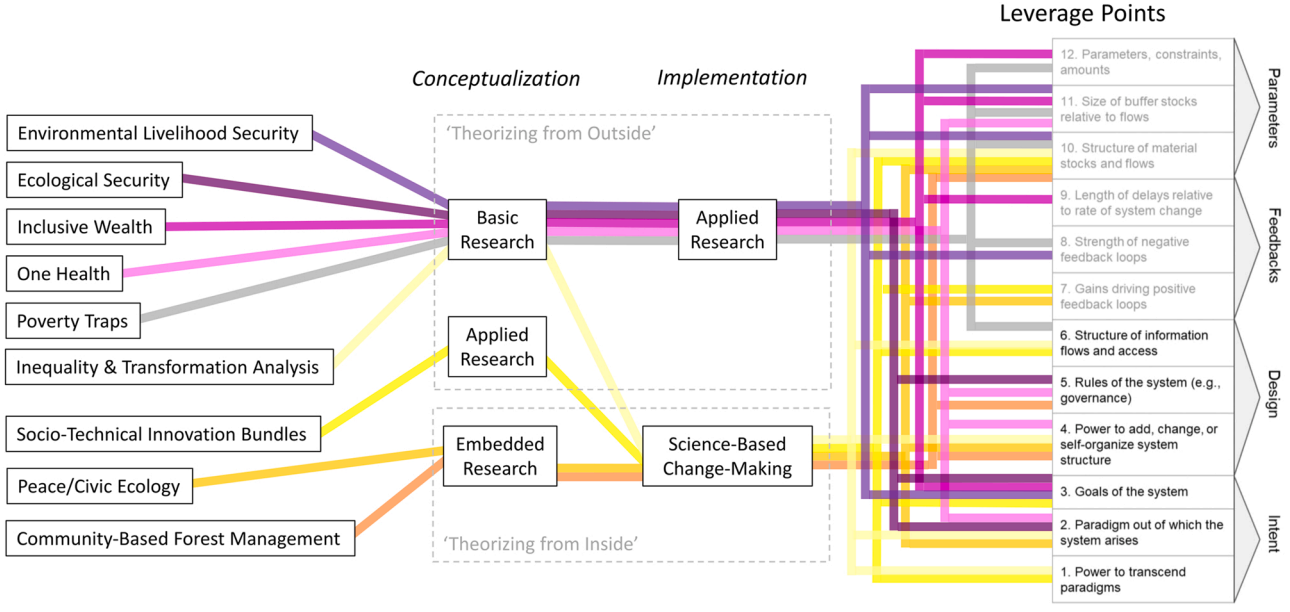

Fig. 3. Pathways through which integrative concepts with varying purposes and positionalities (i.e., theorizing from outside/inside) in their conceptualization and implementation targeted systemic leverage points.

2021) as keys to transformative change, but their case studies noted the marginalization of such viewpoints because of the lack of clear, actionable guidance for interventions. Also evident from the case studies was the difficulty in practice to address all of the leverage points that were targeted conceptually. For example, a broader review of case studies aligned with Socio-Technical Innovation Bundles (beyond what was summarized in the previous section) emphasized the importance of social innovations, but analyses were still heavily focused on technological contributions to transformation. One Health case studies all adopted the more holistic view of distributional equity espoused by the concept, but application of the concept often lacked attention to representational or procedural aspects of equity (e.g., participatory methods).

6. Discussion

This scanning review mapped out the diverse definitions and framings of SES dimensions used in transformation research and identified nine integrated concepts and associated selection of case studies that explicitly addressed the interactions of SES dimensions. To navigate this vast body of knowledge, a set of guiding questions were used to clarify the objects of security, equity, or sustainability interventions, actors responsible for and beneficiaries of those interventions, and primary goals of the interventions. The purposes and positionalities of the integrated concepts were also interrogated to understand the modes of theorization used to develop each concept. Finally, the system leverage points targeted by each integrated concept, theoretically and/or in practice, were identified to assess the potential for systemic change.

Given the breadth of scholarship and practice around each SES dimension, a trade-off between review rigor and relevance of the evidence base emerged (Grant and Booth, 2009), and this review could only scratch the surface of that knowledge. State-of-the-art and umbrella review methodologies were used to focus on contemporary research and synthesize existing systematic reviews. While these approaches were well suited to the knowledge base, they are limited to time bound and subjective pictures of current knowledge. Specifically, this review's focus on interactions among SES dimensions for transformation likely biased the selection of integrated concepts to those with a causal perspective for all three SES dimensions. For example, the concept of 'double exposure' (O'Brien and Leichenko, 2000) describes pathways through which climate change and economic globalization drive changes with spatially and socially differentiated 'winners' and 'losers'. This concept is foundational to much of the contemporary transformation scholarship (e.g., Gill et al., 2023; McDermott et al., 2022). However, its exclusion was based on its treatment of causation. Pressures exerted by climate change and economic globalization are understood to exacerbate SES issues, rather than interactions among SES dimensions creating opportunities for/barriers to transformation in response to such pressures. There are other integrative concepts that were excluded based on this lens, but the insights drawn from the review and analysis of included integrated concepts have applicability to the broader sustainable transformations domain.

Generally, concepts that integrated SES dimensions by explicitly considering their interactions targeted more and a wider mix of shallow and deep leverage points than what has been found in research and practice in specific problem domains (Clark and Harley, 2020; Dorninger et al., 2020). The integrated concepts identified in this review also spanned multiple locations in the Explanatory-Action and Inside-Outside theorizing space (Schlüter et al., 2022). Similarly, the epistemological orientations of each integrated concept influenced which SES dimensions and focal points for interventions were emphasized, however their attention to interdependencies among SES dimensions expanded the scope of leverage points that were targeted. This illustrates the additional insights that can be gained from examining how SES dimensions can reinforce and reproduce one another with the leverage points perspective. This also suggests that the ways in which SES dimensions intersect are structured by deep leverage points of system design and intent, and therefore understanding interactions between shallow and deep leverage points must be a research priority (Abson et al., 2017; Dorninger et al., 2020).

The current view of leverage points for sustainability transformations is that of a hierarchical structure in which shallow leverage points are constrained by deeper ones (Abson et al., 2017). "The system intent (the goal to which the system is oriented) shapes the physical and institutional design of the system, which in turn determines the feedback that the system provides regarding (un)sustainable functioning and therefore the type of parameter that can, or should be, adjusted to shift systems towards sustainability" (Dorninger et al., 2020: 8). There is certainly evidence for the validity of this view in practice (Dorninger et al., 2020) and it serves as the theoretical basis for several of the integrated concepts identified in this review (e.g., Ecological Security, Civic Ecology, and Community-Based Forest Management). However, this view is somewhat limiting by its emphasis on complex systems concepts of 'slaving' or 'entrainment' causation (Kast and Rosenzweig, 2017; von Bertalanffy and Sutherland, 1974; Werner, 1999). In other words, causation is constrained to the direction of deep leverage points to shallow leverage points, or from system intent to system parameters.

Equally important, though, is causation from 'emergence' and 'self-organization' that operate in the complementary direction. In the context of leverage points for transformation, targeting shallower leverage points, such as those constituting feedbacks (LP 7–9) and 'structure of information flows' (LP 6) has the potential to create new, emergent interactions among SES dimensions that make deeper leverage points more accessible. For example, interventions that directly address representational and procedural aspects of equity, such as the participatory approaches (LP 6) core to the integrated concepts of Civic Ecology, Socio-Technical Innovation Bundles, and Inequity and Transformation Analysis, can bring previously marginalized knowledge, values, and goals into the system that initiate positive feedback loops reinforcing self-(re)organization of existing relations (Oswald Spring et al., 2014). Similarly, Riechers et al. (2021) and West et al. (2020) argue that reconnecting to natural systems processes and the feedback information (LP 7–9) they present can have positive ripple effects for human well-being and potentially shift worldviews.

Considering both modes of causation equally in social-ecological systems reinforces existing calls for more research attention on feedbacks and interactions among leverage points more generally. Consistent with research priorities outlined by Abson et al. (2017) and findings from Dorninger et al. (2020), this review found little attention paid to feedbacks as leverage points. This is surprising because system feedbacks were originally identified by Meadows (1999) as key points for maladaptation by weakening of negative feedbacks that regulate or dissipate imbalances, or reinforcing or accelerating positive feedbacks that produce inequities. However, feedbacks can also be powerful leverage points for adaptive transformation. For example, targeted weakening of negative feedbacks associated with poverty traps, such as dissipation of savings during periods of low food production and climate volatility, can be key moving out of low well-being states (Barrett et al., 2016). Similarly, diffusion of socio-technical innovations relies on positive feedbacks from social learning to scale-up their adaptive impacts (Herrero et al., 2020). This review suggests that explicit consideration of how SES dimensions intersect is a promising entry point for studying leverage point interactions, and the potential of feedbacks leverage points in particular, for triggering transformation processes.

Moreover, increasing attention to feedbacks as leverage points would be consistent with the 'relational turn' in sustainability science (West et al., 2020) and the theoretical basis for the integrated concept of Inequality and Transformation Analysis (Tschakert et al., 2013). A 'relational' perspective shifts focus away from the structure of interactions among system components as the analytical target, and instead emphasizes understanding the social-ecological systems in which we are embedded as constituted and (re)created through the continual unfolding of dynamic processes. Similarly, a key tenet of

Inequality and Transformation Analysis is the recognition that vulnerability is not static nor inherent to a location or population, but rather is the dynamic product of both structural and relational drivers. If one adopts this view, then security, equity, and sustainability of social-ecological systems are not outcomes to be targeted by interventions, but rather are snapshots of processes that continually reinforce and create one another. Thus, feedbacks leverage points are critical because they focus our attention on dynamics rather than structures of social-ecological systems for addressing SES dimensions.

Such a refocusing has two important implications for transformation research and practice. First, a dynamics-oriented perspective is more attuned to the potential risks, i.e., the 'dark side' (Blythe et al., 2018), of transformation concepts and action. When particular framings and operationalizations of transformation gain momentum, one can be more critical of the types and strengths of feedbacks that are created – whether negative feedbacks preventing transformation are reinforced, or positive feedbacks leading to disruption of the status quo are unfolding. Transformation research and practice would benefit from a reconceptualization of SES dimensions as dynamically generated by or reconfiguring deeper leverage points. Second, a relational view opens engagement around transformation research and practice to a broader intellectual community, and diversity of epistemological and methodological approaches is key for confronting the diversity of challenges presented by rapidly changing social-ecological systems. For example, participatory methods are key to addressing deep leverage points of empowerment and changing values and paradigms. Additionally, a large and diverse body of knowledge exists about the importance of social learning in changing behaviors and catalyzing positive feedbacks. Linking these two perspectives through participatory action research (PAR) can deepen social-ecological system understanding and target deep leverage points through empowerment and co-production of knowledge (Méndez et al., 2017; Sachet et al., 2021). PAR focused on social learning and scaling processes can activate deep leverage points of changing system Design and Intent that can directly address representational and procedural inequities. Social learning underpins positive feedbacks driving innovation diffusion, which is necessary to scale-up transformative adaptations with the potential to produce regionally sustainable outcomes. More intentional mixing epistemological and methodological approaches, with an eye toward the dynamics of intersecting SES dimensions, have the power to both enrich our understanding of transformation while also targeting deep leverage points for change.

7. Conclusions

Transformations towards a more secure, equitable, and sustainability Anthropocene are complex, contested, and multifaceted. Evidence from this review, and the many that have preceded it, is mounting that interventions that address only one of the SES dimensions will most likely fail due to ineffective targeting of leverage points for systemic change and/or because of numerous tradeoffs and unintended consequences that are likely to emerge. Moreover, integrative concepts exist that explicitly address all three SES dimensions and their interactions, and in doing so target multiple shallow and deep leverage points. Yet, it remains challenging in practice to design and implement specific interventions guided by these integrative concepts that can activate all the leverage points that were identified conceptually – in other words, the 'sustainability gap' persists (Fischer et al., 2007; Fischer and Riechers, 2019). Perhaps even more concerning is the lack of clarity in the definition and framing of SES dimensions in transformation scholarship. As noted by Blythe et al. (2018) and McDonald (2021), the increasing mainstreaming of transformation discourses means they are informing practical interventions, but ambiguity in the objects, actors, motivations, and goals of SES initiatives risks reinforcing existing power structures that resist change, i.e., the 'dark side' of transformation.

Although these challenges and risks are significant, the importance of the evolution of transformation thinking, scholarship, and practice cannot be overstated. Intersection of SES dimensions are increasingly recognized and serve as focal points for basic research and science-based change-making. The integrative concepts identified in this review demonstrate how research and practitioner communities have moved beyond simply stating the importance of SES dimensions or offering descriptive analyses. Research frontiers are shifting focus to the causal interactions among SES dimensions, leading many researchers to blend explanatory and action-oriented paradigms and partner with practitioners and stakeholders to pursue transdisciplinary approaches (and vice versa). Recent discourses in land system science, for example, have elevated the role of normative science and co-production of knowledge in transformation research (de Bremond et al., 2019; Nielsen et al., 2019) based on the need to attend to SES dimensions and their interactions. Explicit attention to SES dimensions in the context of transformation can ensure an intentionally critical and normative approach is operationalized (West et al., 2020). As this review has illustrated, using SES intersections as an entry point for transformation research can effectively connect more tangible outcomes targeted by shallower leverage points to the deep leverage points that structure SES intersections.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

Acknowledgements

This work was supported by grants from the National Science Foundation INFEWS (# 1856054) and D-ISN (# 2039975) and National Aeronautics and Space Administration ROSES LCLUC (# 80NSSC21K0297) programs. This study also contributes to the Global Land Programme (https://glp.earth).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ancene.2023.100396.

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