Received: 14 February 2020 | Revised: 13 May 2020 | Accepted: 5 June 2020

DOI: 10.1111/gec3.12534

ARTICLE

WILEY

Assemblages and complex adaptive systems: A conceptual crossroads for integrative research?

Michael Spies | Henryk Alff

Centre for Econics and Ecosystem Management, Eberswalde University for Sustainable Development, Germany

Correspondence
Michael Spies, Centre for Econics and Ecosystem Management, Eberswalde University for Sustainable Development, Schwappachweg 3, 16625 Eberswalde, Germany.
Email: michael.spies@hnee.de

Abstract

In human geography and beyond, assemblage thinking has increasingly gained attention as a perspective from which to investigate the emergence and dynamics of more-than-human entanglements. Similarly, in the interdisciplinary field of social-ecological systems analysis, theories of complex adaptive systems have been employed to investigate how social and ecological dynamics and actors interact with each other on different scales. Nonetheless, despite the success of these conceptual perspectives in their respective research fields, there have been few attempts so far to bring these theoretical strands together to explore their common ground and investigate how they could cross-fertilize each other. This contribution seeks to address this gap, by investigating the ontological compatibility of these two approaches and exploring the potential for meaningful syntheses that could be utilized for integrative research—combining perspectives, approaches, and methods taken from social and environmental sciences for the analysis of human-environmental relations. Based on a comparative discussion of four selected "guiding principles" found in assemblage thinking and complex adaptive systems, namely, socio-nature, emergence/historicity, relationality, and self-organization, we find not only significant common ground between the two perspectives but also discrepancies that may be utilized for cross-fertilization. In particular, we argue complex adaptive systems would benefit from a deeper

engagement with society-nature theorizations found in the assemblage literature, while assemblage thinking could borrow from complex adaptive systems to broaden its conception of how elements relate to and co-function with each other.

KEYWORDS
historicity, more-than-human social theory, relationality, social-ecological systems, socio-natures

1 | INTRODUCTION

Assemblages, or more-than-human perspectives, have gained considerable popularity in human geography in recent years (see for example, Anderson, Kearnes, McFarlane, & Swanton, 2012; Dittmer, 2014; Müller & Schurr, 2016). Investigating diverse research objects such as data networks (Bittner, Glasze, & Turk, 2013; Pickren, 2018), border areas (Karrar & Mostowlansky, 2018; Sohn, 2016), and infrastructure projects (Alff, 2020; Han & Webber, 2020), an increasing number of researchers have adopted conceptual perspectives that can be subsumed under the term "assemblage geographies" (Robbins & Marks, 2010). As a common theme, these approaches attempt to overcome the social-material divide by acknowledging that societal interactions are actively co-produced by human and non-human elements. Not surprisingly, therefore, assemblage approaches have received a warm welcome in "classical" human-environmental research topics such as food systems (Dwiartama, Rosin, & Campbell, 2016; Sharp, 2018), agricultural change (Dressler, Smith, & Montefrio, 2018; Gengenbach, Schurman, Bassett, Munro, & Moseley, 2018), forestry and forest politics (Mattissek & Wiertz, 2014; Nel, 2018), social-ecological system research (Briassoulis, 2017a; Lejano, 2017), and environmental or climate change (Spies, 2016; Burnham, Ma, & Zhang, 2016). This research highlights the inextricability of society and nature, and emphasizes complexity, nonlinear causality, and emergence, thus rejecting one-sided explanation models that prioritize one type of factor or driving force (social or natural) over another. In addition to the interconnected understanding of society and nature being in the focus of social-science-based assemblage thinking, the term assemblage has been widely used in ecology and biology to frame (multi-) species correlations in a given habitat (Blair & Launer, 1997; Korhonen, Soininen, & Hillebrand, 2010; Wright & Reeves, 1992). While being aware of the long-established application of the term in the natural sciences, we refrain from following up its conceptual underpinnings in the context of this article.

While the philosophical assemblage concept originates from the writings of Deleuze and Guattari (1987), in practice, many scholars combine ideas from assemblage thinking and another prominent perspective on socio-material entanglements: actor-network theory, primarily based on the work of Latour (1987, 2005) (see for example, Bennett, 2010; Forney, Rosin, & Campbell, H. (Eds.)., 2018; Spies, 2016). There are major similarities between assemblage and actor-network theory, in particular their relational worldview, their emphasis on emergence, and their attention to "the socio-material, that is, that the world is made up of associations of human and nonhuman elements" (Müller & Schurr, 2016, p. 217). We argue that these—and possibly other—features can also be found in another, well-established strand of theory that has largely been ignored by the above literature, namely, complex adaptive systems (CAS). In the 2000s, CAS and associated theories of complexity, emergence, and nonlinear dynamics gained some momentum in human geography (Chapura, 2009; Egner & von Elverfeldt, 2009; Harrison, Massey, & Richards, 2006; S. Manson & O'Sullivan, 2006; O'Sullivan, 2004; Ratter, 2012), but they seem to be currently out of fashion. Reasons for this may include the origin of these approaches in natural sciences, and their affiliation with the resilience concept that has been criticized by human geographers for its "mainstream usage [as] conservative,

[focusing] on the persistence of a 'system'" (Brown, 2014, p. 109), and for their neglect of power relations and normative factors, among others (Brown, 2014; Cannon & Müller-Mahn, 2010; Watts, 2015).

Overall, conceptual and empirical research based on assemblage thinking (AT) and CAS appear to exist largely in isolation from each other, albeit with some exceptions, most notably in the field of planning (de Roo, Hillier, & van Wezemael, 2016). We argue that, particularly in the field of human-environmental research, this may be a missed opportunity. On the one hand, a dialogue between the two theoretical perspectives may be fruitful in terms of conceptual cross-fertilization for the investigation of social-ecological processes. On the other hand, bringing together these approaches rooted in very different disciplines (social sciences/philosophy and ecology) could help find a common ontological ground for integrative research that is acceptable to both social and natural scientists. This paper aims at exploring the commonalities and differences between AT and CAS, addressing the question whether the ontological standpoints of the two schools of thought are compatible, and discussing potentials for meaningful syntheses in the context of integrative human-environmental research.

Needless to say, both strands of theory are by no means homogeneous but subject to manifold conceptual debates and disagreements—as reflected, for instance, in the critique by Deleuzian philosopher Ian Buchanan (2017) on the tendency of researchers to detach assemblage theory from the original writings of Deleuze and Guattari, or in the diverse classifications of key CAS features found in the literature and as summarized by Preiser, Biggs, De Vos, and Folke (2018). Our investigation is necessarily selective, focusing mainly on the work of DeLanda (2006, 2016) and recent geographical debates on assemblage theory, on the one hand, and the work on CAS centered around prominent scholars from the Resilience Alliance (e.g., Gunderson & Holling, 2002; Lade & Peterson, 2019; Preiser et al., 2018), on the other.

We structure our inquiry along four identified guiding principles of AT and CAS that we find particularly relevant for human-environmental research: (a) the entanglement of society and nature, (b) an emphasis on historicity and emergence, (c) a relational worldview, and (d) the notion of self-organization or adaptability. The choice of these guiding principles is based on a review of extensive literature regarding the defining properties of both assemblages and complex adaptive systems as holistic social-ecological entanglements. For our purpose, the chosen principles provide a heuristic framework to make sense of the conceptual qualities of AT and CAS as stand-alone strands of thought and in their connectedness alike. We begin with a principle that we find to be more central to AT than to CAS (social-natural entanglements), and we end with a key feature of CAS that appears to be largely absent in AT (self-organization). Finally, we outline the conceptual intersections between the two approaches, discuss their value for integrative research, and highlight selected points for meaningful cross-fertilization in the context of human-environmental research.

2 | ASSEMBLAGES AND COMPLEX ADAPTIVE SYSTEMS

An assemblage can be described as "some form of provisional socio-spatial formation […] composed of heterogeneous elements that may be human and nonhuman, organic and inorganic, technical and natural" (Anderson & McFarlane, 2011, p. 24). The concept has become popular among scholars in human geography and beyond, and it is employed to emphasize the multiplicity and fluidity of social phenomena and to investigate the diverse roles of both material and immaterial elements in stabilizing and destabilizing relations. While keeping their individual identity, the elements of an assemblage are united by their temporary co-functioning. As Müller (2015, p. 28) puts it, "assemblage is a mode of ordering heterogeneous entities so that they work together for a certain time."

While the concept is rooted in the writings of Deleuze and Guattari (1987), assemblage theorizations have developed dynamics of their own, sometimes in conjunction with concepts borrowed from ANT and other schools of thought (see, for example, Bennett, 2005; Briassoulis, 2017a, 2017b; Dittmer, 2014). The work on "assemblage theory" by DeLanda (2006, 2016) is particular noteworthy in this regard despite its relatively little acknowledgement by human geographers, and some controversial opinions it triggered. For instance, Müller and Schurr (2016, p. 220) find

that DeLanda's accounts of assemblages describe "stable, coherent actualizations" "that have little to do with [the] potentialities and capacities" found in Deleuze and Guattari's work. Harman (2008, p. 367), in turn, has much praise for DeLanda's philosophical realism, but—in direct opposition to Müller and Schurr—criticizes his "shift from the actual to the virtual." We find DeLanda's work useful, not only for providing a clear and more comprehensible interpretation of "Deleuze and Guattari's obscure, garbled, and accessible only-to-the-initiated texts" (Briassoulis, 2017b, p. 213), but also for his sincere efforts to cross disciplinary boundaries into fields such as chemistry, biology, and physics. Moreover, the inter- or transdisciplinary character of DeLanda's theorizations helps identify meaningful links to the second school of thought under investigation.

The notion of complex adaptive systems (CAS) has its roots in complexity theories (Cilliers, 1998; Prigogine & Nicolis, 1989) and nonequilibrium ecology (Holling, 1973; May, 1977; Wu & Loucks, 1995). In the influential field of social-ecological systems research, associated with the Resilience Alliance and the journal *Ecology & Society*, there is now a common understanding that social-ecological systems are in fact CAS (Glaser, Ratter, Krause, & Welp, 2012; Lade & Peterson, 2019;Levin et al., 2013 ; Preiser et al., 2018). The increasing popularity of CAS in human-environmental research can be linked to a broader "complexity turn" across natural and social sciences (Urry, 2005). Behind the concept is an understanding of social-ecological systems as inherently complex, shaped as they are by nonlinear dynamics and feedbacks on (and between) multiple spatial and temporal scales. CAS studies attempt to overcome the mechanistic, single-equilibrium understanding of systems found in "traditional systems theory," arguing that the CAS approach "contains no a priori assumptions about key variables, emphasizes nonlinear causal effects between and within systems, and views system equilibrium as multiple, temporary, and moving" (Duit & Galaz, 2008, p. 312; cited in Preiser et al., 2018). By highlighting context-dependency and the existence of multiple stable states, CAS theory rejects traditional notions of "balance of nature" (Cote & Nightingale, 2012, p. 476) in ecological and social-ecological systems. Thus, the dynamics of social-ecological systems are viewed as "inherently unpredictable and deeply uncertain" (Preiser et al., 2018, p. 46).

Nevertheless, a number of conceptual tools have been developed that aim at describing the non-linear dynamics of CAS, in particular the two related concepts of resilience (Berkes & Folke, 1998; Cote & Nightingale, 2012; Holling, 1973) and self-organization (see section below). Moreover, by using agent-based and other advanced modelling approaches, researchers attempt to describe CAS and their trajectories in non-reductionist ways by incorporating uncertainties, non-linear feedbacks, and emergent properties (Levin et al., 2013; Preiser et al., 2018).

Here, we see a major difference between CAS and assemblage-informed research, in that while empirical studies inspired by AT rely heavily on qualitative social research and narrative approaches (Baker & McGuirk, 2017; Dressler et al., 2018; Han & Webber, 2020; Sohn, 2016), CAS-based research puts a much stronger emphasis on quantitative research or modeling approaches. This can be explained not only by the disciplinary differences between the two schools, but possibly also by the stronger focus of CAS on policy-oriented research, where "hard" data seem to be preferred (see, for example, An, 2012; Glaser, 2012; Levin et al., 2013). Thus, one of the conceptual implications of these methodological differences is the stronger developed epistemological approach of system thinking in constructing scales and boundaries for analytical inquiry (Friis & Nielsen, 2017). While methodological differences between the two approaches create barriers for their integration, we argue that in conceptual and ontological terms there is significant potential for collaboration.

3 | POINTS OF CROSS-FERTILIZATION OF ASSEMBLAGE THINKING AND COMPLEX ADAPTIVE SYSTEMS

In the field of human geography, few authors have brought together elements from assemblage theory and CAS. Sheppard (2008) provides a useful overview of parallels found in relational dialectics, assemblage and complexity theory, and Bonta and Protevi (2004), while not explicitly looking at assemblage theory, offer a rich exploration of some close linkages between complexity theory and Deleuze and Guattari's philosophy. Briassoulis (2017a) draws on both AT and CAS—or social-ecological systems—in her conceptualization of "response assemblages," which triggered

a controversial discussion about connecting AT to or embedding it within what Head (2017, p. 204) describes as "something conceived in a completely different ontology." Head argues that "resilience thinking"—and, indirectly, CAS—implies a clear "ontological separateness" of social and ecological systems that is in stark contrast to AT (ibid.). We begin our inquiry into conceptual intersections and differences between the two schools by following this theme.

3.1 | Socio-natural entanglements

Albeit not as explicitly as in the literature on actor-network theory (esp. Latour, 1993, 2005), assemblage thinking clearly refrains from notions of society and nature as separate ontological domains. An ecological symbiosis of wasps and orchids can be conceived as assemblage (Deleuze & Guattari, 1987, p. 10), but so can languages (DeLanda, 2016, p. 51), electrical power grids (Bennett, 2005), or anthropogenically transformed mushroom ecologies (Tsing, 2015). What they have in common, however, are particular part-to-whole relations, with heterogeneous components forming more or less durable, larger wholes that have unique emergent properties.

Rather than categorizing assemblages and their components as social or natural with different ontological principles, entities can be described by their *material* and *expressive* roles (DeLanda, 2006; see Deleuze & Guattari, 1987 for the related conceptualization of "content" and "expression"). Material assemblage components may be more obvious and include, for instance, the physical infrastructure of a city or the soils, rocks, water, and plants of an ecosystem. Expressive roles, in turn, can be taken not only by discourses, ideas, and values, but also by genetic codes or, in the example above, a specific scent produced by orchids to sexually attract male wasps. Moreover, an element can "play a mixture of material and expressive roles by exercising different sets of capacities" (DeLanda, 2006, p. 12). It may be argued that all assemblages, or at least those including living beings, are composed of material *and* expressive components. Ontological differences between social and other assemblages can thus be understood, in the words of Bryant (2011, p. 32), as "in degree, not kind," whereby social assemblages are characterized by a high number of specialized expressive components such as values, rules, desires, etc. Needless to say, the expressive components of social assemblages are always inextricably linked to material elements such as human bodies, infrastructure, and technologies. In this sense, "social" may be used as a synonym for "socio-material," or "socio-natural."

In one of the most often cited publications related to the Resilience Alliance, Berkes and Folke (1998, p. 4) clearly state, "We hold the view that social and ecological systems are in fact linked, and that the delineation between social and natural systems is artificial and arbitrary." Moreover, humans—and social systems—are regarded as *part* of natural ecosystems, not external or above them (Berkes & Folke, 1998; Folke, Biggs, Norström, Reyers, & Rockström, 2016; Preiser et al., 2018). However, there is relatively little theorization of "social" or "natural" in this school of thought, or of how these two spheres are interrelated. Westley, Carpenter, Brock, Holling, and Gunderson (2002) and Holling (2001) discuss a number of distinctive features of social (or human) systems not found in ecological systems, such as foresight, intentionality, reflexivity, and technology. Furthermore, while it could be argued that at least some of these features may also apply to other intelligent species (see for example, Andrews & Beck, 2017; Lurz, 2009), the authors frame social systems as fundamentally different from ecosystems despite the assertion that the general properties of CAS such as self-organizational capacities and "panarchical relationships across scales" (Holling, Gunderson, & Peterson, 2002, pp. 98–99) apply to both types. Moreover, there is a lack of theorization in the CAS literature on how social systems are embedded in natural ecosystems, and frequently used terms like "coupled human and natural systems" (An, 2012; Liu et al., 2007) or "linked social-ecological systems" (Westley et al., 2013) imply that de-coupled, nature-independent social systems actually exist. This way, CAS approaches seem to contradict their basic claim that "human systems and ecosystems are inextricably linked" (Preiser et al., 2018, p. 46) and could benefit from a deeper engagement with the assemblage literature. We do not see why a conceptualization of social and ecological systems along a continuum rather than in separate categories,

acknowledging the fact that social systems are always co-produced by "natural" elements, would contradict the basic principles of CAS outlined in the following.

3.2 | Historicity and emergence

Both AT and CAS theory deal with processes of becoming over multiple time-scales, pointing to historicity and emergence in their conceptions of social-ecological systems or assemblages. Both concepts are closely related: Historicity, "or the idea that history matters" (Desjardins, 2011, p. 340), emphasizes that individual phenomena are a result of contingent history, whilst emergence broadly refers to the process of assemblages or systems (and their constituent components) gaining new individual properties or qualities through mutual interaction over time.

AT draws attention to the dynamically evolving emergence of coherent sociomaterial entanglements, for example, from patterns to institutions (Briassoulis, 2017a), through complex interaction. According to DeLanda (2016, p. 12), emergence needs to be included as a "part of the definition of the term 'assemblage'." Based on the concept of "emergent properties," describing "the properties of a whole caused by the interactions of its parts" (DeLanda, 2016, p. 9), DeLanda (2016, p. 12) argues, first, that an assemblage is irreducible, and thus the parts of the whole are not just an aggregate but become assembled in a qualitatively new entity. Second, DeLanda determines the emergent condition of an assemblage as being dependent on the ongoing interactions of its components. In so doing, DeLanda seeks to reject any essentialist notion of the assembled whole: According to him, even atoms or the chemical elements of the periodic system are not universal or eternal; instead, they are historical results of recurrent processes (DeLanda, 2006, p. 28). In their emergent properties, and thereby in their ever-changing condition, communities and organizations (in a more-than-human, social-natural understanding) also co-exist as "historically individuated" and therefore as unique and contingent entities (DeLanda, 2016, p. 13).[1]

An important aspect to this "realist [rather than structured] ontology" of "individual emergent wholes operating at different (relational) scales" (DeLanda, 2016, p. 16) is socio-temporal path-dependency. Thus, nested sets of actors in assemblages do not emerge out of nowhere; rather, components more commonly become embedded (or accommodated) into already constituted wholes, and they are therefore constrained and enabled by historically sedimented patterns within and emergent capacities of the whole (Murray Li, 2000). Once in place, assemblages act as a source of limitation and opportunity for their components alike, and often they come with a tendency towards homogenization and with a resulting decrease in individual differences (DeLanda, 2016, pp. 21–22).

Similarly, CAS entail their past relational compositions (Dittmer, 2014, p. 391) or evolutionary histories (Holling, 1973, 2001). As Manson (2001, p. 410, cited in Dittmer, 2014) states with regard to complex systems, "a system 'remembers' through the persistence of internal structure […]. Components and sub-systems with the capacity to accommodate the influx of energy, matter, and information from the environment will grow." Preiser and her colleagues additionally outline the organizational capacity of complex systems to adapt "in response to feedbacks from interactions between different systems, and between elements and their environment" (Preiser et al., 2018, p. 46). The history of how a system acts and reacts, according to Preiser et al., is captured in its memory and determines its state in the present and its capability to adapt in future trajectories of change. Moreover, the concept "remember," as outlined in Holling et al.'s (2002) "panarchy" framework, describes an important cross-scale connector between different systems, whereby renewal processes in a small-scale system draw on "the potential that has been accumulated and stored in a larger, slower cycle [or system]" (Holling et al., 2002, p. 75). Generally, CAS approaches often highlight (ecological or societal) evolution (Holling et al., 2002; Preiser et al., 2018), a process described as "idiosyncratic and profoundly influenced by history," thereby rejecting any "teleological principles […] at the level of the whole system, or even at the local level" (Levin, 1999, pp. 23, 30).

Therefore, it is important to note that AT and CAS theory share a focus on the dynamic emergence of social-natural wholes and their largely autonomous components, which is dependent on complex (down- and upward) causalities determined both by historical framing conditions and everyday interaction. While AT and CAS theory draw on a

similar conceptual perspective, they do so coming from different scholarly domains. In our opinion, AT's focus on human history, on the one hand, and CAS's reference to ecological dynamics on different temporal scales, on the other, could provide opportunities for theoretical and empirical cross-fertilization.

3.3 | Relationality

Relationality comes as one of key principles in assemblage thinking, and in fact it is the core element/process in the very constitution of assemblages. As Müller (2015, p. 28) describes the role of relationality, drawing on Deleuze and DeLanda, "assemblages consist of relations of exteriority," thus referring to a "certain autonomy of the terms (people, objects, animals, etc.) from the relations between them." In the context of AT, relationality is therefore understood as a complex interaction between assemblages and their constituent parts (DeLanda, 2006), albeit with a clear focus on interactions and attached meaning-making processes rather than on the (human or nonhuman) actors themselves. In the sense of what Briassoulis (2017a) describes as "socio-ecological fit," if an entanglement is maintained, then there must be "some sense in which the assembling is coherent (fit being some kind of tentative conciliation between processes of ordering and disordering)" (Lejano, 2017, p. 199).

Despite this paramount significance of relationality in AT, there is still considerable debate about how relationality can be theorized and, even more so, how it can be operationalized in empirical research, for instance on land-use decision-making. Lejano (2019, p. 4) in his conceptualization stresses that "we must understand relationship as encompassing the material (e.g., activities and mass/energy exchange) and the nonmaterial (i.e., identity and meaning)." Likewise, Lejano (2019) suggests that relational research necessarily needs to go beyond "classical" social network analysis, for example in counting relations or analyzing the density of relations, or more generally focusing "less on the structure of the network […] but on the relationships themselves that constitute each link" (2019, p. 6). As one of the key challenges in this regard, however, comes the anthropocentrism that is inherent in descriptions of particularly cognitive or emotional aspects of relationality (Lejano, 2019, p. 7) and which cannot be adequately assessed for nonhuman actors such as animals or plants.

Similarly, in CAS theory, interactions among constituent components, rather than the components themselves, are considered a defining feature (Preiser et al., 2018). Such an understanding implies that CAS are to be grasped in their processual "emergent" dimension, not as a teleological structure (see section above). Furthermore, the character of relations between system components and between a system and its wider environment comes into focus. Other than in AT that explicitly pronounces a flat ontology of relationality (Marston, Jones III, & Woodward, 2005), and thus aims to distance itself from conceptual boundary-making or strict distinctions between in- and outside, complex systems theory despite its "radical openness" (Preiser et al., 2018) distinguishes more clearly between intra- and inter-system relations. This is particularly evident in the abovementioned panarchy framework that differentiates between a system's inner dynamics ("adaptive cycles") and its relations to larger systems that operate at "higher" levels (Holling et al., 2002). In doing so, CAS theory implies a sort of ontological structurization that may, in some cases, misguide research towards postulating system boundaries that lack any empirical grounding. This is particularly problematic in regards to the persistent society-nature dichotomy in much CAS-related work, as discussed above. Thus, through its questioning of ontological categories, AT may refine (or broaden) the understanding of relationality in theories of CAS.

3.4 | Self-organization

As the term "complex *adaptive* system" implies, a defining feature of CAS is their self-organizing character and their ability to adapt and transform. Since (all) social-ecological systems are considered CAS (Folke et al., 2016; Preiser

et al., 2018), this principle needs further scrutiny. We begin this section by outlining the concept of self-organization in CAS, before discussing conceptual parallels or contradictions to AT.

As Holling makes clear, self-organization is considered a key process in the very constitution or historical evolution of CAS: "'Self-organization' is a term that characterizes the development of complex adaptive systems, in which multiple outcomes typically are possible depending on accidents of history" (Holling, 2001, p. 391). Here, the emphasis on multiplicity is crucial, as it should be clear by now that social-ecological systems are never single-equilibrium "mechanical systems" that "exhibit no learning, no local detail, and no individual diversity" (Bonta & Protevi, 2004, p. 21). Unfortunately, a neglect of these underlying principles has often resulted in a rather mechanical understanding of self-organizing social-ecological systems in applications of the above-mentioned resilience concept, focusing on adaptability and durability of a given system rather than on more fundamental dimensions of change (Brown, 2014; Hatt, 2013; Kirchhoff, Brand, Hoheisel, & Grimm, 2010).

While their outcomes are unpredictable, self-organizational dynamics of CAS are often stylized in terms of an "adaptive cycle" consisting of four phases—exploitation/growth, conservation/consolidation, collapse/creative destruction, and reorganization/renewal (Holdschlag & Ratter, 2016; Holling et al., 2002). These dynamics can take many forms, and "[t]he adaptive cycle […] should not be read as a rigid, predetermined path and trajectory" (Holling & Gunderson, 2002, p. 51). Generally, change is regarded as episodic rather than continuous and gradual (ibid., p. 26), with phases of slow accumulation and increasing rigidity interrupted by rather sudden release or collapse resulting from disturbances that may be internally (by elements of the system itself) and/or externally (by processes originating from a different system) triggered. A trigger can be "entirely random […]—a transient drying spell for the forest, a new critic appointed to the board of directors of the company, an election of a new minister of government responsible for the agency" (Holling & Gunderson, 2002, p. 45). Consequently, the system then may develop an entirely new logic of self-organization, or, in CAS terminology, flip into a new "basin of attraction" or "region of state space" (Bonta & Protevi, 2004, p. 20; Levin et al., 2013, p. 119)—combining new and old system elements in novel ways and incorporating the experiences (in AT terms, in the form of "expressive" components) into the system's memory.

While self-organization is a process, it can also be understood as an emergent, multi-causal, decentralized "force" (Bonta & Protevi, 2004, p. 88) that structures or governs the interactions of the system elements within their (temporary) basins of attraction. Thus, it creates the bonds between the heterogeneous elements of a social-ecological system.

In the (geographic) assemblage literature, in contrast, there is no clear conceptualization of self-organizing forces. Statements like "there is no single organizing principle behind assemblages" (Müller, 2015, p. 28) seem to dismiss any generalizing principles of how assemblage components interrelate or stick together. However, if there is no self-organizing force and agency is always distributed/distributive (Baker & McGuirk, 2017; Briassoulis, 2017b), what is the "glue" that holds assemblages together and guides their components' co-functioning? One concept central to Deleuze and Guattari's philosophy that may be helpful here is the concept of desire, which Müller and Schurr describe as "a positive, productive force—'a spontaneous emergence that generates relationship through a synthesis of multiplicities'" (Müller & Schurr, 2016, p. 224, citing Goodchild, 1996, p. 4). However, while desire is to be understood as a distributed property that may not be restricted to humans alone (Bonta & Protevi, 2004), its conceptual value for non-human assemblages can be questioned. The concept has a clear anthropocentric connotation, and as Müller and Schurr (2016, p. 224) argue, "it founders without humans and the human body." An emphasis on desire as a binding force can risk reintroducing an anthropocentric perspective into the investigation of social-ecological assemblages. Consider an agri-food system of fruit production, for instance: The desire of consumers for fresh fruit is literally a defining force in the emergence of the assemblage, but in what way does the term help explain the co-functioning of the manifold ecosystem elements involved (soil, climate, trees, pollinating bees, etc.)? A broader conception of self-organizational or "self-ordering" (Bonta & Protevi, 2004, p. 54) forces in assemblages may be more useful here. As demonstrated by Bonta and Protevi (2004), principles and terms from theories of self-organizing systems can be closely related to the conceptual tools offered by Deleuze and Guattari. Deleuze's conception of the

"virtual"—pointing to the multiple potentialities of a system or assemblage—can be understood as "the ontological equivalent of the state space of a system" defined by its potential "attractors" ("patterns of behavior of the system") and "bifurcators" ("points where systems flip between one region of state space and another"), among others (Bonta & Protevi, 2004, pp. 20, 25). Furthermore, the concepts of "deterritorialization" and "reterritorialization" by Deleuze and Guattari describe processes of bifurcation and somewhat resemble the above-mentioned phases of "collapse/creative destruction" and "reorganization/renewal." Here, Deleuze and Guattari offer some refinement through the distinction between two types of bifurcation: relative and absolute deterritorialization. The former describes a shift to a "pre-established pattern" (or attractor), while the latter involves the release of an "entire new set" of patterns and bifurcators (ibid., p. 20).

To conclude, assemblage approaches could benefit from a deeper engagement with the conceptualizations of self-organizing systems found both in the CAS literature and the writings of Deleuze and Guattari. Moreover, the latter may provide some useful new avenues for conceptual refinements in the CAS literature on processes of reorganization and renewal in social-ecological systems.

4 | CONCLUSIONS

Through this article we have suggested bringing together AT and CAS theory to identify a common ontological ground despite their differences in terms of terminology, methods, and research traditions. In doing so, we have identified a number of key principles in which both AT and CAS theories not only resemble similar viewpoints, but also offer potential to complement each other.

Both schools of thought share a similar understanding of emergence, nonlinearity, and historicity as defining processes of systems and assemblages, and they both accentuate relationality, looking primarily at the interrelations between assemblage/system components, rather than at the components themselves. These are key concepts that can be operationalized in a meaningful way for collaborative research involving CAS-inspired natural scientists (or physical geographers) and AT-informed social scientists (or human geographers). Moreover, both fields can learn from each other's disciplinary insights, in particular in relation to the environmental and human histories making up systems/assemblages.

However, there are potential points of conflict. First, in contrast to AT, the ontological standpoint of CAS on society-nature dualism is rather ambiguous: Notwithstanding claims made on the inseparability of society and nature (Berkes & Folke, 1998; Preiser et al., 2018), and an emphasis on general principles that pertain to all systems (Holling et al., 2002), "social systems" are often framed as if they exist independently from natural ecosystems and belong to a separate ontological domain. This implied "ontological separateness" (Head, 2017, p. 204) is not compatible with AT and needs to be overcome in order to make collaboration work. However, we believe that AT has much to offer to the CAS literature by providing more rigorous theorizations on social-natural entanglements, and that incorporating these ideas into CAS thinking would only enrich, rather than compromise, this strand of theory.

Second, CAS emphasizes principles of self-organization that appear to have little credence in current AT. However, the very concept of assemblage implies the existence of some sort of decentralized, emergent force generating relationships between heterogeneous elements; otherwise, the assemblage would cease to exist. While the AT concept of "desire" can be a helpful tool to investigate human–human and human–nonhuman relations, theorizations on self-organizing systems from the CAS literature and the writings of Deleuze and Guattari could provide some guidance to develop a more general understanding of self-organizing principles that also applies to relations between nonhuman elements. This way, a closer attention to the (temporary) function or roles of particular elements in the self-organization of a social-ecological assemblage can serve as a criterion for outlining the assemblage's (current) boundaries. A challenge for operationalizing AT for empirical research is the question of where to draw analytical boundaries without overlooking important elements (Spies, 2016), and the concept of self-organization could provide some useful guidance in this regard. Nevertheless, there is always a need to distinguish between systems/

assemblages as ontological entities or epistemological constructs shaped by research interests and methods (Friis & Nielsen, 2017). Here, both fields can learn from each other's experiences with different methodological constraints.

To conclude, we find that the ontological standpoints of assemblage thinking and theories of complex adaptive systems are mostly compatible, and there are various complementary aspects that could be usefully deployed in empirical research. There is significant and largely untapped potential for integrative social-ecological research that would benefit from a rich pool of conceptual tools and insights from two well-established strands of theory rooted in very different disciplines and research traditions.

ACKNOWLEDGEMENTS

The work for this article was funded by the German Federal Ministry of Education and Research in the frame of the junior research group TRANSECT—Agrarian Transformation and Social-Ecological Complexities (Grant Number 031B0753).

ORCID

Michael Spies https://orcid.org/0000-0002-4009-0544

ENDNOTE

[1]As one example in which such a conceptualization could enrich the study of a "history of becoming", DeLanda refers to the late work of French historian Fernand Braudel using the concept of "society as a sets of sets" ("The Wheels of Commerce"), rather than a totalized understanding of "the market" or "the state," to make sense of socio-economic development across the Mediterranean.

REFERENCES

Alff, H. (2020). Belts and roads every- and nowhere: Conceptualizing infrastructural corridorization in the Indian Ocean. *Environment and Planning C: Politics and Space. Special Issue on 'Politics and Spaces of China's Belt and Road Initiative'*, *Online first*, 21–25. https://doi.org/10.1177/2399654420911410

An, L. (2012). Modeling human decisions in coupled human and natural systems: Review of agent-based models. *Ecological Modelling*, *229*, 25–36. https://doi.org/10.1016/j.ecolmodel.2011.07.010

Anderson, B., Kearnes, M., McFarlane, C., & Swanton, D. (2012). On assemblages and geography. *Dialogues in Human Geography*, *2*(2), 171–189. https://doi.org/10.1177/2043820612449261

Anderson, B., & McFarlane, C. (2011). Assemblage and geography. *Area*, *43*(2), 124–127. https://doi.org/10.1111/j.1475-4762.2011.01004.x

Andrews, K., & Beck, J. (Eds.). (2017). *The Routledge handbook of philosophy of animal minds*, New York: Routledge.

Baker, T., & McGuirk, P. (2017). Assemblage thinking as methodology: Commitments and practices for critical policy research. *Territory, Politics, Governance*, *5*(4), 425–442. https://doi.org/10.1080/21622671.2016.1231631

Bennett, J. (2005). The agency of assemblages and the North American blackout. *Public Culture*, *17*(3), 445–466.

Bennett, J. (2010). *Vibrant matter: A political ecology of things*, Durham: Duke University Press.

Berkes, F., & Folke, C. (Eds.). (1998). *Linking social and ecological systems: Management practices and social mechanisms for building resilience*, Cambridge: Cambridge University Press.

Bittner, C., Glasze, G., & Turk, C. (2013). Tracing contingencies: Analyzing the political in assemblages of web 2.0 cartographies. *GeoJournal*, *78*(6), 935–948. https://doi.org/10.1007/s10708-013-9488-8

Blair, R. B., & Launer, A. E. (1997). Butterfly diversity and human land use: Species assemblages along an urban gradient. *Biological Conservation*, *80*(1), 113–125. https://doi.org/10.1016/S0006-3207(96)00056-0

Bonta, M., & Protevi, J. (2004). *Deleuze and Geophilosophy: A guide and glossary*, Edinburgh: Edinburgh University Press.

Briassoulis, H. (2017a). Response assemblages and their socioecological fit: Conceptualizing human responses to environmental degradation. *Dialogues in Human Geography*, *7*(2), 166–185. https://doi.org/10.1177/2043820617720079

Briassoulis, H. (2017b). Why I fell for assemblages: A response to comments. *Dialogues in Human Geography*, *7*(2), 212–220. https://doi.org/10.1177/2043820617720096

Brown, K. (2014). Global environmental change I: A social turn for resilience? *Progress in Human Geography*, *38*(1), 107–117. https://doi.org/10.1177/0309132513498837

Bryant, L. R. (2011). *The democracy of objects*, Ann Arbor: Open Humanities Press.

Buchanan, I. (2017). Assemblage theory, or, the future of an illusion. *Deleuze Studies*, *11*(3), 457–474. https://doi.org/10.3366/dls.2017.0276

Burnham, M., Ma, Z., & Zhang, B. (2016). Making sense of climate change: Hybrid epistemologies, socio-natural assemblages and smallholder knowledge. *Area*, *48*(1), 18–26. https://doi.org/10.1111/area.12150

Cannon, T., & Müller-Mahn, D. (2010). Vulnerability, resilience and development discourses in context of climate change. *Natural Hazards*, *55*(3), 621–635. https://doi.org/10.1007/s11069-010-9499-4

Chapura, M. (2009). Scale, causality, complexity and emergence: Rethinking scale's ontological significance. *Transactions of the Institute of British Geographers*, *34*(4), 462–474. https://doi.org/10.1111/j.1475-5661.2009.00356.x

Cilliers, P. (1998). *Complexity and postmodernism: Understanding complex systems*, London: Routledge.

Cote, M., & Nightingale, A. J. (2012). Resilience thinking meets social theory: Situating social change in socio-ecological systems (SES) research. *Progress in Human Geography*, *36*(4), 475–489. https://doi.org/10.1177/0309132511425708

de Roo, G., Hillier, J., & van Wezemael, J. (Eds.). (2016). *Complexity and planning: Systems, assemblages and simulations*, Oxon: Routledge.

DeLanda, M. (2006). A new philosophy of society: Assemblage theory and social complexity. *Continuum*. New York: Continuum.

DeLanda, M. (2016). *Assemblage theory*, Edinburgh: Edinburgh University Press.

Deleuze, G., & Guattari, F. (1987). *A thousand plateaus: Capitalism and schizophrenia (B. Massumi, Trans.)*, London: University of Minnesota Press.

Desjardins, E. (2011). Historicity and experimental evolution. *Biology and Philosophy*, *26*(3), 339–364. https://doi.org/10.1007/s10539-011-9256-4

Dittmer, J. (2014). Geopolitical assemblages and complexity. *Progress in Human Geography*, *38*(3), 385–401. https://doi.org/10.1177/0309132513501405

Dressler, W. H., Smith, W., & Montefrio, M. J. F. (2018). Ungovernable? The vital natures of swidden assemblages in an upland frontier. *Journal of Rural Studies*, *61*, 343–354. https://doi.org/10.1016/j.jrurstud.2017.12.007

Duit, A., & Galaz, V. (2008). Governance and complexity—Emerging issues for governance theory. *Governance*, *21*(3), 311–335. https://doi.org/10.1111/j.1468-0491.2008.00402.x

Dwiartama, A., Rosin, C., & Campbell, H. (2016). Understanding agri-food systems as assemblages: Worlds of rice in Indonesia. In R. L. Heron, H. Campbell, N. Lewis, & M. Carolan (Eds.), *Biological Economies: Experimentation and the politics of agri-food frontiers* (pp. 82–94). London: Routledge.

Egner, H., & von Elverfeldt, K. (2009). A bridge over troubled waters? Systems theory and dialogue in geography. *Area*, *41*(3), 319–328. https://doi.org/10.1111/j.1475-4762.2008.00874.x

Folke, C., Biggs, R., Norström, A. V., Reyers, B., & Rockström, J. (2016). Social-ecological resilience and biosphere-based sustainability science. *Ecology and Society*, *21*(3), 41. https://doi.org/10.5751/ES-08748-210341

Forney, J., Rosin, C., & Campbell, H. (Eds.). (2018). *Agri-environmental governance as an assemblage: Multiplicity, power, and transformation*, New York: Routledge.

Friis, C., & Nielsen, J. (2017). On the system. Boundary choices, implications, and solutions in telecoupling land use change research. *Sustainability*, *9*(6), 974. https://doi.org/10.3390/su9060974

Gengenbach, H., Schurman, R. A., Bassett, T. J., Munro, W. A., & Moseley, W. G. (2018). Limits of the New Green Revolution for Africa: Reconceptualising gendered agricultural value chains. *The Geographical Journal*, *184*(2), 208–214. https://doi.org/10.1111/geoj.12233

Glaser, M. (2012). Transdisciplinary multi-agent modelling for social-ecological systems analysis: Achievements and potentials. In M. Glaser, G. Krause, B. M. W. Ratter, & M. Welp (Eds.), *Human-nature interactions in the Anthropocene: Potentials of social-ecological systems analysis* (pp. 141–160). New York: Routledge.

Glaser, M., Ratter, B. M. W., Krause, G., & Welp, M. (2012). New approaches to the analysis of human–nature relations. In M. Glaser, G. Krause, B. M. W. Ratter, & M. Welp (Eds.), *Human-nature interactions in the Anthropocene: Potentials of social-ecological systems analysis* (pp. 3–12). New York: Routledge.

Goodchild, P. (1996). *Deleuze & Guattari: An introduction to the politics of desire*, London: Sage.

Gunderson, L. H., & Holling, C. S. (Eds.). (2002). *Panarchy: Understanding transformations in systems of humans and nature*, Washington, D.C.: Island Press.

Han, X., & Webber, M. (2020). From Chinese dam building in Africa to the Belt and Road Initiative: Assembling infrastructure projects and their linkages. *Political Geography*, *77*, 102102. https://doi.org/10.1016/j.polgeo.2019.102102

Harman, G. (2008). DeLanda's ontology: Assemblage and realism. *Continental Philosophy Review*, *41*(3), 367–383. https://doi.org/10.1007/s11007-008-9084-7

Harrison, S., Massey, D., & Richards, K. (2006). Complexity and emergence (another conversation). *Area*, *38*(4), 465–471. https://doi.org/10.1111/j.1475-4762.2006.00711.x

Hatt, K. (2013). Social attractors: A proposal to enhance "resilience thinking" about the social. *Society & Natural Resources*, *26*(1), 30–43. https://doi.org/10.1080/08941920.2012.695859

Head, L. (2017). Why stop at response? *Dialogues in Human Geography*, *7*(2), 203–206. https://doi.org/10.1177/2043820617720094

Holdschlag, A., & Ratter, B. M. W. (2016). Caribbean Island states in a social-ecological panarchy? Complexity theory, adaptability and environmental knowledge systems. *Anthropocene*, *13*, 80–93. https://doi.org/10.1016/j.ancene.2016.03.002

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

Holling, C. S. (2001). Understanding the complexity of economic, ecological, and social systems. *Ecosystems*, *4*(5), 390–405. https://doi.org/10.1007/s10021-001-0101-5

Holling, C. S., & Gunderson, L. H. (2002). Resilience and adaptive cycles. In L. H. Gunderson & C. S. Holling (Eds.), *Panarchy: Understanding transformations in human and natural systems* (pp. 25–62). Washington, D.C.: Island Press.

Holling, C. S., Gunderson, L. H., & Peterson, G. D. (2002). Sustainability and panarchies. In L. H. Gunderson & C. S. Holling (Eds.), *Panarchy: Understanding transformations in human and natural systems* (pp. 63–102). Washington, D.C.: Island Press.

Karrar, H. H., & Mostowlansky, T. (2018). Assembling marginality in northern Pakistan. *Political Geography*, *63*, 65–74. https://doi.org/10.1016/j.polgeo.2018.01.005

Kirchhoff, T., Brand, F. S., Hoheisel, D., & Grimm, V. (2010). The one-sidedness and cultural bias of the resilience approach. *Gaia-Ecological Perspectives for Science and Society*, *19*(1), 25–32.

Korhonen, J. J., Soininen, J., & Hillebrand, H. (2010). A quantitative analysis of temporal turnover in aquatic species assemblages across ecosystems. *Ecology*, *91*(2), 508–517. https://doi.org/10.1890/09-0392.1

Lade, S. J., & Peterson, G. D. (2019). Comment on "resilience of complex systems: State of the art and directions for future research". *Complexity*, *2019*, 1–4. https://doi.org/10.1155/2019/6343545

Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*, Cambridge: Harvard University Press.

Latour, B. (1993). *We have never been modern (C. Porter, Trans.)*, Cambridge: Harvard University Press.

Latour, B. (2005). *Reassembling the social: An introduction to actor-network-theory*, Oxford: Oxford University Press.

Lejano, R. P. (2017). Assemblage and relationality in social-ecological systems. *Dialogues in Human Geography*, *7*(2), 192–196. https://doi.org/10.1177/2043820617720093

Lejano, R. P. (2019). Relationality and social–ecological systems: Going beyond or behind sustainability and resilience. *Sustainability*, *11*(10), 2760. https://doi.org/10.3390/su11102760

Levin, S. A. (1999). *Fragile dominion: Complexity and the commons*, Reading: Perseus Books.

Levin, S. A., Xepapadeas, T., Crépin, A.-S., Norberg, J., de Zeeuw, A., Folke, C., … Walker, B. (2013). Social-ecological systems as complex adaptive systems: Modeling and policy implications. *Environment and Development Economics*, *18*(2), 111–132. https://doi.org/10.1017/S1355770X12000460

Liu, J., Dietz, T., Carpenter, S. R., Alberti, M., Folke, C., Moran, E., … Taylor, W. W. (2007). Complexity of coupled human and natural systems. *Science*, *317*(5844), 1513–1516. https://doi.org/10.1126/science.1144004

Lurz, R. W. (Ed.). (2009). *The philosophy of animal minds*, Cambridge: Cambridge University Press.

Manson, S., & O'Sullivan, D. (2006). Complexity theory in the study of space and place. *Environment and Planning A: Economy and Space*, *38*(4), 677–692. https://doi.org/10.1068/a37100

Manson, S. M. (2001). Simplifying complexity: A review of complexity theory. *Geoforum*, *32*(3), 405–414.

Marston, S. A., Jones, J. P., III, & Woodward, K. (2005). Human geography without scale. *Transactions of the Institute of British Geographers*, *30*(4), 416–432.

Mattissek, A., & Wiertz, T. (2014). Materialität und Macht im Spiegel der Assemblage-Theorie: Erkundungen am Beispiel der Waldpolitik in Thailand. *Geographica Helvetica*, *69*(3), 157–169. https://doi.org/10.5194/gh-69-157-2014

May, R. M. (1977). Thresholds and breakpoints in ecosystems with a multiplicity of stable states. *Nature*, *269*(5628), 471–477. https://doi.org/10.1038/269471a0

Müller, M. (2015). Assemblages and actor-networks: Rethinking socio-material power, politics and space. *Geography Compass*, *9*(1), 27–41. https://doi.org/10.1111/gec3.12192

Müller, M., & Schurr, C. (2016). Assemblage thinking and actor-network theory: Conjunctions, disjunctions, cross-fertilisations. *Transactions of the Institute of British Geographers*, *41*(3), 217–229. https://doi.org/10.1111/tran.12117

Murray Li, T. (2000). Articulating indigenous identity in Indonesia: Resource politics and the tribal slot. *Comparative Studies in Society and History*, *42*(1), 149–179.

Nel, A. (2018). Assembling value in carbon forestry: Practices of assemblage, overflows and counter-performativities in Ugandan carbon forestry. In J. Forney, C. Rosin, & H. Campbell (Eds.), *Agri-environmental Governance as an Assemblage: Multiplicity, Power, and Transformation* (pp. 117–136). New York: Routledge.

O'Sullivan, D. (2004). Complexity science and human geography. *Transactions of the Institute of British Geographers*, *29*(3), 282–295. https://doi.org/10.1111/j.0020-2754.2004.00321.x

Pickren, G. (2018). 'The global assemblage of digital flow': Critical data studies and the infrastructures of computing. *Progress in Human Geography*, *42*(2), 225–243. https://doi.org/10.1177/0309132516673241

Preiser, R., Biggs, R., De Vos, A., & Folke, C. (2018). Social-ecological systems as complex adaptive systems: Organizing principles for advancing research methods and approaches. *Ecology and Society*, *23*(4), 46. https://doi.org/10.5751/ES-10558-230446

Prigogine, I., & Nicolis, G. (1989). *Exploring complexity: An introduction*, New York: WH Freeman.
Ratter, B. M. W. (2012). Complexity and emergence: Key concepts in non-linear dynamic systems. In M. Glaser, G. Krause, B. M. W. Ratter, & M. Welp (Eds.), *Human-nature interactions in the Anthropocene: Potentials of social-ecological systems analysis* (pp. 90–104). New York: Routledge.
Robbins, P., & Marks, B. (2010). Assemblage geographies. In S. J. Smith, R. Pain, S. A. Marston, & J. P. Jones, III (Eds.), *The Sage handbook of social geographies* (pp. 176–194). London: Sage.
Sharp, E. L. (2018). (Re)assembling foodscapes with the Crowd Grown Feast. *Area*, *50*(2), 266–273. https://doi.org/10.1111/area.12376
Sheppard, E. (2008). Geographic dialectics? *Environment and Planning A: Economy and Space*, *40*(11), 2603–2612. https://doi.org/10.1068/a40270
Sohn, C. (2016). Navigating borders' multiplicity: The critical potential of assemblage. *Area*, *48*(2), 183–189. https://doi.org/10.1111/area.12248
Spies, M. (2016). Glacier thinning and adaptation assemblages in Nagar, northern Pakistan. *Erdkunde*, *70*(2), 125–140. https://doi.org/10.3112/erdkunde.2016.02.02
Tsing, A. (2015). *The mushroom at the end of the world: On the possibility of life in capitalist ruins*, Princeton: Princeton University Press.
Urry, J. (2005). The complexity turn. *Theory, Culture & Society*, *22*(5), 1–14. https://doi.org/10.1177/0263276405057188
Watts, M. J. (2015). Now and then. The origins of political ecology and the rebirth of adaptation as a form of thought. In T. Perreault, G. Bridge, & J. McCarthy (Eds.), *The Routledge Handbook of Political Ecology* (pp. 19–50). New York: Routledge.
Westley, F., Carpenter, S. R., Brock, W. A., Holling, C. S., & Gunderson, L. H. (2002). Why systems of people and nature are not just social and ecological systems. In L. H. Gunderson & C. S. Holling (Eds.), *Panarchy: Understanding transformations in human and natural systems* (pp. 103–119). Washington, D.C.: Island Press.
Westley, F., Tjornbo, O., Schultz, L., Olsson, P., Folke, C., Crona, B., & Bodin, Ö. (2013). A theory of transformative agency in linked social-ecological systems. *Ecology and Society*, *18*(3), 27. https://doi.org/10.5751/ES-05072-180327
Wright, D. H., & Reeves, J. H. (1992). On the meaning and measurement of nestedness of species assemblages. *Oecologia*, *92*(3), 416–428. https://doi.org/10.1007/BF00317469
Wu, J., & Loucks, O. L. (1995). From balance of nature to hierarchical patch dynamics: A paradigm shift in ecology. *The Quarterly Review of Biology*, *70*(4), 439–466. https://doi.org/10.1086/419172

AUTHOR BIOGRAPHIES

Michael Spies is head of the junior research group "TRANSECT—Agrarian Transformations and Social-Ecological Complexities. Local Bioeconomy Scenarios in Central and South Asia" at Eberswalde University for Sustainable Development, Germany. His research interests include theories of human-environmental relations, agrarian change and bioeconomy, and transboundary dimensions of farming systems in Central and South Asia. He holds a PhD in human geography from Freie Universität Berlin, Germany, where he employed an assemblage approach to investigate processes of agricultural change in northern Pakistan.

Henryk Alff is a senior research associate in the TRANSECT project at Eberswalde University for Sustainable Development, Germany. His research interests are in spatial theory, mobilities research as well as in agricultural and fisheries development research with a regional focus on Central Asia and coastal West Africa, respectively. He has an MA in human geography and doctoral degree in migration studies from the University of Potsdam.

How to cite this article: Spies M, Alff H. Assemblages and complex adaptive systems: A conceptual crossroads for integrative research? *Geography Compass*. 2020;14:e12534. https://doi.org/10.1111/gec3.12534