Sustainability of human–environment systems through the lens of landscape

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Sustainability is the theme of our time and has been widely studied by almost all disciplines (Kates et al. 2001; Bettencourt and Kaur 2011). In particular, landscape—the interface of human–environment interactions—provides a unique lens for studying sustainability dynamics of complex adaptive human–environment systems (Wu 2006, 2012; Naveh 2007; Turner 2010; Levin 2015). During the last decade, landscape sustainability science (LSS) (Wu 2013) has been developing into a vibrant research field (Musacchio 2009, 2013; Pearson and McAlpine 2010; Zhou et al. 2019). In recent years, particularly, a growing research community of diverse backgrounds has been making notable efforts to further advance LSS (e.g., Opdam et al. 2018; Frazier et al. 2019; Liao et al. 2020b). To give a timely introduction of such ongoing progress and to inspire critical dialogues within the community, this special issue of *Landscape Ecology*

brings together a suite of review, perspective, and research papers. The 15 papers are drawn from contributions to the 7th Landscape Sustainability Science Forum (July 12th–16th, 2019 in Xining, China) and the 1st Young Scholars Symposium on Sustainability Science with the theme “Geography, Landscape, and Sustainability” (June 3rd, 2019 in Changchun, China), supplemented by additional invited submissions. These papers reflect some recent exciting developments of LSS, including theoretical perspectives, methodological toolkits, and place-based studies.

Topics of the special issue

The special issue starts with three review papers. Xie et al. (2020) put LSS in a broader context of sustainability studies of landscapes/land systems that include research efforts from disciplines other than Landscape Ecology (e.g., land system science). They conduct a bibliometric review of 1104 research articles published during January 1, 1990 to May 10, 2019, by query-based searches in paper titles in Web of Science Core Collection. Their results show that sustainability studies of landscapes/land systems have gained special momentum since 2013, among which papers employing the term “landscape sustainability” experienced the fastest growth in number. The authors

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highlight the need of moving beyond bibliometric reviews toward more in-depth reviews by innovative methods, and the necessity of conducting more focused reviews about sustainability of specific landscapes. The second review paper, by Zhang et al. (2020), quantitatively assesses the state-of-the-art of the ecological and sustainability research of the Inner Mongolian Grassland region, highlighting three different perspectives—ecology in the grassland, ecology of the grassland, and sustainability of the grassland. The authors further propose a research framework tailored for this region by modifying Wu's LSS framework of "landscape pattern-ecosystem services-human wellbeing" (Wu 2013), so as to better understand the functioning of grassland socio-ecological systems across scales for identifying sustainability pathways. The third review paper by Liao et al. (2020a) employs a more traditional, qualitative approach to synthesize the relevant social-ecological literature on global drylands, which occupy 41% of the global terrestrial surface. The authors examine the patterns of rangeland vegetation dynamics and livelihood transformations through the lens of pastoralist mobility, and find a general trend of declining mobility associated with livelihood intensification and diversification, which can have significant implications for dryland sustainability, especially for informing policy-making to better reconcile concerns on food security and environmental conservation across global drylands. Together these three review papers demonstrate the promise of LSS, and enrich its repertoire of place-based and system-specific studies.

The next section of this issue presents four empirical studies for advancing landscape sustainability in the context of urbanization—one of the major long-term global trends that have fundamental impacts on sustainability at local, regional, and global scales (Kates and Parris 2003). Specifically, Jia et al. (2020) quantify the patterns and drivers of landscape urbanization in Chongqing City (1990–2015), a major montane metropolis of China. They find that the landscape urbanization patterns of Chongqing differed from those of flat regions, and that Chongqing's landscape urbanization drivers evolved from more demography-driven to more economy-driven. Accordingly, they propose a conceptual framework that integrates LSS and GeoDesign (see Huang et al. 2019; Wu 2019 for similar efforts) to facilitate sustainable landscape planning for montane cities. The studies by

Zhou and Lv (2020) and Hu et al. (2020) adopt a problem-driven, diagnostic approach (as so advocated in Zhou et al. 2019) to examine a worldwide landscape sustainability challenge that is commonly associated with urbanization: farmland loss. By comparatively examining different types of farmland loss and associated socioeconomic and agri-food dynamics in a core-periphery system in China, Zhou and Lv (2020) question the popular problem framing that urban sprawl onto farmland threatens food security. They contend that focusing on urban containment for farmland preservation is often insufficient and that instead, policy efforts are needed to address the real problem of social injustice in existing mandatory farmland preservation practices. Hu et al. (2020) focus on the quantity and quality of the farmland lost to urban development in 370 different-sized cities of China, and find that, contrary to the common belief, urban growth of larger cities actually consumed a smaller quantity of farmland of lower quality than smaller cities did when accommodating the same amount of urban population. Thus, the authors argue that prioritizing urban development of smaller cities instead of larger cities in the name of food security may pose double challenges to both farmland protection and economic growth. The fourth paper in this section by Zimmer et al. (2020) reports on the spatiotemporal dynamics and potential drivers of population growth in the secondary cities across Southern Africa between 1975 and 2015. Their results highlight the importance of studying not just primary cities but also secondary ones, which can have distinct implications for sustainable urbanization and landscape sustainability.

The issue continues with five papers which present useful methods or methodological advancements for landscape sustainability studies. Xiao et al. (2020) propose an evaluation framework by integrating ecosystem services and ecological sensitivity indicators to identify key landscape patches for constructing conservation networks, which is applied to a case study of Jiangsu Province of China. Duarte et al. (2020) propose a user-inspired framework and an associated tool for integrating stakeholders and scientific knowledge of landscape services for restoring multifunctional landscapes. Their approach reflects the trend of increasing transdisciplinarity (emphasizing stakeholder engagements and participatory landscape planning, etc.) in LSS (Zhou et al. 2019).

Cebrián-Piqueras et al. (2020) conduct a survey-based case study that reveals how residents' ecological knowledge systems, comprised of both local and scientific, mediated the relationship between their characteristics and landscape sustainability. They adopt a comprehensive methodological design that combines bi- and multi-variate analysis, partial least squares path modeling, and principal component analysis and redundancy analysis of respondent characteristics, ecological knowledge, and landscape perceptions—their measurements of local and scientific knowledge should be particularly useful for similar studies that aim to link knowledge with action. The study by Qiu et al. (2020) uses linear mixed effects models and variance partitioning to tease out the variability of ecosystem services among “space” and “time” components. Aside from the different implications for sustainably managing urban- and rural-dominated landscapes, the paper's methodology can be readily used to design place-based, adaptive policies for sustaining ecosystem services of heterogeneous landscapes. Liu et al. (2020) design seventeen 3-D spatial metrics that can be calculated with GIS at patch-, class-, and landscape-levels using building footprints and height information. With growing 3-D datasets, the introduced metrics are expected to be increasingly useful for quantifying spatial patterns and characterizing vertical features in landscape sustainability research and practices.

This issue ends with three different perspective papers for advancing LSS. Resonating with earlier efforts for embracing the socio-cultural dimension of landscape sustainability (Musacchio 2009; Wu 2011; Zhou et al. 2019), Riechers et al. (2020) argue for connecting work on relational values and insights from Landscape Ecology to enrich the theoretical framing of LSS, and apply this perspective to examine place-variant interconnections between ecological and social changes that are associated with the global trend of landscape simplification for industrial agriculture. Using the analytical concept of relational values, this perspective opens space for new types of landscape analysis that simultaneously scrutinizes interconnected ecological, social and economic dynamics in changing landscapes. To advance the socio-institutional dimension of landscape sustainability, Cumming and Epstein (2020) argue for integrating an institutional perspective with insights from Landscape Ecology to better understand the spatial dynamics of

the interplay between institutions and landscape heterogeneity. They highlight three central themes in understanding landscape sustainability through an institutional perspective and identify four emerging frontiers for future landscape sustainability research. Echoing earlier calls for embracing transdisciplinarity for advancing landscape sustainability (Wu 2006; Naveh 2007; Nassauer and Opdam 2008; Opdam et al. 2018; Zhou et al. 2019), Opdam (2020) combines a theory of knowledge management with a theory of behavioral change to construct a transdisciplinary framework of four phases to facilitate the collective action between landscape scientists and non-academic stakeholders. Opdam emphasizes that knowledge from social sciences is indispensable for Landscape Ecology to play a greater role in developing sustainable landscapes.

Closing remarks

The 15 papers in this special issue represent a sample of ongoing research of LSS. To some extent, these papers demonstrate how LSS has expanded its conceptual and theoretical bases, methodological foundations, and application domain since its emergence around 2013 (Wu 2013; Zhou et al. 2019). The papers also point to the development of LSS as converging toward a transdisciplinary landscape science at the intersection of Landscape Ecology, land system science, and sustainability science (Zhou et al. 2019; Zhou 2020). Unified by the landscape lens for examining and intervening the sustainability dynamics of human–environment systems (Wu 2013), this special issue can hopefully inspire more studies to further advance LSS and promote sustainability transitions. In particular, we propose the following research priorities:

- New theoretical insights from Landscape Ecology, land system science, sustainability science, and other disciplines need to be embraced for comprehensively assessing the complex adaptive relationships between landscape patterns, ecosystem services, and human well-being across different scales.
- Relevant methodological advancements in other research fields, such as big data, machine learning, agent-based modeling, and participatory

envisioning, need to be used for better characterizing multidimensional spatial heterogeneity of different landscapes, exploring nonlinear feedbacks underlying coupled human–environment landscapes, and co-producing generalizable and actionable knowledge.

- Emerging landscape sustainability challenges associated with climate change, agricultural intensification, and other long-term, global trends need to be addressed through a large number of place-based case studies and subsequent meta-synthesis, which is essential for linking local actions to regional and global sustainability.

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