# Urban land teleconnections and sustainability

Karen C. Seto[a,1], Anette Reenberg[b], Christopher G. Boone[c], Michail Fragkias[d], Dagmar Haase[e], Tobias Langanke[f,2], Peter Marcotullio[g], Darla K. Munroe[h], Branislav Olah[i,j], and David Simon[k]

[a]Yale School of Forestry and Environmental Studies, Yale University, New Haven, CT 06511; [b]Department of Geography and Geology, University of Copenhagen, 1350 Copenhagen, Denmark; [c]School of Sustainability, and [d]International Human Dimensions Programme on Global Environmental Change Urbanization and Global Environmental Change Project, Arizona State University, Tempe, AZ 85287; [e]Department of Geography, Humboldt University and Helmholtz Centre for Environmental Science, 12489 Berlin, Germany; [f]International Human Dimensions Programme on Global Environmental Change/ International Geosphere-Biosphere Programme Global Land Project, University of Copenhagen, 1350 Copenhagen, Denmark; [g]Department of Geography, Hunter College, New York, NY 10065; [h]Department of Geography, Ohio State University, Columbus, OH 43210; [i]European Environment Agency, 1050 Copenhagen, Denmark; [j]Department of Applied Ecology, Technical University in Zvolen, 96053 Zvolen, Slovak Republic; and [k]Department of Geography, Royal Holloway, University of London, Surrey TW20 0EX, United Kingdom

Edited by Susan Hanson, Clark University, Worcester, MA, and approved April 4, 2012 (received for review October 25, 2011)

**This paper introduces urban land teleconnections as a conceptual framework that explicitly links land changes to underlying urbanization dynamics. We illustrate how three key themes that are currently addressed separately in the urban sustainability and land change literatures can lead to incorrect conclusions and misleading results when they are not examined jointly: the traditional system of land classification that is based on discrete categories and reinforces the false idea of a rural–urban dichotomy; the spatial quantification of land change that is based on place-based relationships, ignoring the connections between distant places, especially between urban functions and rural land uses; and the implicit assumptions about path dependency and sequential land changes that underlie current conceptualizations of land transitions. We then examine several environmental "grand challenges" and discuss how urban land teleconnections could help research communities frame scientific inquiries. Finally, we point to existing analytical approaches that can be used to advance development and application of the concept.**

coupled human–natural systems | land change science

Urbanization and land change are two global processes with far-reaching consequences. Although the two are tightly intertwined, their literatures and analytical frameworks were largely developed separately. We argue that these parallel but distinct conceptualizations limit progress in these fields and in sustainability science, specifically given the environmental impacts of urbanization on the land system, and associated social and political challenges. The magnitude and accelerating rate of contemporary urbanization are reshaping land use locally and globally in ways that require a reexamination of land change and urban sustainability. Worldwide, urban populations are projected to increase by almost 3 billion by 2050 (1) and the total global urban land area by more than 1.5 million square kilometers—an area three times the size of Spain—by 2030 (2). Urban economies currently generate more than 90% of global gross value added, meaning few rural systems are unaffected by urbanization (3). Given such trends, we must reconsider how we conceptualize the many connections and feedbacks between urbanization and land change processes. To date, a large body of literature has considered the proximate land changes brought about by urbanization, but the more distant land-use implications of urbanization remain underexamined.

In climate science, the concept of teleconnections refers to climate anomalies that correlate over large geographic distances. During warm phases of the Atlantic multidecadal oscillation, for instance, the incidence of synchronous wildfires increases in the western United States (4). The virtual shrinking of distances between places, strengthening connectivity between distant locations, and growing separation between places of consumption and production are emerging topics in "telecoupled" human–natural systems (5–7) and tropical teleconnections of deforestation (8). We introduce the concept of urban land teleconnections to refer to the distal flows and connections of people, economic goods and services, and land use change processes that drive and respond to urbanization. Thus, urban sustainability and land change studies cannot focus solely on a place of fixed geographical locations, but should examine the complex set of dynamic processes that link distant and sometimes multiple locations—longstanding themes in the urban literature (9, 10). The concept of urban land teleconnections therefore breaks away from a placed-based conceptualization of urban sustainability and land, and instead emphasizes a process-based conceptualization along a continuum of land systems (Fig. 1). By jointly conceptualizing land and urban processes, the framework provides more opportunity to identify the leverage points to intervene in complex global land and urban systems.

A process-based conceptualization of urban sustainability and land serves a secondary goal: urban land teleconnections provide a means to investigate and challenge equity principles of sustainability. There is a growing consensus that achieving sustainability and associated desirable futures will be an ongoing process rather than an end state, one that considers fairness of tradeoffs at multiple spatial and temporal scales (11). Fairness in decision-making, recognition of constituents, and stakeholder participation are forms of justice critical for sustainable futures (12). In an increasingly urban world, characterized by global flows of commodities, capital, and people, where land that provides goods and ecosystems services for people is becoming more segregated from the space of habitation, teleconnections captures links between distant processes and places, and can be used to explore consequences of urbanization and land changes at great distances from points of origin that would otherwise go unrecognized. Because explicit examination of urban teleconnections calls attention to linked processes that lie beyond the immediate geographical scope of urbanization or land change, it enables broader normative assessment of these processes.

The purpose of this paper is to introduce a conceptual framework that explicitly links land change to underlying urbanization dynamics. Such a conceptualization of urban-land linkages could lead to improved understanding and new discoveries of contemporary urbanization and land change. We begin by illustrating how three key themes that are typically addressed separately in the urban sustainability and land change literatures can lead to incorrect conclusions and misleading results when they are not examined jointly: (*i*) the traditional system of land categorization that is based on discrete classes and reinforces the false idea of a rural–urban dichotomy; (*ii*) the spatial treatment of urbanization and land change that is founded on place-based

SUSTAINABILITY SCIENCE

Author contributions: K.C.S., A.R., C.G.B., M.F., D.H., T.L., P.M., D.K.M., B.O., and D.S. designed research; K.C.S., A.R., C.G.B., M.F., D.H., T.L., P.M., D.K.M., B.O., and D.S. performed research; K.C.S., A.R., C.G.B., M.F., D.H., T.L., P.M., D.K.M., B.O., and D.S. contributed new reagents/analytic tools; K.C.S., A.R., C.G.B., M.F., D.H., T.L., P.M., D.K.M., B.O., and D.S. analyzed data; and K.C.S., A.R., C.G.B., M.F., D.H., T.L., P.M., D.K.M., B.O., and D.S. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

[1]To whom correspondence should be addressed. E-mail: karen.seto@yale.edu.

[2]Present address: European Environment Agency, 1050 Copenhagen, Denmark.

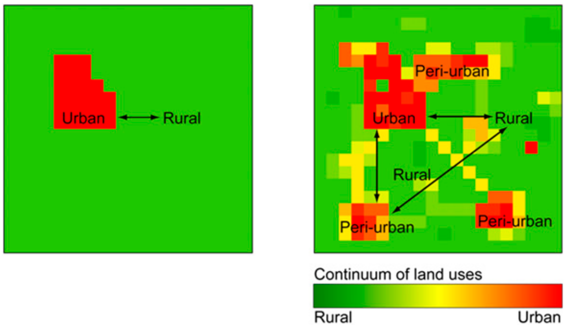


**Fig. 1.** Place-based vs. process-based conceptualizations of land.

relationships and ignores the distant connection between places, especially between urban functions and rural land uses; and (*iii*) the implicit assumptions about path dependency and sequential land changes that underlie current conceptualizations of land transitions (Table 1). Next, we present the concept of urban land teleconnections and its treatment of these key themes. We then take several key "grand challenges for earth system science for global sustainability" and "strategic directions in geographical sciences" identified by the International Council for Science, the International Social Science Council, and the US National Research Council, and indicate how urban land teleconnections could help research communities reframe scientific inquiries (13, 14). Finally, we point to existing analytical approaches that could be used to advance development and application of the concept.

## Current Conceptualizations of Urbanization and Land

**Land Classification Systems.** The conventional system of grouping and categorizing land uses a single scale, with the extremes being urban and wilderness. These categories are parcelized into discrete units, such that each patch of land is assigned to a single category. By labeling each land unit into a single class, we obtain total estimates of land by summing up regional values, aggregating or masking geographical relationships. Land is then enumerated by its total area (e.g., 5,000 $km^2$ of agricultural land in country X). Under this system, differences in land quality, land use intensity, and the functional characteristics of land—such as urban functions located in rural environments but which serve distant places—are ignored.

This system serves fundamentally to place urbanization at odds with sustainability in three ways. The first fallacy of this conceptualization and consequent land accounting system is that land is perfectly substitutable and geographically replaceable (e.g., 1 $km^2$ of agricultural land in country X is equal to 1 $km^2$ of agricultural land in country Y). The second misleading notion that arises from this classification scheme is that land can be unambiguously delineated into discrete, bounded entities. Under this conceptualization, rural land uses do not coexist on the same patch with urban functions. Hence, the fact that urban areas can and do support diverse ecosystems and even agriculture is disregarded (15, 16). As such, urban areas need to be limited in their extent so as to "save land for nature." The third fallacy is the implied human–nature duality, which suggests that land allocated for different activities is distributed in a geographically disconnected way, whereby activities to meet human needs are disconnected from activities to protect nature. By definition, because urban is human-dominated, urban areas "appropriate" natural ecosystems, ecosystem services, and natural capital. By this logic, urban cannot be natural capital. However, such a conceptualization contradicts underlying principles of urban ecology as well as sustainability.

**Table 1. Common conceptualizations of urban sustainability and land vs. urban land teleconnections**

| Theme | Current conceptualizations | Urban land teleconnections |
|---|---|---|
| Land classification | Discrete | Continuous |
| Spatiality | Place-based relationships | Distal relationships |
| Temporality | Successive, predetermined sequence | Leapfrogging, simultaneous and multidirectional change |

**Place-Based Definitions.** In land change science, urbanization and land are predominantly described as a place or as bounded geographical areas. This contrasts with other literatures that argue that places have multiple identities and are networked through social processes (10, 17). Placed-based conceptualizations of land use assume sharp and distinguishable boundaries between urban and nonurban. They do not permit multiple classifications of the same physical space. Moreover, place-based conceptualizations assume spatial units as fixed containers of uniform characteristics (18). For example, urban areas are monolithic units that can vary by size, but typically react uniformly to similar influences (19). This simplistic conception is caused—or at least perpetuated—by the use of categorical maps and land classification schemes that produce discrete polygons in which spatial heterogeneity within an area is ignored and internal homogeneity is assumed. For example, categorical maps are typically produced by aggregating individual pixels into polygons by using the value of the most common occurring pixel (20).

The place-based conceptualization enforces the idea that urban sustainability requires urban self-sufficiency. Sustainability efforts are prone to localism (21, 22). Clearly, social and ecological benefits accrue from use of local resources and ecosystems. However, decisions and behaviors that are local or even regional in scope do not account for critical consequences of teleconnections, which may undermine sustainability efforts at great distances or influence the overall sustainability for the entire system. Eating locally might undermine livelihoods of distant farmers who may be using less energy-intensive methods to produce food than local growers (23). Put another way, sustainability initiatives often focus on the importance of place while ignoring the processes of urbanization that may have far-reaching effects on distant places and people. These processes can generate uneven and undesirable outcomes that may be undetected when focusing solely on place.

The place-based conceptualization also produces false clusters of presumably similar types of cities linked by geography rather than by process and tend to emphasize systematic differences in the experience of the Global North from the experience in the Global South. However, in classifying cities along dimensions of North and South, we run the risk of overemphasizing the difference or specificity of either (24). Simplistic and "watertight" categories of North–South or similar characterizations including the aspect of change and development pathways, especially with regard to urbanization, limit our ability to understand underlying processes and their driving forces. These categories are conceptually limiting because they can homogenize significantly different places such as São Paulo, Shanghai, Bangalore, and Lagos, and hence produce false analogues that hamper understanding. The same holds true for European cities that are veering away from the prevailing picture of the compact city (25), with some becoming more dispersed while others shrink (26).

**Land Transitions.** What are the concrete spatial and material manifestations of urban change? The concept of land transitions, which has recently become prominent in the land change literature (27), is based on classical land intensification theory (28). The land transition concept envisages a unidirectional process of intensification in land systems in response to locally driven increased demands for land-based products and services. Implicitly, this compelling sketch of land changes assumes that resources are delivered by a finite, constantly and confined land surface, and that intensification pathways are given. The embedded perception is that the land change processes in a given (i.e., delimited) territory are driven by the increased demand located in the same territory. Hence, over time, land use will change from natural habitat through a sequence of initial forest clearings by small-scale peasants, who then practice intensive agriculture and gradually build up land or new recreational landscapes created to serve the demands of increasingly urban populations on the one hand and industrialized commercial agriculture on the other. Although types of land transitions differ significantly—forest to agriculture, agriculture to urban, agricultural intensification—the literature uses the lens from one type of land transition to examine all land transitions.

The concept of land use transitions may provide insight into pathways of land change that capture cross-scale processes, such as how macrostructural factors affect microagency and land use decisions (29, 30). However, the issue of spatial scale remains a huge challenge. Explanations for processes vary importantly by the spatial scale at which they are studied, and the spatial reach of land transformations driven by human action has accelerated with contemporary globalization (7). Thus, the land transitions framework can result in focusing on the local at the expense of assuming the macrostructural variables as given (31).

The land transition framework also depicts significant land changes as linear. This notion ignores the possibility that transitions occur in a punctuated, discontinuous, chaotic fashion. The related concepts of pathways and trajectories of land change hypothesize that there are a number of generalizable patterns of change that result from recurrent interaction between driving forces, following specific sequences of events. Even though, at the detailed level, these sequences may play out differently in specific situations, their identification might confer some predictive power by analogy with similar pathways in comparable regional and historical contexts. Hence, land transitions are often understood to be temporally and spatially universal: a transition of land use during one phase in time at a particular place will repeat itself during different historical periods and in a completely different geographic location. Although not always explicit, a common assumption is that land transitions in Europe and North America can help understand future trends in Asia, South America, and Africa. Such assumptions disregard the realities that cultural differences influence conceptions, codifications, and uses of space and land, and that use of distant land to meet demand for local populations can significantly alter the pathways of change. As a result, there is no universal or linear transition process; phases identified in one context can be shortened, prolonged, overlapped, or even omitted or transgressed elsewhere.

## Urban Land Teleconnections

Urban land teleconnections is a process-based conceptualization that intertwines land use and urbanization by linking places through their processes (Fig. 2). It answers a need to improve on classical theories by capturing changes in nonurban places that affect urban places, and vice versa. One of the primary underpinnings of urban land teleconnections is that contemporary urbanization and globalization processes make the identification of distinct urban versus hinterland areas nearly impossible (31). The economic complexities and dynamic interrelations among local, regional, and global processes and commodity flows mean that there are important linkages between urban areas and nonurban places (32), which in turn have land use implications. Transboundary and nonlocal impacts on land from urbanization can occur in multiple and distant locations. Conversely, urbanization processes in multiple locations can drive land change in one place, because numerous cities can simultaneously draw on resources in the same setting, such as rare earth elements that are geographically limited to a few locations. In turn, such conceptualizations open the possibility of sustainable interventions to achieve desirable, plausible futures. Intervening in the

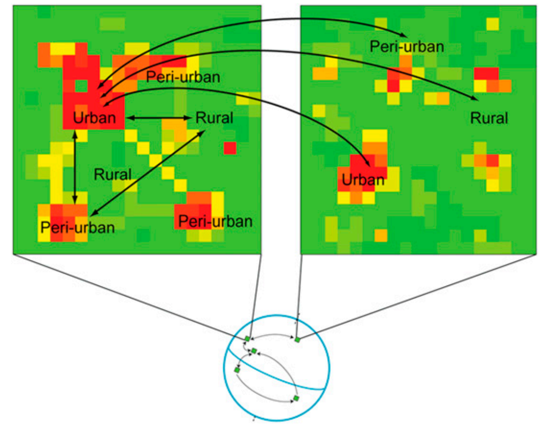


**Fig. 2.** Urban land teleconnections.

processes that create teleconnections is likely to have much broader and longer-lasting effects on global sustainability than focusing on the outcomes of a single place. In this regard, urban land teleconnections differs from concepts such as the ecological footprint because it accounts explicitly for interrelations between specific parcels of land rather than a general "global hinterland" (33). It relates consequences to particular places and hence highlights processes between actual locations.

We hypothesize that four major types of urban land teleconnections exist (Fig. 3). The first type of teleconnection (Fig. 3, *1*) occurs when decisions in multiple urban places (e.g., manufacturing demand for mobile phone production) lead to land change in a limited number of distal sites (e.g., coltan mining in the Congo). The second type of teleconnection (Fig. 3, *2*) occurs when processes within a single urban place (e.g., one city's switch to hydropower) lead to land change in many distal areas (e.g., flooding in multiple upstream communities). A third type of teleconnection (Fig. 3, *3*) occurs when urbanization processes in a single place (e.g., increase in urban population) leads to land change in one or more urban or periurban regions (e.g., land conversion for residential development). Last, a fourth major type (Fig. 3, *4*) is when urbanization processes in multiple locations (e.g., increase urban demand for energy) lead to multiple land impacts in distal and nearby places (e.g., $CO_2$ uptake, appropriation of ecosystem services).

**Theoretical Legacies for Urban Land Teleconnections.** Urban land teleconnections imply that flows between places cannot be explained and modeled empirically without a larger theoretical framework. The concept of urban land teleconnections builds on elements from disparate but allied fields, including theoretical literature on urban systems, commodity and production value chains, and agglomeration economies. Urban systems are typically conceptualized as networks of nodes (cities or metropolitan areas) and linkages (flows of people, goods and services). Several

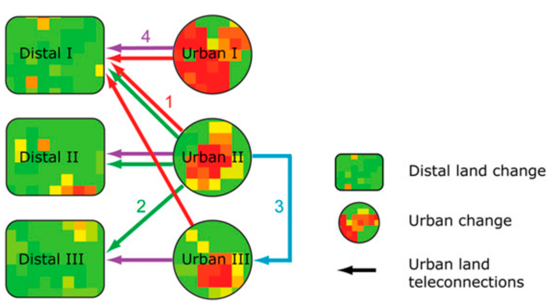


**Fig. 3.** Four major types of urban land teleconnections.

SUSTAINABILITY SCIENCE

streams of inquiry have emerged to understand urban patterns and their underlying processes, and flows through the links that integrate the urban nodes of city networks or systems: innovation diffusion theory (34), central place theory (35), and complex adaptive urban systems (36). The concepts of influence over large distances and networked urban processes have been in the urban and geographic literature for decades (9, 37–39), but have not been incorporated explicitly into land change or urban sustainability research.

By focusing on how processes of urban competition and urban interdependence simultaneously shape urban settlement patterns, central place theory aims to explain hierarchical urban systems and the "sphere of influence" of urban places. Extensions of these models add a temporal dimension (40, 41), but to date have not been incorporated in sustainability studies. Similarly, the literature on complex systems informs our understanding of hierarchical urbanization dynamics. Complex systems are comprised of a set of heterogeneous agents with interdependent behaviors that can be described as a stochastic process (42). Although urban and regional analysis has deep foundations in complex spatial systems theory, including emphases on relationally networked societies and systems of cities (43–45), relatively few land change studies have begun to explore complexity in explaining land change patterns—and especially in the context of teleconnections—but without incorporating its empirical implications (46). A contribution of complex systems thinking for urban land teleconnections is the central position of feedback loops, nonlinearities, and emergent phenomena. Regional and historical explanations for the growth and change of urban systems are based on the idea that the configuration of urban space as a path dependent process reflects past decisions and actions as well as a manifestation of today's socioeconomic and political interactions.

Urban land teleconnections also builds on elements of world city systems theories, namely the emphasis on flows of goods and services across scales within a global urban network comprising core and peripheral places (43). At the same time, the urban land teleconnections concept goes beyond world city systems theories in two critical ways. First, it includes connections of urban to nonurban places. Second, it includes noneconomic valued goods and services. In these respects, it shares much with urban metabolism, or urban material and energy flows accounting studies (47). Although the urban metabolism framework has been useful in identifying the amount and types of material and energy flows through a city, it typically treats urban centers as "black boxes." The concept of urban land teleconnections embraces the larger flows of energy and materials examined in urban metabolisms studies. At the same time, teleconnections attempts to move away from the input/output black box approach. It does so by focusing more on processes, including all contributing factors that occur within these different spaces and that influence flows.

Finally, urban land teleconnections shares some commonalities with the literature on value chains (48), commodity chains (49), and global production networks (50). Although research in these fields has mapped the complexity of the global economy, it tends to neglect the land use implications and the institutional context within which goods are created and traded (51), and overemphasizes the linear nature of commodity chains (52). In summary, the concept of urban land teleconnections builds on a wide body of theoretical work on urban systems, land use, and commodity chains to examine the connections between urban processes and land change and the implications of these connections for sustainability.

**Land Systems, Distal Connections: A Processed-Based Continuum.** As an alternative to attributes of discrete, bounded spatial entities, many of the processes and structures that represent urban (and nonurban) land uses can be represented as continuous fields. Adopting this conceptual framework makes new land forms that do not conform to a fixed rural/urban dichotomy more obvious and understandable. This conceptual framework is based on spatial variability of land systems along a continuum (Fig. 1). The periurban interface refers to spatially and structurally dynamic transition zones where land use, populations, and activities are neither fully urban nor rural (53). Periurban areas are dynamic zones of often rapid transition from typically rural to urban, with a shifting mix of respective land uses and other activities. In many cases, the range of activities is particularly diverse for this reason; some are distinctive to the periurban interface. The geography of the zones is constantly changing so that a spatial fixation, as in static boundaries between zones, is of little value (54). Although it is often assumed that populations and economic activities can be sharply divided between urban (i.e., industrial) and rural (i.e., agricultural), periurban households can be multispatial, with some family members living in rural areas but not used in agricultural activities and others living in urban areas but engaged in agriculture. As such, peri-urban areas are hybrid landscapes, economies, and livelihoods. Periurbanization refers to both a place and a process, not just regions in the periphery of existing urban areas. One goal of examining periurbanization through the lens of teleconnections is a better understanding and recognition of new urban forms as they develop.

**Reconceptualizing Teleconnected Land Transitions: Leapfrogging and Simultaneous and Multidirectional Change.** In a highly interconnected world, the successive sequence of land use and land cover change implicit in the land transition framework may not unfold in a linear fashion across the world. As such, the value of the land transition conceptual framework as an analogue will become increasingly limited. The spatial disconnection of the drivers of land use change and the land change process itself creates situations of "spatial leapfrogging." In certain places, it is realistic to expect that land change processes follow a nonsuccessive sequence that bypasses one or several intermediate stages in the classical transition sequence, because local pressure on land is changing rapidly and alleviated through use of land in distant places (55, 56).

The urban land teleconnections framework can help focus analytical attention to the linkages among land uses over large geographical distances that are driven by urban processes through different types of inquiry. For example, the "footloose" nature of feed-crop and industrial livestock production is well documented (57). However, the urban land teleconnections framework goes beyond identifying the linkages between Chinese pork demand and land conversion for soybean production in the Brazilian cerrado. It requires different types of questions to identify the site-specific spatial and temporal pathways through which actions and decisions in urban areas drive land change in distal rural or periurban areas, and vice versa. These pathways could include flows of capital, information, people, goods, materials, energy, and services that connect distal places. For example, what are the pathways through which urban pork demand drives land conversion in the cerrado (e.g., price signals, policies, in-migration)? How does the outsourcing of pork and feed production to areas beyond the immediate urban environs reduce pressure on local farmland and enable additional local urban growth?

The teleconnections framework emphasizes at least three key aspects of these linkages, often overlooked but crucial to sustainability. First, rural land changes may be driven by distal urbanization processes. Prior aggregate land change studies have identified critical underlying drivers, but have not connected them to specific urban processes, except in such vague terms as "globalization." Second, the teleconnections framework emphasizes decisions, actions, and land changes at both urban and rural ends of the pathway, i.e., the spatial and temporal structure of land change through production, consumption, disposal, and the intermediate stages of manufacturing and adding value. Third, the normative implications of urban sustainability, the effects of land changes in urban and rural systems on well-being and equity, become more explicit.

## Research Agenda for Moving Forward

**Grand Challenges in Geographical and Global Sustainability Sciences and Potential Insights Gained from an Urban Land Teleconnections Approach.** What insights can we gain from using an urban land teleconnections framework? Recent, forward-looking science policy discussions have proposed a series of pressing questions to guide future research efforts in the broad field of global change and sustainability. Here we take a few of the key grand challenge questions identified by International Council for Science, the International Social Science Council, and the US National Research Council, and illustrate how urban land teleconnections can deepen our understanding of a changing planet. Use of the teleconnections perspective could help reorient the types of analysis undertaken and create new knowledge about how humankind is reshaping our planet and the sustainability implications of our decisions (Table 2).

**Methods and Analytical Tools.** Urban land teleconnections is a conceptual framework for classifying and organizing land change related to urban processes. An important point is that urban land teleconnections is not a large-scale empirical model intended to capture all the complexities of the real-world system. Rather, we argue that adopting this conceptual lens will require a rethinking of our understanding of the individual components of land and urban systems. Here we provide an initial list of ideas from existing analytical approaches anchored in allied fields that could be used to implement the framework.

***Multilevel modeling.*** Multilevel modeling approaches are useful for hierarchical data analysis whereby observations in a dataset belong in groups—such as land change within a single territory—and model parameters are jointly estimated by group, such as different groups of territories or urban clusters at different scales or locations. Multilevel models are being used by land-change scientists (58), but the research community has yet to realize fully the gains from incorporating multilevel modeling methods and approaches used in statistics (59).

***Spatially explicit life-cycle analysis.*** Efforts have already begun to examine land use consequences of crop consumption (60), and the industrial ecology community has begun to couple geographic information systems with life-cycle assessments (61). Much more can be developed in this area to identify links between urban processes and land change.

***Multiagent modeling.*** Multiagent-based models represent autonomous agents who interact with each other and their environment (62). Agent-based applications in land-use change are usually spatially explicit, and agents represent, for example, households relocating their homes or individuals using transport systems. The challenge of multiagent-based models in teleconnected systems is to incorporate decision-making of different and distal actors to discover and explain emergent effects.

***Climate modeling tools.*** Climate scientists have used statistical tools to examine "cells" of different sizes and geographic locations to study El Niño/Southern Oscillation teleconnections, or covariance of atmospheric circulation, precipitation, and temperature over large distances (63, 64). Such approaches can be adapted to model urban land teleconnections.

***Human–nature metabolism studies.*** The environmental implications of trade-related teleconnections in the global land systems have been explored by applying the concept of human appropriation of net primary production. By focusing on the teleconnections between producing and consuming regions, it is possible to associate the pressure on ecosystems with imports and exports. Hence, the approach provides a useful entrance point to understanding how changes in one place result in ecological, economic, and social impacts elsewhere driven by the global biomass metabolism (6).

***Spatializing commodity chains.*** An urban land teleconnections perspective can incorporate the emerging literature on spatializing commodity chains and production networks (49, 65). This approach would place explicit attention on linking actors (e.g., households, institutions, and firms), processes, and places of production and consumption. Spatially explicit commodity chain data make the relationships between state and nonstate actors as well as their spatial connections apparent.

## Conclusions

We propose urban land teleconnections as a process-based framework for integrating urbanization and land change, for revealing their linkages and pathways across space and time, and for identifying potential intervention points for sustainability. Through the lens of urban land teleconnections, new and surprising diverse urban forms and processes, such as periurbanization, can be better understood and foreseen. The urban land teleconnections concept could also be useful to the wider research community to anticipate implications for global land resource use.

By using an urban land teleconnections framework, we move away from conceptualizing urban sustainability and land as attri-

**Table 2. Grand challenges in global change and sustainability and guiding questions to help uncover urban land teleconnections**

| Issue | Guiding question |
| --- | --- |
| Strategic directions in the geographical sciences | |
| 5b. How do changing consumption patterns, regulations, and costs in one place affect farming systems, land use, and food security in other places? | What processes (e.g., flows, decisions, or actions) occur along a continuum of land systems? |
| 7a. How does virtual interaction reflect and alter the organization and movement of people, goods, and ideas in geographical space? | How and where do these processes lead to specific pathways (e.g., capital, information, people, goods, materials, energy, and services) that link urban areas to distal places? |
| 8c. How are poverty, wealth, and consumption interrelated across space and at multiple geographical scales? | What are the pathways by which rural land change influences an urban area? Conversely, what are the pathways by which an urban area influences land decisions in distal places? |
| Grand challenges in global sustainability | |
| 4.3. What changes in behavior or lifestyle, if adopted by multiple societies, would contribute most to improving global sustainability, in the context of global environmental change, and how could they be achieved? | How are land transitions across multiple rural places connected through urbanization? |
| 5.2b. How can competing demands for scarce land and water be met over the next half century while dramatically reducing land-use greenhouse gas emissions, protecting biodiversity, and maintaining or enhancing other ecosystem services? | How is the continuum of production, consumption, and disposal linked through land and urban processes? |

butes specific only to a place, to begin to link dynamic global processes to their spatial "imprint." Moreover, we can study multiple urban regions jointly, rather than trying to aggregate and generalize across many disconnected sets of case studies, and consequently provide a more organized way to integrate knowledge globally. A more holistic analysis of the underlying and spatial effects of production, consumption, and disposal will enable development of policies that promote viable and fair solutions, and ultimately global sustainability.

**ACKNOWLEDGMENTS.** Preparation of this paper was funded by the International Human Dimensions Programme on Global Environmental Change (IHDP) Urbanization and Global Environmental Change Project and the International Geosphere-Biosphere Programme (IGBP)/IHDP Global Land Project.

1. United Nations (2010) *World Urbanization Prospects: The 2009 Revision* (United Nations, New York).
2. Seto KC, Fragkias M, Güneralp B, Reilly MK (2011) A meta-analysis of global urban land expansion. *PLoS ONE* 6:e23777.
3. United Nations (2011) National Accounts Main Aggregates Database (United Nations Statistics Division, New York). Available at http://unstats.un.org/unsd/snaama/. Accessed March 21, 2012.
4. Kitzberger T, Brown PM, Heyerdahl EK, Swetnam TW, Veblen TT (2007) Contingent Pacific-Atlantic Ocean influence on multicentury wildfire synchrony over western North America. *Proc Natl Acad Sci USA* 104:543–548.
5. Erb KH, Krausmann F, Lucht W, Haberl H (2009) Embodied HANPP: Mapping the spatial disconnect between global biomass production and consumption. *Ecol Econ* 69:328–334.
6. Haberl H, et al. (2009) Using embodied HANPP to analyze teleconnections in the global land system: Conceptual considerations. *Geogr Tidsskr* 109:119–130.
7. Reenberg A, Fenger NA (2011) Globalizing land use transitions: The soybean acceleration. *Geogr Tidsskr* 111:85–92.
8. Cardille JA, Bennett EM (2010) Ecology: Tropical teleconnections. *Nat Geosci* 3: 154–155.
9. Berry BJL, Horton FE, Abiodun JO (1970) *Geographic Perspectives on Urban Systems with Integrated Readings* (Prentice-Hall, Englewood Cliffs, NJ).
10. Massey D (1991) A global sense of place. *Marxism Today* 38:24–29.
11. Adger WN (2003) Social capital, collective action, and adaptation to climate change. *Econ Geogr* 79:387–404.
12. Boone CG (2010) Environmental justice, sustainability and vulnerability. *Int J Urban Sustain Dev* 2:135–140.
13. National Research Council (2010) *Understanding the Changing Planet: Strategic Directions for the Geographical Sciences* (National Academies Press, Washington, DC).
14. Reid WV, et al. (2010) Earth system science for global sustainability: Grand challenges. *Science* 330:916–917.
15. Savard J-PL, Clergeau P, Mennechez G (2000) Biodiversity concepts and urban ecosystems. *Landsc Urban Plan* 48:131–142.
16. Niemelä J (1999) Ecology and urban planning. *Biodivers Conserv* 8:119–131.
17. Allen J, et al. (1998) *Rethinking the Region* (Routledge, London).
18. Irwin EG, et al. (2009) The economics of urban-rural space. *Annu Rev Resour Econ* 1: 435–459.
19. Ravetz J (2000) *City Region 2020: Integrated Planning for a Sustainable Environment* (Earthscan, London).
20. Goodchild MF (1994) Integrating GIS and remote sensing for vegetation analysis and modeling: Methodological issues. *J Veg Sci* 5:615–626.
21. DuPuis EM, Goodman D (2005) Should we go "home" to eat? Toward a reflexive politics of localism. *J Rural Stud* 21:359–371.
22. Curtis F (2003) Eco-localism and sustainability. *Ecol Econ* 46:83–102.
23. Saunders C, Barber A, Taylor G (2006) *Food Miles-Comparative Energy/Emissions Performance of New Zealand's Agriculture Industry* (Lincoln Univ, Canterbury, New Zealand).
24. Mansfield B, Munroe DK, McSweeney K (2010) Does economic growth cause environmental recovery? Geographical explanations of forest regrowth. *Geography Compass* 4/5:416–427.
25. Kasanko M, et al. (2006) Are European cities becoming dispersed? A comparative analysis of 15 European urban areas. *Landsc Urban Plan* 77:111–130.
26. Kabisch N, Haase D (2011) Diversifying European agglomerations: Evidence of urban population trends for the 21st century. *Popul Space Place* 17:236–253.
27. Foley JA, et al. (2005) Global consequences of land use. *Science* 309:570–574.
28. Boserup E (1965) *The Conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure* (G. Allen and Unwin, London).
29. Lambin EF, Geist HJ, eds (2005) *Land Use and Land Cover Change: Local Processes, Global Impacts* (Springer, New York).
30. Turner II BL, Lambin EF, Reenberg A (2007) The emergence of land change science for global environmental change and sustainability. *Proc Natl Acad Sci USA* 104: 20666–20671.
31. Irwin EG, Jayaprakash C, Munroe DK (2009) Towards a comprehensive framework for modeling urban spatial dynamics. *Landscape Ecol* 24:1223–1236.
32. Hayter R, Barnes TJ, Bradshaw MJ (2003) Relocating resource peripheries to the core of economic geography's theorizing: Rationale and agenda. *Area* 35:15–23.
33. Wackernagel M, Yount JD (1998) The ecological footprint: An indicator of progress toward regional sustainability. *Environmental Monitoring and Assessment* 51: 511–529.
34. Rogers EM (1962) *Diffusion of Innovations* (Free Press, New York).
35. Christaller W (1966) *Central Places in Southern Germany*, Translated from Die zentralen Orte in Süddeutschland by Baskin, CW (Prentice-Hall, Englewood Cliffs, NJ).
36. Allen PM (1997) *Cities and Regions as Self-Organizing Systems: Models of Complexity* (Gordon and Breach, Amsterdam).
37. Smith DA, White DR (1992) Structure and dynamics of the global economy: Network analysis of international trade 1965-1980. *Soc Forces* 70:857–893.
38. Swyngedouw E (1997) Neither global nor local: "Glocalization" and the politics of scale. *Spaces of Globalization: Reasserting the Power of the Local*, ed Cox KR (Guilford Press, New York).
39. Sheppard E (2002) The spaces and times of globalization: Place, scale, networks, and positionality. *Econ Geogr* 78:307–330.
40. White RW (1977) Dynamic central place theory: Results of a simulation approach. *Geogr Anal* 9:226–243.
41. Berry BJL (1967) *Geography of Market Centers and Retail Distribution* (Prentice-Hall, Englewood Cliffs, NJ).
42. Durlauf SN (2005) Complexity and empirical economics. *Econ J* 115:F225–F243.
43. Castells M (1996) *The Rise of the Network Society* (Blackwell, Cambridge, MA).
44. Ernstson H, et al. (2010) Urban transitions: On urban resilience and human-dominated ecosystems. *Ambio* 39:531–545.
45. Wilson AG (2000) *Complex Spatial Systems: The Modelling Foundations of Urban and Regional Analysis* (Pearson Education, New York).
46. Messina JP, Walsh SJ (2005) Dynamic spatial simulation modeling of the population—environment matrix in the Ecuadorian Amazon. *Environ Plann B Plann Des* 32: 835–856.
47. Wolman A (1965) The metabolism of cities. *Sci Am* 213:179–190.
48. Porter ME (1990) *The Competitive Advantage of Nations* (Free Press, New York).
49. Gereffi G (1996) Global commodity chains: new forms of coordination and control among nations and firms in international industries. *Competition Change* 1:427–439.
50. Coe NM, Dicken P, Hess M (2008) Global production networks: Realizing the potential. *J Econ Geogr* 8:271–295.
51. Whatmore S (2002) From farming to agribusiness: Global agri-food networks. *Geographies of Global Change: Remapping the World in the Late Twentieth Century*, eds Johnston RJ, Taylor PJ, Watts MJ (Wiley, New York).
52. Dicken P, Kelly PF, Olds K, Yeung HW-C (2001) Chains and networks, territories and scales: Towards a relational framework for analysing the global economy. *Glob Netw* 1:89–112.
53. Haase D, Nuissl H (2010) The urban-to-rural gradient of land use change and impervious cover: A long-term trajectory for the city of Leipzig. *Journal of Land Use Science* 5:123–141.
54. Simon D (2008) Urban environments: Issues on the peri-urban fringe. *Annu Rev Environ Resour* 33:167–185.
55. Lambin EF, Meyfroidt P (2011) Global land use change, economic globalization, and the looming land scarcity. *Proc Natl Acad Sci USA* 108:3465–3472.
56. Meyfroidt P, Rudel TK, Lambin EF (2010) Forest transitions, trade, and the global displacement of land use. *Proc Natl Acad Sci USA* 107:20917–20922.
57. Naylor R, et al. (2005) Agriculture. Losing the links between livestock and land. *Science* 310:1621–1622.
58. Overmars KP, Verburg PH (2006) Multilevel modelling of land use from field to village level in the Philippines. *Agric Syst* 89:435–456.
59. Snijders TAB, Bosker RJ (1999) *Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modelling* (Sage, New York).
60. Kløverpris J, Wenzel H, Nielsen PH (2008) Life cycle inventory modelling of land use induced by crop consumption. Part I: Conceptual analysis and methodological proposal. *Int J Life Cycle Assess* 13:13–21.
61. Geyer R, Stoms D, Lindner JP, Davis FW, Wittstock B (2010) Coupling GIS and LCA for biodiversity assessments of land use. Part I: Inventory modeling. *Int J Life Cycle Assess* 15:454–467.
62. Parker DC, Manson SM, Janssen MA, Hoffmann MJ, Deadman P (2003) Multi-agent systems for the simulation of land-use and land-cover change: A review. *Ann Assoc Am Geogr* 93:314–337.
63. Mikolajewicz U, Crowley TJ, Schiller A, Voss R (1997) Modelling teleconnections between the North Atlantic and North Pacific during the Younger Dryas. *Nature* 387: 384–387.
64. Trenberth KE, et al. (1998) Progress during TOGA in understanding and modeling global teleconnections associated with tropical sea surface temperatures. *J Geophys Res* 103(C7):14291–14324.
65. Leslie D, Reimer S (1999) Spatializing commodity chains. *Prog Hum Geogr* 23:401–420.